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Faculty of Engineering Publication No. 73

XVI. IITAS

XVI[th] INTERNATIONAL IZMIR TEXTILE AND APPAREL SYMPOSIUM

BOOK OF PROCEEDINGS

25-27 October 2023
Altın Yunus Hotel, Cesme - izmir

www.iitas2023.com

Dalya

Ege University Publications
Faculty of Engineering Publication No: 73

XVITH INTERNATIONAL İZMİR TEXTILE & APPAREL SYMPOSIUM

IITAS 2023

OCTOBER 25 - 27, 2023
İZMİR-TÜRKİYE

BOOK OF PROCEEDINGS

Organizer
IITAS 2023 is organized by Ege University
Faculty of Engineering, Department of Textile Engineering

IITAS 2023
XVITH INTERNATIONAL İZMİR TEXTILE & APPAREL SYMPOSIUM

BOOK OF PROCEEDINGS

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XVIth International İzmir Textile & Apparel Symposium
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www.itkib.org.tr/

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Ege University

Prof. Dr. Hale KARAKAŞ
Organizing Committee Member
İstanbul Technical University

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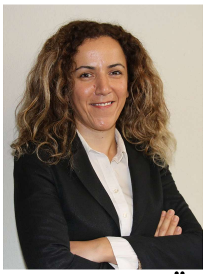

Dr. Seniha MORSÜMBÜL
Organizing Committee Member
Ege University

SCIENTIFIC COMMITTEE
(In Alphabetical Order)

Dear participants,

The 16th of the International Izmir Textile and Apparel Symposiums, which have been held regularly since 1976, **IITAS 2023 (XVIth International Izmir Textile and Apparel Symposium) was carried out between 25-27 October 2023 in İzmir-Çeşme**, by Ege University Faculty of Engineering, Department of Textile Engineering. IITAS, which is organized every three years, aims to discuss current issues in the field of textiles, bring together many researchers and experts in the national and international arena, and exchange information on scientific developments and the latest innovations. IITAS is also an important event in terms of demonstrating the power of Türkiye in the field of textile and apparel, strengthening relations in this field, and establishing new collaborations. Organizing such a symposium in 2023 on the 100th Anniversary of the Republic of Türkiye has a special meaning.

As in the past International Izmir Textile and Apparel Symposiums, there was a high rate of participation in the symposium this year as well. **More than 450 participants** (38 foreign participants) from **20 different countries**, including academicians, middle and senior managers working in the textile and apparel industries, employers and students, participated in IITAS 2023.

The opening ceremony; including valuable opening speeches, a presentation entitled "**The Development of Textile Industry in the Republic of Türkiye**" and a panel on "**Opportunities and Threats for the Turkish Textile and Apparel Industry on the 100th Anniversary of the Republic**" was performed on 25 October. The plenary sessions held by well-known keynote speakers from home and abroad on 26-27 October 2023 were followed by oral and poster presentations in three parallel sessions, where innovative studies in the field of textile engineering were discussed by researchers. In these sessions, **68 oral presentations and 22 poster presentations** were made by a total of 24 researchers from industry and 44 academicians.

Thank you for your attendance to IITAS 2023, we hope to be together again at the IITAS 2026 in İzmir!

Best Regards

Prof. Dr. E. Perrin Akçakoca Kumbasar
Chairperson of Organizing Committee

XVI^th INTERNATIONAL IZMIR TEXTILE AND APPAREL SYMPOSIUM

25-27 October 2023
Altın Yunus Hotel, Çeşme - izmir

OCTOBER 25, WEDNESDAY

16:00 - 17:00 REGISTRATION

17:00 - 20:00 OPENING SPEECHES - OPENING PRESENTATIONS - PANEL

OPENING SPEECHES

E. Perrin AKÇAKOCA KUMBASAR
Chairperson of IITAS 2023 Organizing Committee

Abdulkadir KONUKOĞLU
SANKO Holding, Honorary President, Türkiye

Burak SERTBAŞ
Vice Chairperson of the TIM Apparel Sector Board
Aegean Exporters' Associations (EİB), Chairperson of the Board of Directors of Aegean Apparel Exporters' Association, Türkiye

Jak ESKİNAZİ
Aegean Exporters' Associations (EİB), Coordinator Chairperson
Chairperson of the Board of Directors of Aegean Textile and Raw Materials Exporters' Association, Türkiye

Ahmet ÖKSÜZ
Istanbul Textile and Raw Materials Exporters' Association (ITHIB), Chairperson of the Board of Directors of Istanbul Textile and Raw Materials Exporters' Association, Türkiye

Ahmet Fikret KİLECİ
Türkiye Exporters Assembly (TIM), Deputy Chairperson
Chairperson of the TIM Textile and Raw Materials Sector Board
Southeast Anatolian Exporters' Associations (GAIB), Coordinator Chairperson
Chairperson of the Board of Directors of Southeast Anatolian Textile and Raw Materials Exporters' Association, Türkiye

*** Opening speeches can be updated*

OPENING PRESENTATION

E. Perrin AKÇAKOCA KUMBASAR, *Chairperson of IITAS 2023 Organizing Committee*
THE DEVELOPMENT OF TEXTILE INDUSTRY IN THE REPUBLIC OF TÜRKIYE

PANEL:
OPPORTUNITIES AND THREATS FOR THE TURKISH TEXTILE AND APPAREL INDUSTRY ON THE 100TH ANNIVERSARY OF THE REPUBLIC

MODERATOR

E. Perrin AKÇAKOCA KUMBASAR
Chairperson of IITAS 2023 Organizing Committee

PANELISTS

Ahmet Fikret KİLECİ
Türkiye Exporters Assembly (TIM), Deputy Chairperson
Chairperson of the TIM Textile and Raw Materials Sector Board
Southeast Anatolian Exporters' Associations (GAIB), Coordinator Chairperson
Chairperson of the Board of Directors of Southeast Anatolian Textile and Raw Materials Exporters' Association, Türkiye

Ahmet ÖKSÜZ
Istanbul Textile and Raw Materials Exporters' Association (ITHIB), Chairperson of the Board of Directors of Istanbul Textile and Raw Materials Exporters' Association, Türkiye

Burak SERTBAŞ
Vice Chairperson of the TIM Apparel Sector Board
Aegean Exporters' Associations (EİB), Chairperson of the Board of Directors of Aegean Apparel Exporters' Association, Türkiye

Muzaffer Turgut KAYHAN
Vice Chairperson of the Board of Directors of Aegean Textile and Raw Materials Exporters' Association, Türkiye

Hayati ERTUĞRUL
Aegean Clothing Manufacturers Association (EGSD), Chairperson of the Board

Hüseyin KADOĞLU
Ege University Textile Engineering Department

20:00	DINNER

OCTOBER 26, THURSDAY

08:30 - 09:30	REGISTRATION
	PLENARY SESSION
	CHAIR: Hüseyin KADOĞLU, *Ege University, Türkiye*
09:30 - 10:00	**Savvas VASSILIADIS,** *University of West Attica, Greece* TEXTILE BASED TRIBOELECTRIC GENERATORS
10:00 - 10:30	**Ender YAZGAN BULGUN,** *Izmir University of Economics, Türkiye* TEXTILE AND FASHION TRENDS; INNOVATION AND BEYOND
10:30 - 11:00	COFFEE BREAK
	CHAIR: Arzu MARMARALI, *Ege University, Türkiye*
11:00 - 11:30	**Mirela BLAGA,** *Gheorghe Asachi University of Iasi, Romania* EDUCATION FOR SUSTAINABLE DEVELOPMENT IN TEXTILES
11:30 - 12:00	**Chokri CHERIF,** *Technische Universität Dresden, Germany* REVOLUTIONIZING THE CONSTRUCTION INDUSTRY BY USING CARBON CONCRETE COMPOSITES RESOURCE-FRIENDLY - SLENDER CONSTRUCTION - BEAUTY
12:00 - 13:30	LUNCH

	SESSION I	SESSION II	SESSION III
	CHAIR: **Nida OĞLAKCIOĞLU** *Ege University, Türkiye*	CHAIR: **İsmail USTA** *Marmara University, Türkiye*	CHAIR: **Ayşegül KÖRLÜ** *Ege University, Türkiye*
13:30 - 13:50	**Ümit Halis ERDOĞAN** *Dokuz Eylül University, Türkiye* PRODUCTION AND CHARACTERIZATION OF MICROCRYSTALLINE CELLULOSE PARTICLES FROM CELLULOSIC FIBER WASTES	**Mehmet TOPALBEKİROĞLU** *Gaziantep University, Türkiye* THE COATING OF POLIACRILONITRILE STRIP WITH NANOFIBERS PRODUCED BY ELECTROSPINNING	**Hale KARAKAŞ** *Istanbul Technical University, Türkiye* ECO-FRIENDLY DENIM WASHING PROCESS
13:50 - 14:10	**Neslihan OKYAY** *Karacasu Tekstil, Türkiye* BRINGING SUSTAINABLE FIBER FROM STEM, LEAF AND FOOD PRODUCT WASTE TO RING SPINNING TECHNOLOGY	**Seniha MORSÜMBÜL** *Ege University, Türkiye* TEA TREE OIL LOADED NANOFIBERS FOR WOUND DRESSING APPLICATIONS	**Eylen Sema DALBAŞI** *Ege University, Türkiye* DESIGN AND DEVELOPMENT OF MULTIFUNCTIONAL FABRIC USING COATING METHOD WITH DIFFERENT FINISHING PROCESSES
14:10 - 14:30	**Ebru ÇALIŞKAN** *Baykan Denim R&D Center, Türkiye* AN INVESTIGATION ON THE EFFICIENCY OF AN IN-HOUSE FABRIC RECYCLING LINE UTILISATION FOR PRE-CONSUMER DENIM WASTES	**Yeşim ÜNVAR** *Dokuz Eylül University, Türkiye* EXPANDING OPPORTUNITIES WITHIN THE UV PROTECTION OF ARAMID FIBERS: MATERIAL INDEPENDENT LBL TECHNOLOGY	**Ayşe GENÇ** *Çalık Denim Tekstil San. Tic. A.Ş., Türkiye* THE OPTIMIZATION STUDY ON TREATMENT OF DENIM FABRICS WITH SOL-GEL METHOD
14:30 - 14:50	**Esra GÜNEŞ** *SANKO Textile R&D Center, Türkiye* EFFECT OF RING YARN MACHINE SPINNING ELEMENTS ON RECYCLE YARN PRODUCTION	**Fabien SALAÜN** *University of Lille - ENSAIT, France* PCL PHOTO-RESPONSIVE ELECTROSPUN MEMBRANE BASED ON PHOTOCHROMIC MOLECULE	**Kübra SABANCI KAPUKAYA** *Maritaş Denim San. Tic. A.Ş, Türkiye* THE EFFECT OF USING GRAPHENE IN DENIM FABRICS ON THERMAL PERFORMANCE CHARACTERISTICS
14:50 - 15:10	**Buket GÜLER** *TYH Uluslararası Tekstil Pazarlama A.Ş., Türkiye* SPORTSWEAR COLLECTION DEVELOPED FROM PULP BASED BIODEGRADABLE REGENERATED CELLULOSE FIBERS	**Gizem Ceylan TÜRKOĞLU** *Dokuz Eylül University, Türkiye* INVESTIGATION OF THE PVA SOLUTIONS PROPERTIES ON THE ELECTROSPINNING MAT	**Ferhan GEBEŞ** *ORMO Yün İplik San. Tic. A.Ş., Türkiye* MACHINE MODIFICATION TO SOLVE COLOR CONTAMINATION PROBLEM IN YARN PRINTING MACHINES
15:10 - 15:30	**Alper DİKTAŞ** *SERKON Teknoloji A.Ş & AĞTEKS Ltd. Türkiye* DIGITALIZATION AND AI APPLICATIONS FROM YARN TO GARMENT	**Mert IŞILAY** *Ege University, Türkiye* PROPERTIES OF NANOFIBROUS POLY(VINYL ALCOHOL)/NAFION POLYMER ELECTROLYTE MEMBRANES	**Abdulkadir ERÇAKALLI** *Kıvanç Textile, Türkiye* A STUDY ON REDUCING THE COLOR DIFFERENCE BETWEEN DYEING IN THE LABORATORY AND DYEHOUSE

15:30 - 16:00	COFFEE BREAK

	CHAIR: A. Merih SARIIŞIK *Dokuz Eylül University, Türkiye*	CHAIR: Pınar ÇELİK *Ege University, Türkiye*	CHAIR: Hale KARAKAŞ *İstanbul Technical University, Türkiye*
16:00 - 16:20	**Çiğdem AKDUMAN** *Pamukkale University, Türkiye* SUSTAINABLE PREPARATION OF PROCESS WATER: A CASE STUDY OF DOUBLE REVERSE OSMOSIS IN A TEXTILE DYEHOUSE	**Selçuk POYRAZ** *Adıyaman University, Türkiye* MICROWAVE ENERGY-BASED APPROACH TO PREPARATION AND CHARACTERIZATION OF FUNCTIONAL TEXTILES FOR FIBER REINFORCED POLYMERIC COMPOSITES	**Dilara SEVİNDİK** *Dokuz Eylül University, Türkiye* SUSTAINABLE DYEING PROCESS OF PET FABRICS BY USING IONIC LIQUIDS
16:20 - 16:40	**Hüseyin KARIŞLI** *Erka Mühendislik Ltd. Şti., Türkiye* CLEANER PRODUCTION PRACTICES IN THE TEXTILE SECTOR	**Merve TURAN** *Çalık Denim Tekstil San. Tic. A.Ş., Türkiye* A NEW METHOD IN PRODUCTION OF MULTI-COMPONENT HYBRID YARN AND YARN PROPERTIES	**Seda KESKİN** *Eren Retail & Textile Inc R&D Center, Türkiye* INVESTIGATION OF BLEACHING AND DYEABILITY OF KNITTED FABRICS BY FOAM APPLICATION METHOD
16:40 - 17:00	**Gözde ABACI** *Can Tekstil Entegre Tesisleri ve Tarım Ürünleri San. Tic. A.Ş., Türkiye* INVESTIGATION OF MICROPLASTIC IN WATER AND WASTEWATER SAMPLES IN ERGENE REGION - EXAMPLE OF AN INTEGRATED TEXTILE MILL	**Çağla Deniz ŞENTÜRK** *SANKO Textile and Trading Corporation & Ege University, Türkiye* A RESEARCH ON PROPERTIES OF KNITTED FABRICS PRODUCED WITH RING AND ROTOR-SPUN YARNS CONTAINING RECYCLED COTTON FIBER	**Hüseyin TOPÇU** *Dok-San Denizli Textile Industury and Trade Inc. R&D Center, Türkiye* DEEP LEARNING-BASED CONVOLUTIONAL NEURAL NETWORKS FOR ROTARY SCREEN PIGMENT PRINTING MACHINE PARAMETER ESTIMATION
17:00 - 17:20	**Murat ONAN** *Onan Kimya Tekstil San. ve Tic. Ltd. Şti., Türkiye* NEW OPPORTUNITIES FOR PES FIBRE IN TERMS OF DYEING AND PRINTING	**Kerim KILINÇ** *Polyteks Tekstil San. Araş. Eğit. A.Ş., Türkiye* INVESTIGATION OF UV RESISTANCE PROPERTIES OF BICOMPONENT YARNS PRODUCED WITH DIFFERENT ADDITIVES	**Selenay Elif İŞLER** *Martur Fompak International, Türkiye* EVALUATION OF THE TECHNICAL PERFORMANCE OF AUTOMOTIVE SEAT FABRICS PRODUCED USING POCKET STRUCTURES AND FILLER YARN
17:20 - 17:40	**Özgür CEYLAN** *Eskişehir Technical University, Türkiye* ECO-FRIENDLY DENIM THROUGH THE COLORS OF NATURE	**Christopher JOHNEN** *Saurer Group, Germany* AUTOAIRO - THINK PROGRESS WITH SAURER´S NEW AIR SPINNING MACHINE	**Şafak BİROL** *TYH İzmir R&D Center, Türkiye* DIGITAL TRANSFORMATION AND ITS EFFECTS ON PRODUCTIVITY IN A CLOTHING COMPANY
17:40- 18:00	**Tuğce TÖNGÜÇ YALÇINKAYA** *Ege University, Türkiye* WOOL BASED ACTIVATED CARBON FIBERS FOR CARBON DIOXIDE CAPTURE	**Türkan Kübra BAYKAN** *SANKO Textile R&D Center, Türkiye* THE EFFECT OF YARNS MADE FROM DIFFERENT FIBER BLENDS ON QUALITY VALUES	**Deniz YAZICI** *ATT Clothing, Türkiye* ADVANCED DIGITAL TECHNOLOGIES IN FASHION DESIGN

15:00 - 17:00 AUTEX GENERAL ASSEMBLY (AUTEX MEMBERS ONLY)

18:00 - 19:00 MEETING OF TEXTILE ENGINNERING DEPARTMENTS OF TÜRKİYE (ONLY CHAIRPERSON OF THE DEPARTMENTS)

20:00 GALA DINNER - 100TH ANNIVERSARY OF THE REPUBLIC OF TÜRKİYE

OCTOBER 27, FRIDAY

08:30 - 09:30 REGISTRATION

PLENARY SESSION

CHAIR: Savvas VASSILIADIS, *University of West Attica, Greece*

09:30 - 10:00 **Lieva VAN LANGENHOVE,** *Ghent University, Belgium*
ENHANCING THE USE OF REUSABLES AT HOSPITALS

10:00 - 10:30 **Andrej DEMŠAR,** *University of Ljubljana, Slovenia*
HOLISTIC THINKING AND ACTING

10:30 - 11:00 COFFEE BREAK

CHAIR: Mirela BLAGA, *Gheorghe Asachi University of Iasi, Romania*

11:00 - 11:30 **Vladan KONCAR,** *University of Lille - ENSAIT- GEMTEX, France*
HOW TO IMPROVE THE QUALITY AND RELIABILITY OF E-TEXTILE SYSTEMS - STANDARDS

11:30 - 12:00 **Yordan KYOSEV,** Technische Universität Dresden, Germany
FROM GEOMETRIC MODELING TO SIMULATION OF THE HAPTICS OF TEXTILE PRODUCTS - OPEN MODELING QUESTIONS

12:00 - 13:30 LUNCH

	SESSION I	SESSION II	SESSION III
	CHAIR: Ümit Halis ERDOĞAN *Dokuz Eylül University, Türkiye*	CHAIR: Y. Dilek KUT *Bursa Uludağ University, Türkiye*	CHAIR: Seher KANAT *Ege University, Türkiye*
13:30 - 13:50	**Cevza CANDAN** *Istanbul Technical University, Türkiye* ARTIFICIAL INTELLIGENCE BASED ASSESSMENT AND OPTIMISATION OF KNITTED FABRICS SUITABLE FOR ALLERGIC INDIVIDUALS	**Funda GÖKSEL** *TÜBİTAK Bursa Test and Analysis Laboratory, Türkiye* A STUDY ON THE EFFECT OF ABRASIVE TYPE ON THE PILLING PERFORMANCE OF PLAIN AND BLENDED FABRICS	**Nevin Çiğdem GÜRSOY** *Istanbul Technical University, Türkiye* UNIVERSAL TEXTILE DESIGN CENTER

13:50 - 14:10	**Serdar BAŞEV** *Spinteks Tekstil San. Tic. A.Ş., Türkiye* THE EFFECT OF DIFFERENT FABRIC CONSTRUCTIONS ON BUILDING REINFORCEMENT	**Nazire YILMAZ** *Uşak University, Türkiye* EFFECT OF THERMAL TREATMENTS ON HYGROSCOPIC PROPERTIES OF BIOLOGICALLY DEGUMMED OKRA BAST FIBERS	**Mehmet KERTMEN** *İskur Tekstil Enerji Tic. San. A.Ş., Türkiye* PASSIVE SMART CELLULOSIC KNITTED FABRICS WITH ENHANCED PERMEABILITY AND ABSORPTION FEATURES
14:10 - 14:30	**Bilge KOYUNCU** *DeepTech Engineering Ltd., Türkiye* DESIGN OF A DRYSUIT WITH IMPROVED THERMAL MANAGEMENT PROPERTIES FOR COLD WATER APPLICATIONS	**Yasemin DÜLEK** *SYK Textile R&D Center, Türkiye* OPTIMIZATION OF THE PARAMETERS INFLUENCE BLEACHING PROCESS FOR NETTLE/COTTON MIXED FABRICS BY TAGUCHI METHOD	**Gökçe SAKMAR** *Zorluteks Textile Trade and Industry Inc., Türkiye* DEVELOPMENT OF A PRODUCTION SYSTEM FOR BLEACHING MACHINES INDEPENDENT OF HUMAN CONTROL AND AIMING THE RIGHT PRODUCTION AT ONCE
14:30 - 14:50	**Ahmed EL SHAFEI** *North Carolina State University, USA* SUSTAINABLE DYEING OF COTTON USING ZERO SALT AND ZERO ALKALI WITH ZERO EFFLUENT	**Mehmet KERTMEN** *İskur Tekstil Enerji Tic. San. A.Ş., Türkiye* ENVIRONMENTAL IMPACTS OF 100% VIRGIN COTTON AND RECYCLED COTTON/VIRGIN COTTON BLENDED FABRICS	**Olena KYZYMCHUK** *Kyiv National University of Technologies and Design, Ukraine & Technische Universität Dresden, Germany* THE PRESSURE CHARACTERISTICS OF ELASTIC WARP KNITTED FABRICS
14:50 - 15:10	**Aristeidis REPOULIAS** *University of West Attica, Greece* UTILIZING PTFE FILAMENT TO ACHIEVE EFFICIENCY AND AESTHETICS IN WEARABLE TRIBOELECTRIC GENERATORS	**Benamir FİDANCI** *Martur Fompak International, Türkiye* A STUDY ABOUT THE CORRELATION BETWEEN SEAM FATIGUE AND STATIC FRICTION TESTS FOR AUTOMOTIVE UPHOLSTERY CIRCULAR KNITTED FABRICS	**Sema BAHAR ERDEM** *Dokuz Eylül University, Türkiye* THE IMPORTANCE OF FIBER TYPE AND COLOR IN THE ENVIRONMENTAL EFFECTS OF GARMENTS
15:10 - 15:30	**Aylin Saadet TOKYÜREK** *Ege University, Türkiye* A HYDROGEL/TEXTILE BASED ACTUATOR FOR SOFT ROBOTIC APPLICATIONS	**Merve YARALI** *Menderes Textile Industry and Trade Inc. R&D Center, Türkiye* ENVIRONMENTAL AND SUSTAINABLE 100% COTTON FABRIC PRODUCTION FROM FIBERS OBTAINED FROM FINAL CONSUMER TEXTILE WASTES	**Esra TAŞTAN ÖZKAN** *Bitlis Eren University, Türkiye* THE EFFECT OF DIFFERENT STRUCTURAL PARAMETERS AND WASHINGS ON THERMAL PROPERTIES OF DENIM FABRICS
15:30 - 16:30	POSTER SESSION & COFFEE BREAK		
	CHAIR: **Selçuk POYRAZ** *Adıyaman University, Türkiye*	CHAIR: **Ahmet ÇAY** *Ege University, Türkiye*	CHAIR: **Ebru BOZACI** *Ege University, Türkiye*
16:30 - 16:50	**Esra TAŞTAN ÖZKAN** *Bitlis Eren University, Türkiye* THE EFFECT OF PCM ON THE SURFACE TEMPERATURE OF TIGHT GARMENTS AND SUBJECTIVE COMFORT EVALUATIONS	**Olena KYZYMCHUK** *Kyiv National University of Technologies and Design, Ukraine & Technische Universität Dresden, Germany* THE ADVANCED TECHNOLOGY FOR COMPRESSION GARMENT DESIGN	**Edit CSANÁK** *Óbuda University, Hungary* SUSTAINABLE FASHION: A HISTORICAL REVIEW
16:50 - 17:10	**Bilge KOYUNCU** *DeepTech Engineering Ltd., Türkiye* HEAT ON-THE-GO: DESIGN OF A BABY BOTTLE WARMER BAG WITH A TEXTILE-BASED HEATER SYSTEM	**Merve BULUT** *Istanbul Technical University, Türkiye* INFLUENCE OF COPET DISSOLUTION AND DYEING PROCESSES ON PHYSICAL PERFORMANCE OF BLACKOUTS FROM PET/COPET BICOMPONENT YARNS	**Anne-Marie GRUNDMEIER** *University of Education Freiburg, Germany* FASHION DIET - CHALLENGES AND POTENTIALS OF OPEN EDUCATIONAL RESOURCES (O ER) FOR EDUCATION FOR SUSTAINABLE DEVELOPMENT (ESD) IN TEXTILE EDUCATION
17:10 - 17:30	**Nataliya SADRETDINOVA** *Kyiv National University of Technologies and Design, Ukraine & Technische Universität Dresden, Germany* IMPLEMENTATION OF MODERN DYNAMIC APPROACH IN GARMENT PATTERN DESIGN FOR DEAF PEOPLE	**Chaimae ZOUHRI** *University Med V & Center of Excellence in Logistics (CELOG), Morocco & ESITH & University of Monastir, Tunisia* THE APPLICATION OF ARTIFICIAL INTELLIGENCE FOR ASSEMBLY LINE BALANCING IN THE CLOTHING INDUSTRY	**İsmail İVEDİ** *ROTEKS Tekstil İhr. San. Tic. A.Ş., Türkiye* REVOLUTIONIZING SEWING MACHINES: ANALYZING THE INTEGRATION OF BOBBIN THREAD DETECTION DEVICES
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XVI[th] INTERNATIONAL IZMIR TEXTILE AND APPAREL SYMPOSIUM

25-27 October 2023
Altın Yunus Hotel, Çeşme - izmir

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POSTER PRESENTATION LIST

Alphabetical Order of Surnames

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2. **ARAS ELİBÜYÜK S.**, *OZANTEKS TEKSTIL, TÜRKİYE*
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HEMP AND COTTON AS A NATURAL FIBER

7. **DEMİR GÜNENÇ Ö.**, *OZANTEKS TEKSTIL, TÜRKİYE*
DEVELOPMENT OF MULTIFUNCTIONAL OUTDOOR FABRICS USING ACRYLIC YARN

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19. **ŞEN YUVAYAPAN S.**, *AK-KIM KIMYA SAN. VE TIC. A.Ş, TÜRKİYE*
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20. **TİRYAKİ GÜZEL S.**, *MARMARA UNIVERSITY, TÜRKİYE*
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FULLTEXTS OF PLENARY PRESENTATIONS

HOLISTIC THINKING AND ACTING

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ABSTRACT

The contribution presents the course "Holistic thinking and acting" at the Faculty of Natural Sciences and Engineering of the University of Ljubljana and the explanation why this course (change) is important. Holistic, transdisciplinary and critical thinking about systems and consequence of their interconnections provides insight into the complexity of relationships in the world and encourages listeners to make more responsible and sustainable decisions for the future.

Key Words: holism, education, sustainability, change

1. INTRODUCTION

The humanity is exploiting the Earth's limited natural resources as if they were endless. The measure of our overuse of natural resources is Earth Overshoot Day (Day of ecological debt), the day on which humanity uses all natural resources available in one year. It is the day when we, humanity, enter ecological debt to future generations. The Earth Overshoot Day in 2023 was August 2nd. Earth Overshoot Day in developed countries occurs much earlier, in Slovenia, for example, it occurred on April 18th [1].

In 1987, the United Nations defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs"[2]. Sustainability is often described as having three dimensions (or pillars): environmental, social and economic. In everyday usage, sustainability often (wrongly) focuses just on the environmental dimension. In addition to environmental dimension, focus on social and economic dimensions is needed.

In 2015 the 17 Sustainable Development Goals (SDGs) were adopted by the United Nations as a universal call to action to ensure that by 2030 all people enjoy peace and prosperity. The SDGs are integrated and address social, economic and environmental aspects of sustainability and evolution of them. [3]

According to SDGs definition our actions (education, research, development, production…) should be holistic. In the frame of this article, holism is meant that parts of a system (in our case world) are in intimate interconnection, so that they cannot exist independently of the whole, or cannot be understood without reference to the whole. If we see all parts of the system interconnected, we understand that every change in the system will affect all parts of the system. If this is so than we should plan all our actions holistically. We, as Humanity, face sustainability crisis mainly because we do not think and act holistically.

2. DISCUSSION

2.1 Problem statement

Reasons for the sustainability crisis are proposed as follows: world economic system(s), overproduction and consumerism which all together give rise to unsustainable set of basic values such as: constant growth and profit.

Current world economic system – capitalism promotes constant growth, consequence of which is overproduction. The mindset of overproduction is: produce – sell – get profit. Consumerism is a consequence of overproduction. We buy without asking important questions such as: How and where have the raw materials been grown, produced? How and where have the goods been produced? How many kilometres has the product travelled? Why is the price of the product so low? What will happen to the product when I stop using it?

A balanced world with balanced development and balanced growth for the benefit of all should be our common goal. In the equation of the wealth of the countries' healthy environment, healthy people, healthy society, and balanced GDP should be included.

Stakeholders who can make a change in current sustainability crisis are: Consumer, Economy, Politics (legislation), Educators.

Stakeholders must act responsibly and sustainably. They need knowledge, awareness and courage to make a change. As we change our values, we can also change our habits (as consumers, workers, politicians, and educators). To change our current approaches, thinking out of the box, creativity, holism and ethics are needed. Examples of changed approaches could be for example: lower consumption, local production, homogenous textile products production, products with longer life, fair trade, no child work, 40 hours or less working week, etc.

2.2. Education

Among the stakeholders who can make a change (Consumer, Economy, Politics (legislation), Educators), are the educators those who have the strongest tool to make a long-term change. Noam Chomsky describes current approach in education as:... “still, mostly, the product of the industrial age, focused on profits and wealth which relies on mass consumption, GDP, constant growth concept, etc. Additionally suggests that society simply reduces education to the requirement of the market. The education process is reduced to knowledgeable educators who just transfer information rather than to help students formulate higher level thinking skills on their own. Under this kind of education, people have the idea that, from childhood, young people have to be placed into a framework where they’re going to follow orders. This model of education imposes a debt which traps young people, into conformity. That is the exactly the opposite of what traditionally comes out of the enlightenment in which the highest goal in life is to inquire and create. An essential part of this kind of education is fostering the students need to challenge authority, think critically, and create alternatives to well-worn models. The goals of education should be to encourage the development of the students natural capacity, to produce human beings whose values are not accumulation and domination, but instead free colaboration on equal terms, the development of critical thinking skills and the process of gaining sustainable related values [4] [5] [6].

Richard Felder points out that it is essential to view learning as a community responsibility. Young people need to be integrated, fully contributing members of the broader community, so they can feel useful and valued. Educators should focus on issues of how to nurture well-rounded, emotionally intelligent students and make educational change in more fundamental ways, understanding, acquisition of critical thinking, formation of positive attitudes and self-confidence [7].

Albert Einstein believes that the aim of education must be the training of independently acting and thinking individuals who, however, see in the service to the community their highest life achievement [8].

Because of the rapid technological changes and concomitant information that is now readily available, it is suggested that educational institutions should refocus their curriculum and strategies of teaching. The pedagogy must be more than mere assimilation of facts, figures and knowledge but rather provide a combination of skill set and concepts to anchor the sustainablility-related values that would ensure the optimum balance between technology and humanism in the future.

Modern education will enable us to develop competencies for the future, to switch from one discipline view to transdisciplinary view, to switch from narrow to holistic view and to develop more sustainability-related value system. New education would foster young minds with the tools for creating better tomorrow and more responsible global citizens who will contribute to the wellbeing and progress of humanity.

3. HOLISTIC THINKING AND ACTING

New course "Holistic thinking and acting" is introduced at Faculty of Natural Sciences and Engineering at University of Ljubljana. With the new course the famous thought of Albert Einstein, "that we cannot solve problems with the same thinking we had when we created them", is followed. Our vision is course in which a balanced technological and social sciences knowledge will be given.

In the first part of course, the reflection and discussion about the characteristics of the today's world will be discussed (industrial production, constant growth, new economic trends, the role of people in the work process, ethics, values and social responsibility). The concept of sustainability with emphasis on all three components (environment, society and economy) and the UN SDGs and Holistic approach will be presented and discussed. Students will propose and discuss changes that could alter current trends.

Further, developmental psychology, which connects holistic problem solving with the development of thinking and personality, will be presented. The holistic approach is connected with the development of various forms of post-formal thinking, such as contextual, dispositional, pragmatic, interactionist, relativistic, systemic and dialectical, with the remaining ways of understanding oneself and the world and the development of expertise and wisdom. Through reviews, discussions and case studies, students will become familiar with the laws and forms of the different methods of problem solving. In doing so, they will focus not only on technical, but also on ethical and environmental aspects, impacts on social systems and society, and on diverse interactions between the individual and technological solutions. By learning to solve problems holistically, students of technical professions will expand their work horizons and responsibly understand how their decisions affect the environment.

Basics of lateral thinking, which was founded by Edward de Bono, the world's leading authority in the field of creative thinking, will be presented to students. It's about finding solutions to intractable problems using unorthodox methods that logical linear thinking would normally ignore. It is related to parallel thinking, which is distinguished by tolerance of different points of view, design, creation, research, stringing together possibilities without judgment, overcoming dualism, cooperation, inner world, etc. In the frame of holistic rhetoric, special attention will be paid to respectful, decent, ethical and moral communication.

Fractal drawing method will be one of the topics introduced to the students. The strength of the method is also that it enables us to act and think holistically. Positive effects of drawing fractal drawings are: active relaxation, balancing emotions, greater ability to learn and remember, greater problem-solving ability, improving memory, focus, developing creativity and creative thinking, strengthening self-confidence, improving health, reducing stress etc. [9]

One of the topics of the new course will be also the field of fashion design with sustainability and holistic thinking being its integral part. The teacher will encourage students to think holistically, establish reflections and self-reflections, and question their role. They will reveal the duality of fashion and explore models based on inclusivity, cooperation, empathy and especially compassion. They will explore how cooperation and compassion can transcend existing market practices and social relations.

4. CONCLUSION

A highly evolved and technically developed world needs focus on emotionally and socially developed human beings with high awareness who can use knowledge and new technology tools for building a better world. Based on holistic knowledge and understanding of deep interconnection of technology and social sciences, the strategy(es) for the future would meet the needs of the present without compromising the ability of future generations to meet their own needs. The aim of the new course "Holistic thinking and acting" introduced at Faculty of Natural Sciences and Engineering at University of Ljubljana was formed to address this challenge.

5. REFERENCES

[1] https://www.overshootday.org/
[2] https://www.un.org/en/academic-impact/sustainability
[3] https://www.undp.org/sustainable-development-goals
[4] https://www.openculture.com/2012/11/noam_chomsky_spells_out_the_purpose_of_education.html
[5] http://www.newfoundations.com/GALLERY/Chomsky.html
[6] http://rozenbergquarterly.com/noam-chomsky-on-the-perils-of-market-driven-education/
[7] https://web.archive.org/web/20180815232108/http://www4.ncsu.edu/unity/lockers/users/f/felder/public/Student-Centered.html

[8] http://wisdomquotes.com/albert-einstein-quotes/
[9] https://www.anjaberloznik.com/en/introduction-to-fractal-drawing-method/

FULLTEXTS OF ORAL PRESENTATIONS

INVESTIGATION OF MICROPLASTIC IN WATER AND WASTEWATER SAMPLES IN ERGENE REGION – EXAMPLE OF AN INTEGRATED TEXTILE MILL

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ABSTRACT

Recent scientific studies on water, which is the most important source of living things, focus on microplastic pollution. Microplastics are plastic residues in very different shapes, smaller than 5 mm, and although it is seen as the most serious environmental problem in water resources, waste water, soil and air, although national and international regulation has not been adopted on microplastic pollution yet. This study, which characterizes microplastics in groundwater samples taken from Ergene Basin and process wastewater from an integrated textile mill, is a pioneering research in the sector in terms of microplastic determination.

Key Words: Microplastics, textile wastewater, method evaluation, microscopic analysis, FTIR analysis

1. INTRODUCTION

As a result of decomposition by physical, photodegradation, chemical or enzymatic factors plastics in nature sun, water, air, etc., it mixes with soil, water, air and participates in the food chain by changing its physical properties (such as shape, color, crystallinity and density). With by their surface area and pore size, they also adsorb other toxic chemicals, and the amount they adsorb tends to be higher in naturally aged plastics [1]. Microplastic pollution is a parameter that has started to be monitored relatively late compared to other pollutants, especially in domestic and industrial wastewater. Especially the hydrophobic hazardous chemicals that microplastics can contain show that microplastics are a carrier pollution source especially for the aquatic ecosystem [2]. Although there is no internationally valid method for the determination of microplastics, scientists have developed many physical and chemical determination methods in the face of this pollution that threatens all living things globally. Examples of physical methods are sieving, filtration, visual separation, separation by density difference; separation with the aid of acidic, basic or other chemicals, enzymatic separation and analytical methods are examples of chemical methods such as SEM/EDS, FTIR, NIR, Raman spectrophotometry and NMR [1, 3, 4]. In a study, it was determined that the most abundant microplastics in different WWTP wastewater were polyester terephthalate fibers and polyethylene particles. With the study, they reported the microplastic removal efficiency as 92-99% by weight as a result of primary, secondary and tertiary treatment. It has been emphasized that more attention should be paid to secondary source synthetic fibers obtained from textile products compared to microbeads from primary source personal care products [2].

2. EXPERIMENTAL

In this study, water samples from groundwater and wastewater samples from woven fabric dyeing and finishing processes, which are supplied from integrated textile mill in Ergene

Region, were taken as composite samples totally in 5 lt volumes. Water samples were collected in 1 lt glass bottles. The convensional paramater test result of samples is given in Table 1.

Table 1. Temperature of Water/Wastewater Samples

Samples	Colur (ISO 7887)	Temperature (°C)	pH	Conductvity (µs/cm)
Groundwater (*)	colourless	20	7,8	296
Proses Wastewater (from dyeing, medium coloured) (**)	57; 68; 154	70	11,02	14,81
Proses Wastewater (from finisihing) (***)	NA; 1,7; 1,5	24	6,91	0,49

Test report referances (*) In-house test (F.258);
(**) Third party test TURA190035472; (***)Third party test TURA190035476

All samples kept in refrigerator in ±4°C for a one month. Then samples were get processes to primary treatment to elevate organic compounds from wastewater samples. Although there are many primary treatment methods for the separation of microplastic residues in wastewater samples in the literature, the catalytic Wet Peroxide Oxidation (WPO) method has been preferred because of its effective and fast oxidation time [5]. The water and wastewater samples were treated according to the wet oxidation-chemical method as given in Masura protocol [6].

Figure 1. Sample in wet oxidation process

All samples were treated in temperature 95°C and added H_2O_2 (hidrogeneperoxide) till until the foaming on the water surface ceases. Then all samples were colded to room temperature and filtered under a vacuum pump using a nylon (PA) filter according to the filtration-physical method. Naylon filters (100 micron) were divided equal sections to scan area more easy, shown in Figure 2. The filter papers were examined under a light microscope LEICA DM750.

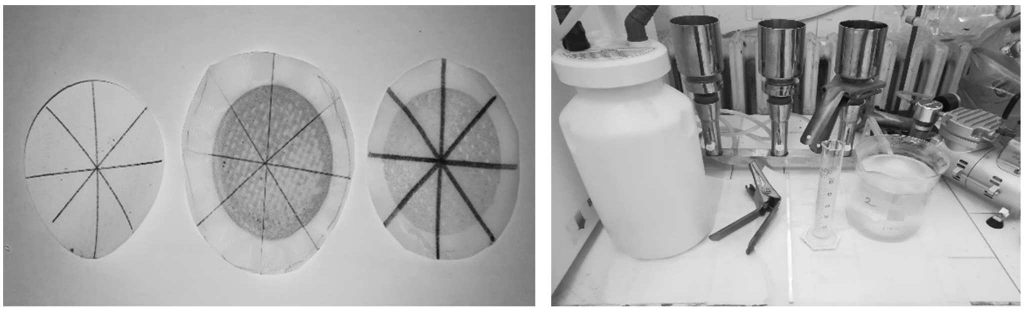

Figure 2. 100 micron naylon filters and vacuum pump

Figure 3. Light microscope (LEICA DM750)

FTIR analyzes of virgin sythetic fiber (polyester), recycle polyester fiber and raw water and untreated wastewater samples were also completed in Thermo Fisher Scientific Nicolet IS 10 FTIR [7].

Figure 4. Thermo Fisher Scientific Nicolet IS 10 [7]

3. RESULTS

In order to better interpret the wastewater microscope analyses, all textile rawmaterials of fabric processed were examined in 4X, shown in Figure 4. Raw materials and wastewater samples have been investigated in light microscope and FTIR. Results are given in Figure 4, Figure 5 and Figure 6.

(a) (b) (c) (d) (e)

Figure 4: Microscobic images of (a) recycled polyester fiber; (b) warp yarn; (c) weft yarn; (d) woven greige fabric; (e) woven dyed fabric

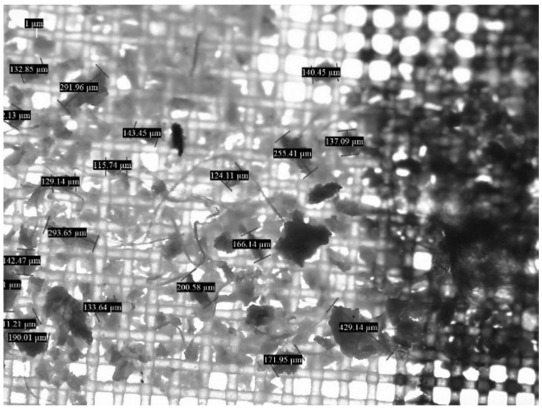

Figure 5: Microscobic images of microplastics from wastewater

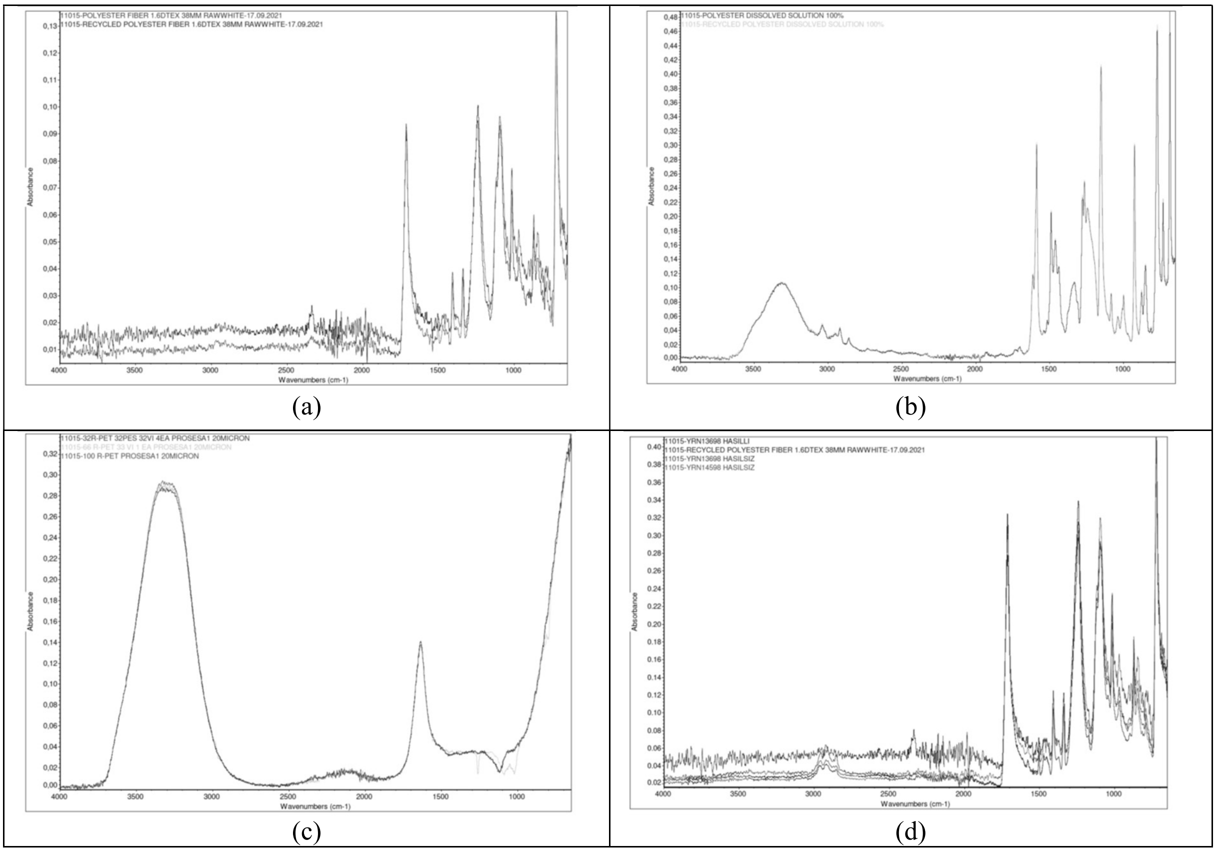

Figure 6: (a) Virgin polyester fiber and recycled polyester fiber;
(b) Dissolved polyester fiber and dissolved recycled polyester fiber;
(c) Proses wastewater from 100% R-PET, 66% R-PET and 32% R-PET fabrics;
(d) Recycled polyester fiber; recycled polyester yarn with sizing; recycled polyester yarn without sizing.

Microplastics on filter counted manually and summarized in Table 2.

Table 2. Temperature of Water/Wastewater Samples

Type of MP's	Number of MP's/ 1 lt in Wastewater	Number of MP's/ Dyeing Process in Wastewater
Fragment	23	more than 115.000
Filaments	126	more than 630.000

In the FT-IR analyzes examined, it is seen that virgin polyester fiber and recycled polyester fiber have similar peaks and wavelengths. Dissolved polyester fiber and dissolved recycled polyester fiber appear at the same peak and wavelength. When process wastewater from 100% R-PET, 66% R-PET and 32% R-PET fabrics is examined, 66% R-PET is seen in the 1270^{-1} IR band corresponding to the C-N stretch. Recycled polyester fiber; recycled polyester yarn with sizing; When recycled polyester yarn without sizing is examined, although the same peaks and wavelengths are observed, the bands corresponding to the C-H, -OH group and the IR band corresponding to C-N stretching have a sharper peak.

4. DISCUSSION

Textile microplastic emission test standard need to be standardized both in production and domestic washings. Different finishes, durable press finishes consume less oxygen and are followed by the lowest degradation. This is due to the chemical bond between the fiber and respective chemicals, resulting in slow down the biodegradation of fibers. Industry need to avoid from mechcnical finishings and high temperature of dyeing/washing processes. Production in low temperature and short processing time are helpful to increase fiber pollution.

5. CONCLUSIONS

Detection of microplastic pollution in water and raw wastewater originating from fabric dyeing finishing processes in an integrated textile mill operating in Ergene Basin producing woven fabrics is considered as a pioneering study. The detected microplastics were supported by microscope analysis and FTIR analysis. The presence of fiber and microplastic was detected in all samples. Microplastic concentration was mostly determined in process wastewater and in the form of polyethyleneterephthalate-based filaments.

The rapid increase in the use of synthetic raw materials together with the increasing consumption in the textile industry in recent years also significantly affects the microplastic pollution. It should be aimed to detect this pollution with detailed analyzes on process (source) basis and to prevent pollution with research and development studies. When the synthetic fiber fragments released to the marine environment, textile chemicals and dyes integrate with fiber fragment to create additional health hazardous to the aquatic environment.
Emissions of hazardous chemicals and microplastic are depends on; raw material (yarn) type, raw material (yarn and fabric) production method, textile wet processes method, textile wet process duration, textile wet process temperature, auxiliary chemicals, garment sewing threads and sewing cunstrucion. These studies will serve as a guide for industrial enterprises for the national/international requirements that are planned to be implemented in the near future.

6. REFERENCES

[1] TIRKEY, A. Upadhyay, L.S.B. Microplastics: An overview on separation, identification and characterization of microplastics. Marine Pollution Bulletin, 2021, vol. 170, no. 112604, ISSN 0025-326X, https://doi.org/10.1016/j.marpolbul.2021.112604.
[2] TUTOĞLU, N. (2019). Sucul ortamdaki mikroplastiklerin insan sağlığına etkisi ve arıtma yöntemlerinin araştırılması (Uzmanlık tezi). T.C. Tarım ve Orman Bakanlığı Su Yönetimi Genel Müdürlüğü, Ankara, Türkiye.

[3] DIERKES, G., LAUSCHKE, T., FÖLDI, C. (2021). Analytical Methods for Plastic (Microplastic) Determination in Environmental Samples. In: Stock, F., Reifferscheid, G., Brennholt, N., Kostianaia, E. (eds) Plastics in the Aquatic Environment - Part I. The Handbook of Environmental Chemistry, vol 111. Springer, Cham. https://doi.org/10.1007/698_2021_744
[4] ZARFL, C. Promising techniques and open challenges for microplastic identification and quantification in environmental matrices. Anal Bioanal Chem 411, 2019, 3743–3756. https://doi.org/10.1007/s00216-019-01763-9.
[5] TURAN, N. B., ERKAN, H.S., ENGIN G.O. Microplastics in wastewater treatment plants: Occurrence, fate and identification, 2021, Process Safety and Environmental Protection, Volume 146, Pages 77-84, ISSN 0957-5820, https://doi.org/10.1016/j.psep.2020.08.039.
[6] MASURA, J., et al. 2015. Laboratory methods for the analysis of microplastics in the marine environment: recommendations for quantifying synthetic particles in waters and sediments. NOAA Technical Memorandum NOS-OR&R-48.
[7] Available on https://www.thermofisher.com/order/catalog/product/IQLAADGAAGFAHDMAPC [22.09.2023].

PCL PHOTO-RESPONSIVE ELECTROSPUN MEMBRANE BASED ON PHOTOCHROMIC MOLECULE

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ABSTRACT

Smart textiles made from electrospun photosensitive membranes have attracted attention due to their promising results in various fields. Electrospinning was selected to prepare poly (ε-caprolactone) (PCL)-based membranes with 5.7 wt.% of DTE content to obtain the photosensitive properties. The influence of DTE on the PCL nanofiber morphology and photo-reactivity of the DTE-PCL-based membrane was studied by scanning electron microscopy (SEM) and photo spectrophotometer. Upon alternative irradiation with ultraviolet (UV) and visible (vis) light, the resultant membranes display photoswitching behaviors. Thus, the electrospun PCL–DTE nanofibers may be promising candidates for photochromic sensors.

Key Words: Photo-responsive textile, electrospinning, PCL, DTE, thermochromism

1. INTRODUCTION

The development of smart fibers that respond to external stimuli has become one of the basic building blocks in the development of smart textiles and wearable devices [1]. Color-changing structures have received particular attention in recent years due to their potential application in wearable screen design and information encryption [2]. As a result, much research has focused on the development of color-changing fibers capable of reacting to UV light, magnetism and temperature [3]. Photoreactive fibers that undergo reversible light-induced color change are expected to be widely used in rewritable optical data storage systems, visual environmental sensors, and information encryption. Smart textile structures based on photochromic molecules have received increasing attention in recent years due to their enormous potential for applications to detect and respond to external environmental conditions and stimuli [4].

Photochemical compounds are generally classified according to the photo-induced chemical reactions involved. Thus, we distinguish quinolones-acetones with intramolecular hydrogen transfer, spironaphtoxazines with a dissociation process, fulgides and diarylethenes with pericyclic reactions, azobenzenes with cis-trans isomerizations [5]. Diarylethene (DAEs) and more specifically Dithienylethenes (DTEs) have gained great popularity in photoactuator research for its bistability (P- Type photochromes) in contrast to AZOs, good quantum yields, high fatigue resistance, and a rapid photochromic response [6]. The functionalization of textile materials using these compounds must take account of their intrinsic properties, such as low affinity with the material, low solubility in water, and sensitivity to high temperatures. So, among the various possible routes, such as encapsulation, sol-gel treatment, and spinning, electrospinning is considered to be one of the preferred methods for using photochromic compounds in textiles [7]. Photochromic dithienylethene (DTE) derivatives as photochromic pigments are interesting since these compounds stand out most for their outstanding thermal stability, rapid photoresponse, and excellent fatigue resistance under a light stimulus. Moreover, in addition to the light-responsive, the design and construction of efficient multi-stimuli responsive switches have attracted numerous studies [8].

Electrospinning is a simple method for producing nanofibers from polymer solutions. The process is based on applying a high electrical potential to a polymer melt or solution over a finite distance between a conductive needle and a grounded collector. When the electrical charge at the tip of the needle overcomes the force due to surface tension and viscosity, a jet of polymer is ejected from the apex of the cone, then directed towards the grounded collector. During the flying time, the solvent evaporates and the fibers are deposited on the collector in the form of a randomly oriented nonwoven. Obtaining an electrospun structure depends on a large number of interdependent variables, including operating and formulation parameters.

The aim of this study is to analyze the effect of incorporating DTE into a PCL matrix on the properties of the electrified structure. The produced fibers can respond to the UV light with a visual color change. The resultant electrospun mat not only presents favorable reversible color-changing performance under UV light, but also exhibits remarkable colors witching ability in a visible light environment. At the same time, the fabric has the advantages of fast fading rate. It is believed that this research will open up a new way for the development of more effective and smart photosensitive textiles.

2. EXPERIMENTAL

2.1 Materials

Polycaprolactone (PCL) with an average molecular weight of 37,000 was procured from Perstorp, located in Skåne County, Sweden. N, N-Dimethylformamide (DMF), obtained from CARLO ERBA (Val-de-Reuil, France) and chloroform ($CHCl_3$), purchased from Sigma Aldrich (Dorset, UK), were used as solvents for PCL. The photochromic molecule used in this study is 1,2-bis(2,3-dimethyl-5-phenyl-3-thienyl)-3,3,4,4,5,5-hexafluoro-1-cyclopentene (DTE), purchased from TCI (Zwijndrecht, Belgium).

2.2 Preparation of photo-responsive fibers

In this work, the photo-responsive fibers were fabricated using the facile electrospinning method. 120 mg of DTE was introduced into a solution of PCL (21 wt.%) solubilized in a chloroform/DMF mixture (9/1 v/v). After stirring for 30 minutes at room temperature, the solution was left to stand for a few minutes to eliminate trapped air bubbles. The experimental setup for producing a series of PCL nanofibers consisted of a CAT000002 electrospray starter kit from Spraybase® AVECATS (Kildare, Ireland), which comprised three main components: a 10 mL plastic syringe fitted with a 20-gauge needle and attached to a microinjection pump, a high-voltage power supply (generator) and a grounded collector. The voltage applied between the nozzle and the manifold was set at 20 kV, while the microinjection pump was set in this study at 0.7 mL/h. An aluminum foil collector was placed 20 cm below the metal needle to collect the electrospun samples. Collection times were adjusted to 1 hour. After collection, the samples were dried for a few minutes at room temperature. All electrospinning experiments were carried out under constant temperature and relative humidity conditions of 25°C and 45%, respectively.

2.3 Characterization

The morphology and size of the obtained nanofibers were analyzed by scanning electron microscopy (SEM) using a Hitachi S4700 instrument.

Color parameters were obtained using a CM-3610a spectrophotometer (Konica Minolta) in reflectance mode in the 360-740 nm wavelength range. Samples were exposed to two types of light radiation, i.e., (i) a UV flashlight (365 nm, 1W) at a distance of 2 cm, and (ii) a visible flashlight (593 nm, 3W) at a distance of 3 cm, in a black box under 90° irradiation. The samples were then exposed to a UV light source (365 nm), and spectrophotometric measurements were taken every 10 seconds after the source was removed, varying the exposure time between 0, 10, 15, 30, 60, 120, 600, and 1200 seconds to analyze staining. The same procedure was used for decolorization under visible light. The spectrophotometer was used to determine the fatigue and fading rate of photochromic membranes. First, the photochromic membranes were irradiated with UV light for 20 minutes and then decolorized for 20 minutes under visible light in the dark. The irradiation and decolorization process was repeated 10 times. After each irradiation, the maximum absorption of the electrospun membrane was measured and compared with the original state of the material.

3. DISCUSSION

3.1 Color characteristic value of photochromic DTE-PCL-based membrane

The photochromic property was studied in detail by CM-3610a spectrophotometer to elucidate the membrane's reversible color change. The membrane was excited by the UV lamp for 20 minutes, then by the visible lamp for 20 minutes. Initially, the membrane shows a white color, which is attributed to its high reflectance to visible light. After being irradiated for 20 minutes, a new absorption band centered at 593 nm appeared. This peak is the characteristic absorption peak in the blue region (Figure 1). The photochromic performance of the membrane is attributed to the incorporation of DTE. The open-form isomer (OF) is the most stable isomer. According to the electro-cyclization reaction of a 1,3,5-hexatriene unit, which involves 6 atoms and 3 double bonds (π pairs), the photochromic reaction - also known as photo-cyclization - consists of closing the OF ring to result in a closed form (CF). After irradiation in the visible light, the photochromic mechanism is reversible, i.e., the light-induced opening of the ring is called photoreversion. In general, for most DTEs, photocycling is induced by UV light, while photoreversion is induced by visible radiation.

In addition, during continuous UV irradiation, there is a significant change in the a* (colors corresponding to red and green) and b* (colors corresponding to blue and yellow) values, L* (value corresponding to brightness). The a* value rises from -0.21 to 4.96, showing an increasing trend towards the red hue, while the b* value rises from -0.53 to -20.26, showing a shift towards the blue hue. The change in the L* value from 93.93 to 71.09 illustrates a decrease in brightness. The absorption value of the fabric can reach saturation after 20 minutes of UV irradiation, and prolonging the irradiation time will hardly increase the absorption rate of the fabric. After 20 minutes of visible irradiation, the a*, b* and L* values are reset to their initial point.

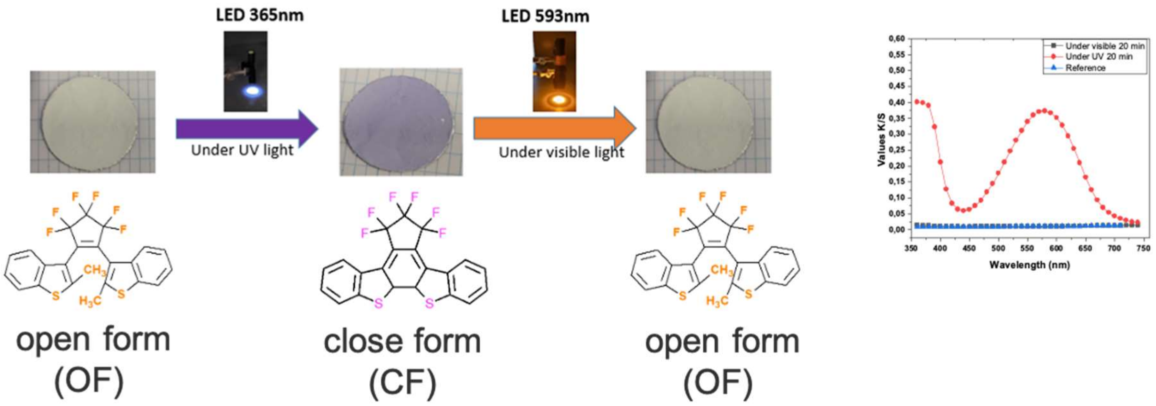

Figure 1. Evaluation of the photochromic response.

3.2 Color performance of the photochromic electrospun membrane

Figure 2 discusses the color-changing performance of photochromic cotton fabric from the aspects of irradiation time and fading time. From the figure, it can be found that the absorption value of the membrane can reach saturation after 600 s of UV irradiation. Similarly, the discolored membrane can quickly return to its original state within 600 s under visible light. Thus, it can be concluded that the manufactured photochromic electrospun membrane can change color rapidly and fade quickly under the induction of UV and visible light.

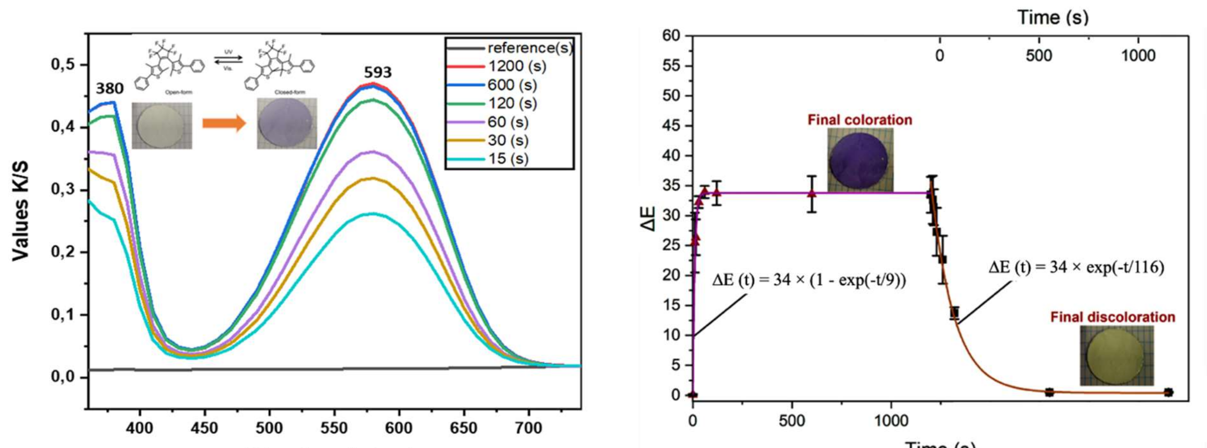

Figure 2. The irradiation saturation time and fading rate of the electrospun PCL membrane.

The kinetic model shown in Eq. (1) follows first-order kinetics and is generally used to describe photochromic colour behaviour for both the colouration and decolouration reaction as seen in figure 2 [9].

$$\Delta E(t) = (\Delta E_{t=0} - \Delta E_{t=1200}) \times \exp\left(\frac{-t}{\tau}\right) + \Delta E_{t=12} \qquad (1)$$

Based on the kinetic model, the electrospun membrane functionality was specified by its achieved colour difference upon activation with UV-light and visible-light, its rate constant of

colour increase $1/\tau_{colouration}$ ($1/\tau_{decolouration}$) or to achieve maximum colouration (decolouration) difference.
At first glance, the coloration kinetic (cyclization process) is approximately 13 times faster than the discoloration kinetic (photoreversion process). Even ig the irradiation power was not the same (2W vs 3W), a quasi-complete photocyclization (97%) is achieved in about 30 seconds while for the photoreversion process it takes 400 seconds. This result was expected since the photocyclization yield is 200 times larger than the reversion process. Nevertheless, the result is rationalized considering the power difference, and the penetration of the light is more efficient for the UV compared to the visible.

The behaviors of DTE incorporated into all of the PCL matrixes studied here manifested normal photochromism, which indicates that the used polymer matrix is not sufficiently polar enough to induce drastic change in the microenvironment of DTE required for observing reverse photochromism. The reverse photochromism can occur only under visible light or in the highly polar microenvironment of the matrixes.

The kinetics of the photochromism in these electrospun membranes were quantified using simple mono-exponential models in order to take into account the homogeneous distribution of free volume in the polymer matrixes and to compare the photodynamics among them. The data were fitted with an exponential function to find the goodness of fit, which show $R^2 > 0.95$.

3.3 Cycle stability of the photochromic electrospun PCL

It is very necessary to evaluate the photochromic performance of the material from the two perspectives of the color change rate and the fading rate because it reflects the light sensitivity of the photochromic material.

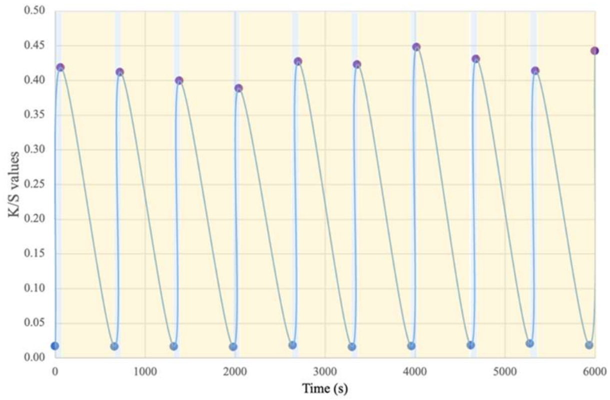

Figure 3. Changes of the K/S value of PCL electrospun membrane at 580 nm before and after UV / visible irradiations for 10 cycles.

Fatigue resistance plays an important role in photochromic materials because it is related to the service life of materials. The fatigue resistance of the photochromic DTE-PCL electrospun membrane can be assessed by the number of cycles of reversible color. It should be pointed out that to test the reversibility of the system, we have operated 10 successive irradiation cycles of 60 seconds for a colorless OF membrane and 10 minutes for CF membrane, starting with visible light (to purge the CF traces present in the membrane). Figure 3 analyzes the fatigue resistance of the photochromic DTE-PCL electrospun membrane from the perspective of K/S value. It can be observed from the figure that the color accounting and absorbance of the photochromic material hardly change after 10 cycles.

4. CONCLUSION

In conclusion, a smart PCL electrospun membrane for photoresponsive properties with a fast light response and high fatigue resistance was fabricated through an electrospinning process based on the use of DTE and PCL. The as-prepared material can reach the maximum color difference within 30 s of UV irradiation and fade after 600 s with visible irradiation. It can still maintain fast color switching after 10 reversible cycles.

In addition, the color changes of this membrane are accompanied by photomechanical effects (PME). Displacement amplitude increases up to 400 µm, and UV and visible amplitudes are not similar for a given irradiation time (1h) and LED power (700µW). The amplitude of displacement in the visible appears to be directly proportional to the amount of DTE, whereas, in the case of UV, the situation is undoubtedly more complex due to the shielding effect (OF and CF both absorb UV). Because of this difference, the overall displacement (additive displacement for each irradiation cycle) can be controlled by the irradiation period. Kinetic analysis of the displacement tracking profile should show that PME is totally controlled by the propagation of the OF/CF gradient along the material. The characteristic forward-backward times are, in this case, fully correlated with the kinetics of coloration or fade of the electrospun substrate.

5. REFERENCES

[1] KONCAR, V. Chapter 1: Introduction to smart textiles and their applications. In Smart Textiles and their Applications, Edited by Vladan Koncar. Cambridge, USA, 2016, pp 1-8.
[2] LIU, S., LIU, X., YUAN, J., BAO, J. Multidimensional Information Encryption and Storage: When the Input Is Light. Research (Wash D C), 2021, 7897849.
[3] SHEN, X., AKBARZADEH, A., HU, Q., SHI, C., JIN, Y., GE, M. Novel photo-responsive composite fibers fabricated by facile wet-spinning process for UV detection and high-level encryption. Journal of Luminescence, 2022, 251, 119179.
[4] SAYEB, S., DEBBABI, F., HORCHANI-NAIFER, K. Investigation of photochromic pigment used for smart textile fabric. Optical Materials, 2022, vol 128, pp 112393.
[5] IRIE, M., KUNGWATCHAKUN, D. Photoresponsive polymers. Mechanochemistry of polyacrylamide gels having triphenylmethane leuco derivatives. Die Makromolekulare Chemie, Rapid Communications, 1984, 5, 12, 829-832.
[6] LI, Z., Zhang, J-R., TIAN, X-K., YANG, S., CHEN, S., ZHOU, H., YANG, X.G. Green-/NIR-light-controlled rapid photochromism featuring reversible thermally activated delayed fluorescence and photoelectronic switching. Chemical Science, 2022, 13, 9381-9386.
[7] KMBASAR, E-P-A., MORSUNBUL, S., ALIR, S. Photochromic Nanofibers [online], InTech; 2018. Available from: http://dx.doi.org/10.5772/intechopen.74663.
[8] YAN, Q., QIAO, Z., XU, J., REN, J., & WANG, S. All-visible-light triggered photochromic fluorescent dithienylethene-phenanthroimidazole dyads: Synthesis, crystal structure, multiple switching behavior and information storage. Dyes and Pigments, 2022, vol. 202, pp. 110298.
[9] VIKAOVA, M., VIK, M. Alternative UV Sensors Based on Color-Changeable Pigments. Advanced in Chemical Engineering and Science, 2011, 1, 224-230.

SUSTAINABLE PREPARATION OF PROCESS WATER: A CASE STUDY OF DOUBLE REVERSE OSMOSIS IN A TEXTILE DYEHOUSE

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ABSTRACT

Today, resin (ion exchange) or reverse osmosis systems can be used depending on the character of the raw water to be treated and the purity of the water to be obtained, or it is possible to use the two as complementary systems. To create a sustainable textile production, the main challenge has been linked to lesser usage of water, energy, and chemicals in production processes. Double RO systems operated with pre-ion exchange systems will be the sustainable solution for consistent and high-quality process water with lower water waste. In this study, a dyehouse that uses, resin (ion exchange) and double reverse osmosis systems is given.

Key Words: Reverse osmosis (RO), Process water, Water consumption, Sustainability

1. INTRODUCTION

The textile industry is one of the longest and most complex industrial production/supply chains in the manufacturing industry [1]. Besides, it is one of the largest consumers of water and chemicals for wet processing of textiles [2]. The textile industry uses water for the generation of steam, for removing impurities, applying dyes, and finishing agents. Therefore, successful results in the textile wet processing are strongly dependent on the quality of water.

Natural and pre-treated water may contain a variety of chemical species that can influence textile wet processing in general and dyeing in particular [3]. Unreliable, inconsistent and/or contaminated incoming water have a major effect on the repeatability of dyeing and the quality of goods. Hard water causes the dyes to precipitate with the hardness components during the alkali fixation stage and therefore soft water should be used in all dissolving and dyebath processes [4]. Wash off processes are less effective with hard water and lead to poor wash and rub fastness. The alkalinity in water can also act as a buffer and make it difficult to achieve the extremes of pH required for reactive dyeing. Sources of water with variable bicarbonate content can adversely affect the reproducibility of the dye fixation conditions [4]. Thus, dye houses need a consistent supply of soft water or the ability to soften water on-site. Consistent and uncontaminated process water ensures on-time delivery in a cost-effective way. To ensure production is as consistent as possible, high-water quality should be maintained, monitored on-line and off-line and records retained as part of quality management systems. Today, resin (ion exchange) or reverse osmosis systems can be used depending on the character of the raw water to be treated and the purity of the water to be obtained, or it is possible to use the two as complementary systems. Ion exchange involves removing the hardness ions calcium and magnesium and replacing them with non-hardness ions, typically sodium supplied by dissolved sodium chloride salt. It is reversible, and regeneration simply involves treatment with a concentrated solution of a salt containing the appropriate anion [3]. On the other hand, reverse osmosis (RO) is a technology that is used to remove a large majority of contaminants from water by forcing the water to pass through a semi-permeable membrane under pressure [5] and provide high and consistent process water. However, main drawbacks of RO are, high installation cost, fast fouling of the membranes and significant water waste during the purification.

In this study ion exchange and RO systems are explained, general water consumptions of these systems are summarized. Then, a dyehouse example is given and analyzed which uses an ion exchange systems and double RO system. Ion exchange systems is used for pre-softening of the municipal water, and it prevents the fast fouling of RO membranes. Second RO system is used for recycling the waste water from first RO and ion exchange systems in order to reduce the total water waste.

2. METHODS FOR PROCESS WATER PREPERATION

2.1 Sand Filtration system

These filters are used to remove pollutants such as particulate matter in water, clay, silt, colloidal particles that cause turbidity from water. Sand filters consist of sand layers with different grain sizes. The water is filtered by passing through these layers at filtration rates selected according to the pollutant concentration it contains. Backwashing takes place automatically depending on time or pressure difference to throw out the pollutants held by the sand filter during filtration. Sand filters are generally used for well water filtration, filtration of surface waters (river, lake, sea), for pre-filtration before softening systems, for pre-filtration before reverse osmosis systems, filtration of treated wastewater and pool water filtration processes [6] They are important because unfiltered water will cause very rapid clogging of membrane systems.

2.2 Ion exchange system

The two most common ion-exchange methods are softening and deionization [7]. Ion exchange in water treatment involves removing undesirable ionic contaminants from the water by exchanging them with another ionic substance. This chemical process works by removing dissolved ionic contaminants from the water. These ions are swapped for better ones that won't degrade the quality of water. Ion exchange system for textile process water mainly used for softening and remove magnesium and calcium ions from the process water [8]. Softening is used primarily as a pretreatment method to reduce water hardness prior to reverse osmosis (RO) processing.

The ion exchange process will take place between a liquid and a solid. While the liquid is always water, the solid can be either zeolite or a resin material. Resin materials can only be charged for a specific period and when ions are no longer able to be exchanged, the resin will need to be recharged. Resins are generally recharged with sodium chloride [8].

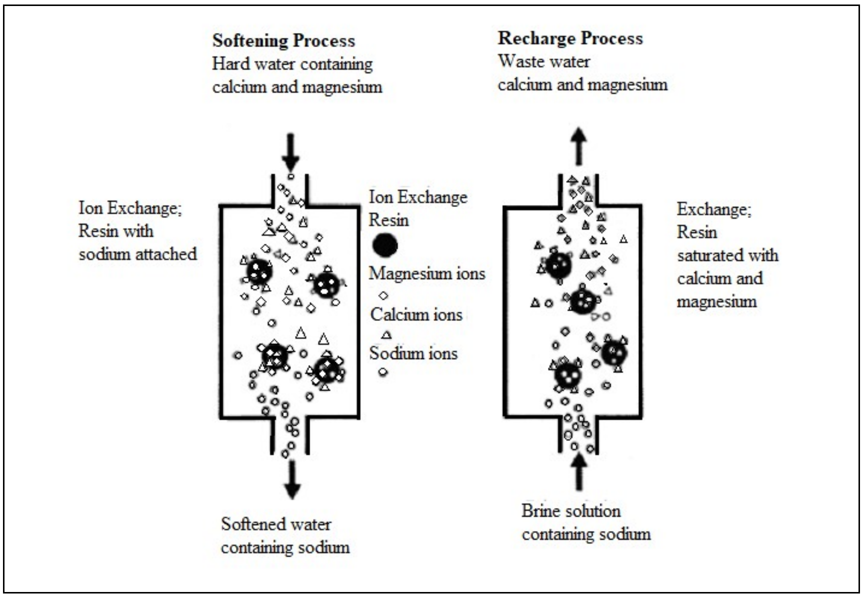

Figure 1. Schematic representation of ion-exchange system

2.3 RO system

Osmosis is the spontaneous movement of water from the low-density side to the high-density side in two solutions of different concentrations with a semi-permeable membrane between them. In this way, the system seeks to reach equilibrium by eliminating the concentration difference. Osmosis is a spontaneous event in nature. All plants take water from the soil and transmit it to the leaves through the semi-permeable cell membrane.

Reverse Osmosis, on the other hand, is the reversal of the osmosis phenomenon by applying pressure to the side with the higher density. Water passes from the pressure-applied side to the low-concentration side. While the semi-permeable membrane allows the passage of water, it does not allow the passage of ions dissolved in the water, purifies the water from all ions (95%-98%). RO requires high pressure depending on processed water because natural osmotic pressure must be overcome. Wastewater carries the rejected contaminants.


a)

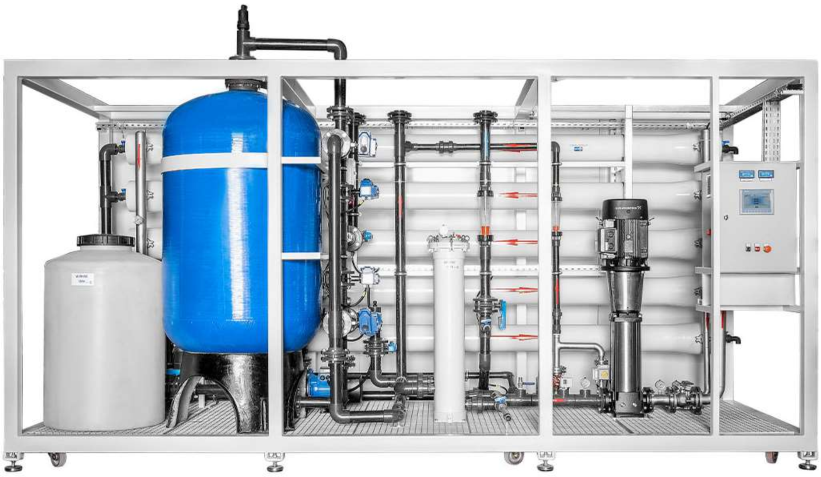
b)

Figure 2. a) Representation of reverse osmosis flow [7], b) Reverse osmosis system [8]

Membrane of Reverse Osmosis
The semi-permeable membrane is the heart of the reverse osmosis water treatment system. Reverse osmosis provides the transition from a less dense medium to a very dense medium by pressure. Membrane pores are about 8-10 angstroms. There can only be a molecular passage through such small pores. The reverse osmosis membrane retains 95 – 98% of the dissolved substances in the water under high pressure. While the trapped ions are thrown out in the concentrate line, the water passing through the membrane and gaining purity is stored in the pure water tank.

There are two common types: cellulose acetate (CA) and polyamide thin film composite (TFC). One advantage of the CA membrane is it is more resistant to chlorine than the TFC membrane. However, TFC membranes are much more efficient and superior in performance overall compared to CA membranes [10].

The RO membrane can be configured in different ways (such as plate & frame, hollow fiber, spiral wound), but the most efficient and economical configuration is spiral wound configuration [Figure 1a]. Unlike dead-end filtration where there are only feed and product streams, crossflow filtration has three streams (feed, permeate and concentrate streams).

3. A CASE STUDY OF DOUBLE REVERSE OSMOSIS

In this study a dyehouse “Nesa-3” is given. Sand filter, softening and reverse osmosis systems (Figure 1b) are used to prepare the process water, respectively. Sand filter prevents the fast fouling of RO membranes, ion exchange systems is used for pre-softening of the municipal water. Then the first RO system (RO1) removes all the ions in the water and this water is given into the RO poll and then to the enterprise for dyeing processes, while the second RO system (RO2) is used for recycling the wastewater from RO1 and ion exchange systems in order to reduce the total water waste. Enterprise has a 1000 tons of hard water pool, a 750 tons of soft water pool, a 250 tons of clean RO poll and two 20 tons of waste holding tanks.

Initial feeding hardness of municipal water in Denizli Organized Industrial Zone (DOSB) is between 40-50 dH° and its conductivity is about 1940 µS depending on seasonal conditions. After softening (ion-exchange) process, hardness decreased to 1-2 dH°, and conductivity increased to 2.55 mS. This water is collected in soft water pool. All pretreatment, washing and finishing processes except dyeing use this softened water.
In ion-exchange process, resin should be recharged periodically and recharging of resin’s total waste water is about 25 tons for each 220 tons of processed water. Approximately 12 tons of this waste is directly discharged because of the high salt content, 13 tons is sent to the waste tanks for recycling at RO2.

Feeding water of RO1 comes from the soft water pool, then permeate is sent to clean RO pool and concentrate stream is sent to waste tanks. When these waste tanks are full, RO2 starts to operate, again permeate is sent to clean RO pool and final concentrate stream is discharged. Hardness of RO permeate is 0 dH° and its conductivity is about 80-90 µS.

Data for softening (ion-exchange) process and double RO are collected between 1st and 11th of September 2023. Softened water which was processed through ion-exchange system was about 5060 tons, resin recharging waste was 575 tons. From this recharging waste, approximately 275 tons was sent to waste tanks. RO1 processed 1610 tons in total, permeate was 1150 tons which was sent to clean RO pool, concentrate was 460 tons which was sent to waste tanks, then to RO2. RO2 processed 275 tons from ion-exchange and 460 tons from RO1, 735 tons in total. RO2 sent 380 tons to clean RO pool and discharged 355 tons to the Central Wastewater Treatment Plant of DOSB. Efficiencies are given in Table 1.

Table 1. Feeding, permeate, concentrate, discharge and efficiency of ion-exchange, RO1 and RO1

01.09.2023-11.09.2023	Total Feeding (tons)	Permeate (tons)	Concentrate (tons)	Discharge (tons)	Efficiency (%)
Ion-exchange	5060	5060	-	299	
RO1	1610	1150	460	-	%71
RO2	735	380	355	355	%52
			Total discharge	654	%13

First RO system generates approximately 30-35% of wastewater. When it is operating feeding stream is about 40 m^3/h, permeate is about 30 m^3/h and the waste stream is about 10m^3/h. For the given days, RO1 generated 29% waste water. Permeate stream was measured 32.5 m^3/h and waste stream was measured 12.5 m^3/h for RO1 which were close, slightly better than the predictions. RO2 system processes both RO1 and ion exchange system's waste and recovers approximately 50-55% back. When the waste tanks are full, it starts to operate and processes 20 m^3/h, and waste stream from RO2 is about 10 m^3/h. In general, approximately 11-15% of total waste (concentrate) is produced which is much lower than the use of single RO system. For the given days, RO2 generated 52% waste water which was as expected. Efficiency of RO2 is generally affected from the concentrate of RO1 and resin washing water contaminants. Thus, its efficiency is lower than RO1. When we evaluated the total waste over 5060 tons of feeding, it was about 654 tons and around 13%.

3. CONCLUSIONS

In order to create a sustainable textile production, the main challenge has been linked to lesser usage of water, energy and chemicals in production processes. Double RO systems operated with pre-ion exchange systems will be the sustainable solution for consistent and high-quality process water with lower water waste. For further studies RO system can also be adapted for finishing waste recycling.

4. REFERENCES

[1] ROTH, J., ZERGER, B., De GEETER, D., GOMEZ BENAVIDES J. and ROUDIER, S., Best available techniques (BAT) reference document for the Textiles Industry, EUR 31392 EN, Publications Office of the European Union, Luxembourg, 2023, ISBN 978-92-76-61945-1, doi:10.2760/355887, JRC131874, p 1029.
[2] PETRINIĆ, I., BAJRAKTARI, N. and HÉLIX-NIELSEN, C. Membrane technologies for water treatment and reuse in the textile industry. In Advances in Membrane Technologies for Water Treatment (pp. 537-550). Woodhead Publishing, 2015.
[3] BROADBENT, A. D. Basic principles of textile coloration Bradford, UK: Society of Dyers and Colorists, (Vol. 132, pp. 332-357). 2001, p 579.

[4] SHORE, J., Chapter 4: Dyeing with Reactive Dyes. In Cellulosic Dyeing, Edited by J.S. Oxford: Society of Dyers and Colourists, 1995, pp 189-244
[5] IDREES, M. F. Performance analysis and treatment technologies of reverse osmosis plant–a case study. Case studies, Chemical and environmental engineering. 2020, vol.2, pp 100007.
[6] FUZYONSU, [cited 13.09.2023]. Available on https://www.fuzyonsu.com/tr/hizmet/multimedya-kum-filtrasyon-sistemleri-0owl
[7] MERCKMILLIPORE, [cited 13.09.2023]. Available on https://www.merckmillipore.com/TR/tr/water-purification/learning-centers/tutorial/purification-techniques/ion-exchange/Y2eb.qB.k.EAAAFAw5twFMvS,nav?ReferrerURL=https%3A%2F%2Fwww.google.com%2F
[8] SENSOREX, [cited 13.09.2023]. Available on https://sensorex.com/ion-exchange-how-does-it-work/#:~:text=The%20ion%20exchange%20chemical%20process,calcium%20ions%20from%20the%20water.).
[9] BAYSU, [cited 13.09.2023]. Available on https://www.baysu.com/portfolio/aquabay-ters-ozmoz-sistemleri/
[10] WATER QUALITY ASSOCIATION, Reverse Osmosis (Ro) Fact Sheet [cited 13.09.2023]. Available on https://wqa.org/wp-content/uploads/2022/09/2019_RO.pdf

ECO-FRIENDLY DENIM WASHING PROCESS

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ABSTRACT

In this study, denim fabrics (99 % cotton /1 % elastane) were dyed with 7 different dyes and washed with 4 different recipes, in three of which ozone technology was applied. Color fastness to crocking, dimensional stability, tear strength, yarn strength, Martindale abrasion resistance, color fastness to washing, color changes of the obtained denim fabrics were evaluated and compared to each other. Positive effects of ozone gas on the physical and fastness properties of the fabrics were observed. In conclusion, ozone technology is successful in denim industry in terms of waste usage, resources, energy and cost.

Key Words: Denim, washing, ozone, sustainability

1. INTRODUCTION

Denim fabric which is one of the oldest fabric forms in the world, still remains young as the most important part of the textile industry. Due to its simplicity, comfort and longevity, denim clothing is found in wardrobes of all ages. In the past, consumers used to wash denim several times at home to soften it. Later, this process was started by the manufacturers and consumers accepted the extra costs from this transaction. Manufacturers used abrasive stone to speed up the color-fading process, which was called as stone washing. Then, chlorine (sodium hypochlorite) was used and followed by the enzyme cellulose. In time, dry processes such as laser, ozone and plasma became popular when wet processes were found to be too harmful to the environment and nature.

The natural element of ozone is referred to as "Active Oxygen". The mixture of three oxygen atoms forms the ozone molecule which is unstable, colorless, has a specific odor, and is gaseous at room temperature. In addition, it can not be stored due to high-temperature sensitivity or can not be moved from one place to another. In this procedure of denim washing, clothes are washed with ozone that breaks up in water in a typical washing machine. However, it can also be performed in a shut chamber by utilizing ozone gas. The advantages of this method are the minimum loss of strength, being simple, being water- and chemical-free. In other words, it is an environmentally friendly process with low energy costs.

Two types of ozone applications, gaseous and wet processes, exist in the textile dyeing industry. For wet cycles, fluid ozone is more useful than vaporous ozone since the working rule of completing machines is appropriate for arrangement. Utilization of vaporous ozone needs exceptional airproof machines in view of word-related wellbeing and solace. The material of the sealed gasket needs to oppose vaporous ozone. (Körlü, A. 2018). On the other hand, levels of ozone can arrive at hazardous degrees of 0.5 ppm, and the breaking down impact that ozone has on denim clothing (especially denim put away on retail retires) is basically irreversible.

In this study, the same type of denim fabrics dyed with seven different dyes were washed with ozone for different durations and they were compared to the control samples which were not processed with ozone washing. The samples were evaluated according to their tear strength, yarn strength, fastness to crocking, and washing fastness. As a result of the tests, it was seen that ozone washing would be a suitable choice for the desired denim end product.

2. EXPERIMENTAL

99% cotton and 1% elastane denim fabrics dyed with 7 different dyes were washed with 4 different recipes. For recipe 1, stone washing was applied for 20 min. For recipe 2, pre-ozone was applied for 2 min followed by stone washing for 20 min and rinsing for 6 min. Finally, ozone was applied for 3 min. For recipe 3, stone washing was applied for 20 min followed by rinsing for 6 min and ozone was applied for 5 min. For recipe 4, stone washing was applied for 20 min followed by rinsing for 6 min and ozone was used for 20 min. After washing processes, color fastness to crocking and washing, dimensional stability, tear strength, yarn strength, and Martindale abrasion tests of the samples were performed and the results were deeply evaluated.

3. RESULTS AND DISCUSSION

3.1 Yarn Strength

This test was conducted by taking 20 yarns in warp and weft direction from fabrics. Test results show the amount of the load that can be applied to the yarn until it breaks. The results are summarized in Table 1. Mechanical and chemical effects in the content of washing recipes affect the yarn strength structure. The effect of washing with ozone on yarn strength is very close to traditional methods. There does not appear to be any significant difference in yarn strength results between recipes.

Table 1. Yarn strength test results of the samples

	Sample Name		Max Force Applied	Min Force Applied	Tensile Strenght (N)	Extension (%)
Recipe 1	T743-Pure Indigo	Warp	1632	1029	1260	10.5
		Weft	856	721	792	8.9
	T750-Indigo-Black Overdye	Warp	1349	1084	1233	10.2
		Weft	784	589	732	8.2
	T746-Sulphur	Warp	1685	1034	1382	9.13
		Weft	632	804	728	10.85
	T744-Islandblue	Warp	1636	1255	1420	10.6
		Weft	884	615	778	13.8
	T747-Sulphur-black overdye	Warp	1361	974	1117	7.2
		Weft	859	648	778	10.52
	T748-Sulphur bottom	Warp	1465	1141	1306	9.18
		Weft	821	692	751	8.8
		Warp	1608	1056	1413	8.01

	T745-Pure indigo	**Weft**	904	642	795	7.76
Recipe 2	**T743-Pure Indigo**	**Warp**	1477	1118	1272	10.8
		Weft	891	743	818	15.59
	T750-Indigo-Black Overdye	**Warp**	1325	1106	1213	8.572
		Weft	886	483	697	12
	T746-Sulphur	**Warp**	1329	1091	1233	7.07
		Weft	706	545	706	6.5
	T744-Islandblue	**Warp**	1315	1150	1241	10.5
		Weft	861	611	737	15.12
	T747-Sulphur-black overdye	**Warp**	1378	948	1186	8.7
		Weft	857	626	738	18.5
	T748-Sulphur bottom	**Warp**	1277	1038	1120	10.38
		Weft	745	615	680	9.78
	T745-Pure indigo	**Warp**	1504	1149	1298	9.5
		Weft	897	663	775	10.8
Recipe 3	**T743-Pure Indigo**	**Warp**	1407	961	1165	7.94
		Weft	827	668	741	7.57
	T750-Indigo-Black Overdye	**Warp**	1232	930	1125	6.19
		Weft	830	598	751	6.6
	T746-Sulphur	**Warp**	1595	818	1149	9.4
		Weft	753	546	637	6.43
	T744-Islandblue	**Warp**	1320	1090	1194	6.98
		Weft	783	630	725	7.2
	T747-Sulphur-black overdye	**Warp**	1296	963	1131	6.3
		Weft	835	484	666	7.23
	T748-Sulphur bottom	**Warp**	1408	926	1134	6.7
		Weft	744	530	579	6.69
	T745-Pure indigo	**Warp**	1444	1089	1237	6.9
		Weft	735	604	656	7.38
Recipe 4	**T743-Pure Indigo**	**Warp**	1592	1017	1200	9.03
		Weft	884	616	776	9.9
	T750-Indigo-Black Overdye	**Warp**	1283	1130	1318	9.6
		Weft	938	722	807	9.85
	T746-Sulphur	**Warp**	1633	1107	1368	9.715
		Weft	825	549	700	8.78
	T744-Islandblue	**Warp**	1498	723	1277	11.7
		Weft	836	666	769	9.3
	T747-Sulphur-black overdye	**Warp**	1405	1007	1135	9.08
		Weft	902	523	736	9.2

	T748-Sulphur bottom	**Warp**	1328	1071	1166	8.8
		Weft	564	743	618	9.75
	T745-Pure indigo	**Warp**	1323	970	1198	10.2
		Weft	946	651	797	8.84

3.2 Color Fastness to Crocking

This test is applied to both the wet sample and the dry sample. But only their fastness in dry conditions were assessed. In general, the application time of ozone plays an effective role in dye transfer. Ozone gas reacts with the sulfur and indigo molecules, which are the dyestuff in the structure of the denim fabric, and destroys its structure. It provides that the dye is removed from the fabric and prevents the dye from sticking to the fabric again. As the application time of the ozone treatment increases, more dye is removed, and tests performed on fabrics washed with the recipe 4 for color fastness to friction resulted in less dye transfer to the scrubbing cloth. Recipe 2, supported by pre-ozone with a short application time, showed a lower performance than other recipes.

3.3 Abrasion Resistance

The fabric weights were measured before and after the test and lost in the fabric weigth was evaluated. If the samples had been washing by other chemical or mechanical methods rather than ozone gas, the abrasion resistance of the fabric would be seriously affected, but products treated with ozone gas generally give better results than traditional method. Therefore, it can be said that denim washing with ozone gas does not abrade the fabric structure. So it will have a more durable fabric against wear in everyday use.

3.4 Dimension Stability

Measurement locations were determined on the samples sewn as half jeans. Throughout the whole study, the same measurement locations were used and their values were recorded. Measurement locations: Inseam, outseam, knee, calf and leg opening. Measurement of all samples was taken from the indicated points before and after washing. When the shrinkage percentages were examined, the values are almost the same.

3.5 Tear Strength

Speed and time are the main potential parameters of ozone washing, which mainly affects the tear strength of the garment. Due to the constant speed parameter applied in production, the points examined were whether ozone gas was used or not and the time applied. The fabric with 3 minutes of ozone treatment after pre-ozoning gave the highest tear strength value for denim fabric.

3.6 Color Fastness to Washing

Specimens were dried after washing. The values were measured with the gray scale. It was has that ozone gas had good washing fastness properties. As a result of the test, it is seen that the use of ozone gas could be preferred instead of traditional methods.

3.7 Color Evaluation

The most clear one is the wash in which the color separated the most intensely from the fabric. In other words, it was after recipe 4, the one ozone gas was applied for 20 minutes.

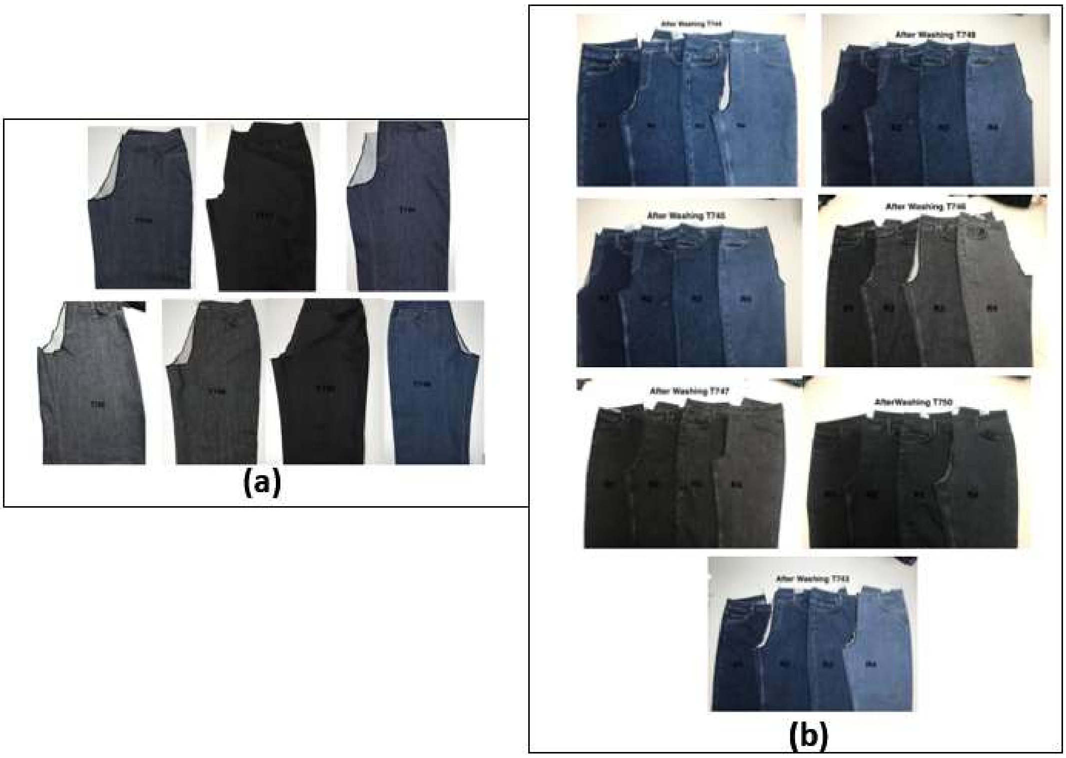

Figure 2. (a) Denim fabrics before washing and **(b)** color changes in denim fabrics after washing.

4. CONCLUSIONS

In this study, it was aimed to compare the physical and fastness performance of denim fabrics washed with 4 different recipes in three of which ozone washing was applied. When the tests of 28 test samples washed with 4 different prescriptions were compared, positive effects of ozone gas on the physical and fastness properties of the fabrics were observed. Thus, it can be summarized that the usage of ozone technology is successful in denim industry in terms of waste usage, resources, energy and cost.

5. REFERENCES

[1] AMUTHA, K. Environmental impacts of denim. In Sustainability in denim. Woodhead Publishing, 2017, 27-48.

[2] BLACKBURN, R. Sustainable textiles: life cycle and environmental impact. Elsevier, 2009,14-45.
[3] POWAR, A.S., PERWUELZ, A., BEHARY, N., HOANG, L., and AUSSENAC, T. Application of ozone treatment for the decolorization of the reactive-dyed fabrics in a pilot-scale process—optimization through response surface methodology. *Sustainability*, 2020, 12(2):471.

THE EFFECT OF DIFFERENT FABRIC CONSTRUCTIONS ON BUILDING REINFORCEMENT

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ABSTRACT

Textile products with functional features rather than aesthetic and decorative purposes are in the technical textile category. One of the areas is construction and buildings. The effect of carbon-based woven fabrics on strengthening depending on their physical and chemical properties is the subject of research. Carbon fiber stands out in the field of reinforcement with its low density and high strength structure. In this study, woven fabrics in the different fabric structure were produced with carbon yarns of 12K 800 tex on specially designed weaving machines. Carbon woven fabrics structure on the bending strength of concrete beams were investigated.

Key Words: Carbon Fabric, Woven Carbon Fabric, CFRP, Beam Strength, Building Reinforcement**,**

1. INTRODUCTION

Technical textiles are textile materials and products primarily produced for their technical performance and functional properties rather than aesthetic and decorative characteristics. Technical textiles have evolved over the last century and have become a specialized field independent of production technology and materials used in various areas. Towards the end of the 1980s, Messe Frankfurt, the organizer of the technical textile exhibition held in Frankfurt, Germany, classified 12 application areas [1]. One of the application area of technical textile is construction and building textiles (Buildtech) which are included in the classification. Buildtech has developed significantly in recent years which are used membrane structures, temporary (modifiable) structures, dams, bridges, auxiliary construction textiles used during construction and construction production [2]. One of the important points of constructions production is reinforcing and retrofitting. So we can say Building textiles, while including various subtopics, one of its fundamental areas of focus is building reinforcing and retrofitting. Most of reinforcing elements in buldings are:

1-Structural Columns: Columns, which provide vertical support in buildings, can be retro-fitted to increase their strength and ductility.
2- Beams: Beams, which distribute loads horizontally between columns, can be retrofit-ted to improve their performance during earthquakes.
3- Slabs: Slabs, which form the floors and roofs of buildings, can be retrofitted to improve their resistance to seismic forces.
4- Shear Walls: Shear walls are vertical structural elements designed to resist lateral forces
5- Foundations: Foundations play a crucial role in transmitting loads from the structure to the ground
6- Connections: Retrofitting building connections, such as beam-column connections or wall-to-floor connections, is crucial for improving the overall structural behavior during earth-quakes.

7- Non-structural Elements: In addition to structural retrofits, attention should be given to non-structural elements such as partitions, facades, suspended ceilings, and mechanical and electrical systems.

Concrete is a construction material formed by mixing cement, aggregates (fine and coarse), water, chemical additives, mineral additives, or fibres, with or without their addition and it acquires the necessary properties through the hydration of cement. The components of concrete can vary depending on specific needs. Generally, it consists of approximately 70-75% aggregate by absolute volume, 10% cement, and 15-20% water. These are the basic ratios. The values can be adjusted according to requirements, including the incorporation of chemical additives. Solid or liquid chemical binders can be used up to 5% of the total cement content. According to TSE 206.2013+A1, concrete is classified into three main categories [3]:

1-Environmental Exposure Classes,
2-Fresh Concrete Classes
3- Hardened Concrete Classes

Hardened concrete is primarily classified based on the strength test conducted by curing the concrete at 20ºC±2 for 28 days in water saturated with lime. Concrete strength tests are applied on hardened concrete. These classifications are used based on these tests, and these classifications are used based on these tests. Hardened concrete strength classes are divided into two categories depending on whether the concrete is lightweight or normal to heavyweight. Lightweight concrete is designated for densities up to 800 kg/m³. Concrete with densities between 800-2600 kg/m³ is considered normal, while concrete with densities greater than 2600 kg/m³ is defined as heavyweight concrete. When measuring the strength of concrete, cylindrical specimens with a diameter of 150 mm and a length of 300 mm or cube specimens with an edge length of 150 mm are used, and the results are evaluated. The compressive strength classes for normal and heavyweight concrete are given in Table 1[3].

Table 1. Compressive Strength Classes For Normal And Heavyweight Concrete

Compressive Strength Classes	Minimum Characteristic Cylinder Strength fck, cyl N/mm²	Minimum Characteristic Cube Strength fck, cube N/mm²
C8/10	8	10
C12/15	12	15
C16/20	16	20
C20/25	20	25
C25/30	25	30
C30/37	30	37
C35/45	35	45
C40/50	40	50
C45/55	45	55
C50/60	50	60

C55/67	55	67
C60/75	60	75
C70/85	70	85
C80/95	80	95
C90/105	90	105
C100/115	100	115

Composite materials are materials formed by the combination of two or more materials that do not mix. Composite materials are created using a basic reinforcement material and materials referred to as resin, which make up the matrix. The combination of these two materials, depending on the type of material, results in the formation of a composite material through heat, pressure, and chemical reactions.

Resins are polymer compounds. They are produced in different classes for various purposes. Polymers in plastic structures are classified into two groups: thermoplastic and thermosetting polymers. These resins falling into this group are further divided into two categories: thermoplastic and thermosetting resins.

Thermosetting polymers form the matrix of complementary resins, with some of the main ones being polyester (PES), vinyl esters, polyurethane (PU), phenolics, epoxy, cyanate ester, polyphenylquinoxaline (PPQ), polyimide, and polybenzimidazole (PBI) [4].

Table. 2 Physical Properties of Resins

Properties	**PU**	**Vinil Ester**	**Epoxy**	**Fenolic**	**BMI Bismaleimide**	**ACTPAsetilenterminated polimid**
Density (g/cm³)	1,2	1,2	1,2-1,3	1,3	1,4	1,35
Tensile Modulus (GPa)	4,0	3,3	4,5	3,0	4-19	4,1
Tensile Strength (MPa)	80	75	130	70	70	82,7
Strain %'si	2,5	4	2,-6	2,5	1	1,5

Thermosetting resins are used in military applications, construction reinforcement, marine vessels, the automotive industry, wind turbines, and areas requiring chemical and mechanical strength properties. The main properties of thermosetting resins are [4]

1- Resistance to solvents and abrasives
2- Heat and high-temperature resistance
3- High strength and modulus
4- Low tensile elongation
5- Low temperature and pressure requirements for composite processes
6- Long curing time due to chemical reactions
7- Non recyclable
8- Limited shelf life
9- Easier composite production due to low viscosity liquid resin

Epoxy resins are one of the polymers belonging to the thermosetting resin group. They are obtained through the polymerization of the epoxy group. They contain epoxy groups consisting of one oxygen atom and two carbon atoms in their structure. The most commonly used commercial version of epoxies is Diglycidyl Ether of Bisphenol-A (DGEBA), which is formed by the reaction of epichlorohydrin and bisphenol-A in a basic condition. Diglycidyl Ether of Bisphenol-A is hardened with a suitable cross-linking agent called a curing agent. Curing agents often contain amine groups. Materials such as diethylenetriamine, triethylenetetraamine, and hexamethylenetetraamine can be used as amine-derived substances. Diethylenetriamine (DETA) is one of the most commonly used amine groups.

High-performance fibres are defined as fibres with high tensile strength and high elastic modulus. Fibers in this group are referred to as HM-HT (high modulus-high tenacity) fibres. Fibers with a tensile strength greater than 3 GPa and an elastic modulus greater than 50 GPa are categorized as high-performance fibres [5]. High-performance fibres include aramid fibres, basalt fibres, glass fibres, carbon fibres, and high-modulus polyethylene fibres (HPPE). Carbon fibres are defined as fibers containing a minimum of 92% carbon content in their composition [6]. According to another definition based on a historical classification among fibres, carbon fibres are those produced through heat treatment at temperatures above 1000-1500°C [7]. Carbon fibres, based on their precursor materials, are classified into three main types:

1- Rayon-based carbon fibres
2- Pitch-based carbon fibres
3- PAN (polyacrylonitrile)-based carbon fibres.

Today, 90% of carbon fibres are produced from polyacrylonitrile precursor fibres. PAN fibres are obtained through an oxidation process between 180-300°C. The primary goal here is to prevent the fibres from melting in the subsequent stages. During oxidation, the fibres are held under a specific tension to prevent them from shrinking. PAN fibres, initially white, change colour and darken during the process. Carbonization takes place at temperatures between 1000-1500°C in an inert (N2) environment. Graphitization occurs between 1500-3000°C. PAN-based carbon fibres are important high-performance fibres known for their high tensile strength and high modulus properties. The physical properties of PAN-based carbon fibres are shown in Table 3 [8].

Table 3. Physical Properties of PAN-based Carbon Fibers

Properties	**Commercial, Standard Modulus**	**Aviation-Space Industry**		
		Standard Modulus	Intermediate Modulus	High Modulus
Tensile Modulus (GPa)	228	220-241	290-297	345-448
Tensile Strength (MPa)	3800	3450-4830	3450-6200	3450-5520
Break Elongation (%)	1,6	1,5-2,2	1,3-2,0	0,7-1,0
Density (g/cm^3)	1,8	1,8	1,8	1,9
Carbon Contented (%)	95	95	95	+99
Fibres Diameter (µm)	6-8	6-8	5-6	5-8

Weaving, in general terms, is defined as the process of manufacturing a surface by intersection two groups of threads known as the weft and the warp, passing over and under each other according to a specific pattern. The surfaces manufactured through the weaving process are referred to as woven fabrics. The weaving manufacturing method has led to the development of several types of woven fabrics. In this study, carbon fabrics will be produced using the two-dimensional two-axial weaving method. In the two-dimensional two-axial weaving fabric production method, the warp and weft threads intersect each other at a 90-degree angle. For carbon fabrics, the warp direction is used as 0°, and the weft direction is used as 90°. The fabric's length can be referred to as the warp direction, while the fabric's width can be referred to as the weft direction. There is theoretically no difference between weaving with carbon threads and traditional weaving. During the weaving process, the warp threads are arranged and moved by the frames they are placed on or move downward to create an opening. With the shed open, the weft is inserted into it using a weft insertion system. As the shed closes, the reed compresses the weft with a beating motion, and fabric formation occurs. As the shed closes, the reed compresses the weft with a beating motion, and fabric formation occurs. According to the weaving pattern, it is determined which of the warp and weft threads will be above and which will be below. The basic weaving fabric patterns are plain weave, twill, and satin. Unidirectional fabrics, also referred to as uniaxial fabrics, contain reinforcement fibres in one direction (either warp or weft) for strength and a fine binding fibres in the other direction to complete the pattern. They often contain carbon fibres in the warp direction. Bidirectional, also known as biaxial fabrics, contain carbon fibres used for reinforcement in both warp and weft directions. In these fabrics, carbon threads are typically of the same thread count in both the warp and weft directions. The weft and warp densities in these fabrics are usually the same. Common patterns for bidirectional carbon woven fabrics include plain weave, 2x2 twill, and 4/1 satin.

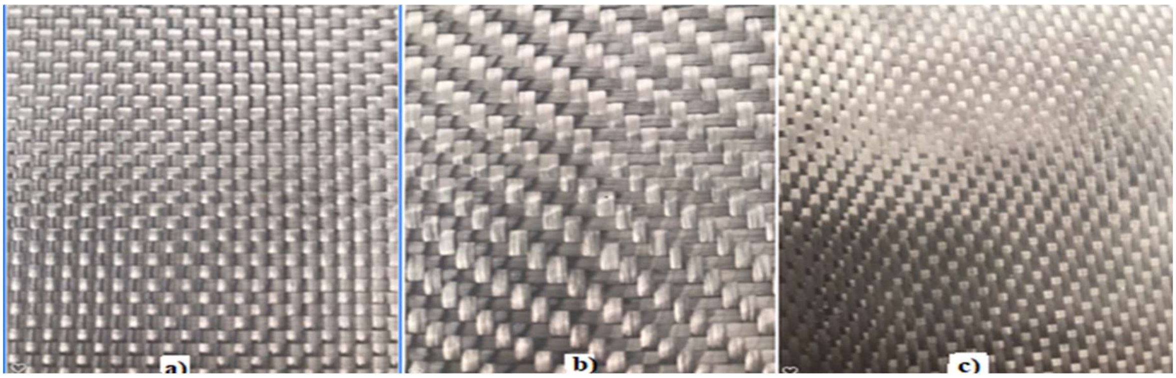

Figure 1. Bidirectional Woven carbon fabric a) plain weave b) 2/2 twill weave c) 4/1 satin weave

Buildtech FRPs (from carbon fibres) epoxy resin and carbon fibre reinforced plastics (CFRP) obtained with building reinforcement fibre polymer structures are seen as the fastest and most cost-effective reinforcement model [9]. In the study on concrete beam samples reinforced with fabrics made of carbon fibre, 5 different carbon reinforcement applications were made with different two-point tests. As a result of the application, the reinforcement type applied at 45° with the axis of the beam gave the highest beam shear strength. [10] Another study conducted a hybrid reinforcement study of carbon, glass and glass-carbon blend, 4-point testing on 5 beams, one of which was a witness, with different layers. It provided flexural strengths between 30% and 98%. Compared to the unreinforced beam, 30% increase in strength was achieved in glass fabric and 57% in carbon fabric. [11] 7 samples in 2 different concrete classes, 1 of the beams with CFRP reinforcement in the C20 and C30 class, with glass fibre fabric and U-shaped strips; the rest are L-shaped with CFRP reinforcement. [12] prepared beam samples with dimensions of 150x250x1500 mm and a compressive strength of 25 MPa, and made measurements with a 3-point test on 4 beams, 3 of which had different reinforcement forms. According to the results of their measurements, they stated that they reached the load capacity of 165% of the value of the witness sample in the reinforced beams. [13] 9 concrete beams with dimensions of 100x100x500 were produced. The concrete used had a compressive strength class of 30 MPa. Out of these beams, one served as a control sample, and the remaining 8 beams underwent CFRP (Carbon Fiber Reinforced Polymer) applications of varying dimensions using epoxy resin during the process. Different measurements were applied, and bending tests were conducted on the concrete beam specimens. Notably, the flexural strength values obtained in the beam specimens with various applications were significantly higher than the control sample. In the control sample, they measured a flexural strength of 3.94 MPa, while the highest flexural strength value achieved in their study was 15.88. They achieved an increase in flexural strength ranging from 11% to 303% in their specimens [14]. 18 T-shaped beam samples were placed in 6 of the beams with different stirrups and reinforcement systems, and in the remaining 12 beams, different reinforcement systems were placed. According to the results, 4% to 90% increase in load carrying capacity in the bending direction for the 1st group and between 6 and 46% for the 2nd group has been achieved [15]

2. MATERIALS AND METHODS

In this study, fabrics produced from 12K (800 tex) carbon yarn, which is the most used in the field of reinforcement, were included in the experiment plan. For the experiments, bidirectional 12 K (800 tex) weft and warp direction carbon woven fabrics were woven in plain, twill and satin. In carbon fabrics, 400 g/m^2 weight fabrics plain, twill and 3/1 broken twill, warp and weft yarn density 2,5 yarns / cm, 600 g/m^2 weight fabrics plain, twill and 4/1 satin, warp and weft yarn density It is produced as 3,7 yarns/cm.

Table 4. Fabric List

Fabric Type/Brand Name	Pattern	Areal Weight (g/m²) ±%5	Warp	Warp Density (threads/cm)	Weft	Weft Density (threads/cm)
Spn B 400 P	Plain	400 g/m²	12 K carbon yarn (800 tex)	2,5	12 K carbon yarn (800 tex)	2,5
Spn B 400 T	Twill 2/2	400 g/m²	12 K carbon yarn (800 tex)	2,5	12 K carbon yarn (800 tex)	2,5
Spn B 400 3/1BT	Broken Twill 3/1	400 g/m²	12 K carbon yarn (800 tex)	2,5	12 K carbon yarn (800 tex)	2,5
Spn B 600 P	Plain	600 g/m²	12 K carbon yarn (800 tex)	3,7	12 K carbon yarn (800 tex)	3,7

Spn B 600 T	Twill 2/2	600 g/m²	12 K carbon yarn (800 tex)	3,7	12 K carbon yarn (800 tex)	3,7
Spn B 600 5HS	Satin 4/1	400 g/m²	12 K carbon yarn (800 tex)	3,7	12 K carbon yarn (800 tex)	3,7

All fabric samples were produced on the same loom and with same carbon yarn. The physical and mechanical properties of the carbon yarn is listed on the table 5.

Table 5. Physical Properties of Carbon Yarn

Properties	12 K 800 Tex Carbon Yarn
Tensile Strength (MPa)	4900
Tensile Modulus (GPa)	235
Yarn Count (Tex)	800
Filament Number	12000
Filament Diameter (µm)	7
Density (g/cm³)	1,8
Elongation (%)	2,1
Twist	Zero

Beams are structural elements of buildings. Reinforcing flexural strength of beams with technical textiles is the subtopics of Buildtech. TS-EN 12390-5 "hardened concrete specimen test, the determination of the flexural strength of test specimens" standard is used for investigating the effects of fabrics. According to TS-EN 12390-5, mold dimensions are adjusted as 100 mm width, 100 mm height, 400 mm length. In this case, the concrete beam sample was created as 100x100x400 mm. The L≥3.5 d requirement in the standard has been fulfilled.

Concrete is prepared, pour them in to mold. Beam samples, which are kept in the mold for 24 hours, are kept in a conditioned pool, cured for 28 days in order to reach their ideal strength in water containing 1-1.5% lime at 20 °C and the concretes reached the ideal concrete strength.

Figure 2 Beam Preparation a) Molds b) Pouring concrete in to mold c) Curing in conditioning pool

After 28 days when beams reach their ideal strength, fabrics are prepared to reinforcing application.

Figure 3. Fabric Preparation

At the experimental stage, Spn Ep 225 brand epoxy was prepared by mixing 4:1. Of the two components, one component is reinforcer and the other is hardener.

Figure 4. Epoxy preparation a) Reinforcer and hardener b) Preparation

Epoxy resins get hardened very quickly. After stirring reinforcer and hardener it is better to apply in 30 minutes. Fabric samples are applied on concrete blocks.

Figure 5. Application a) Epoxy Application on Beam b) Fabric Adhesion c) Epoxy Pouring d) Reinforced Beam Samples

In order for the maximum mechanical strength and for the epoxy not to deteriorate while still wet, each one has been kept individually indoor. Epoxy gets its ideal mechanical strength after 7 days.
The bending strength specified in the test standard is calculated using equation (1).

$$f_{cf} = \frac{3.F.L}{3.d_1.d_2^2} \tag{1}$$

$f_{cf:}$ Flexural strength, MPa (N/mm^2)
F: maximum load, N
L: The distance between the support cylinders, mm
d1, d2: The cross-sectional dimensions of the specimen, mm

The tests were conducted on a computer-controlled testing machine named U-Test UTC-5600, which measures three-point flexural strength. The maximum compression capacity of the machine is 200 kN.

Figure 6. Testing a) Preparing testing points b) Testing c) Breaking Point d) After Maximum Load Applied

All reinforced and witness specimens are tested.

3. RESULTS AND DISCUSSIONS

The test results of the beam samples and the effect of carbon woven fabrics in different patterns on the flexural strength of fabrics with the same unit area weight were investigated. For 400 gr/m² carbon woven fabric, it is 7.36 MPa in plain weave, 8.21 MPa in 2x2 twill, 6.76 MPa in 3/1 broken twill, while the witness sample is 3.60 MPa. When viewed on a proportional basis, an increase of 106% is observed. The highest measurement value was obtained as a result of the reinforcement application made with 2/2 twill fabrics in bidirectional 12 K 400 gr/m² fabrics.

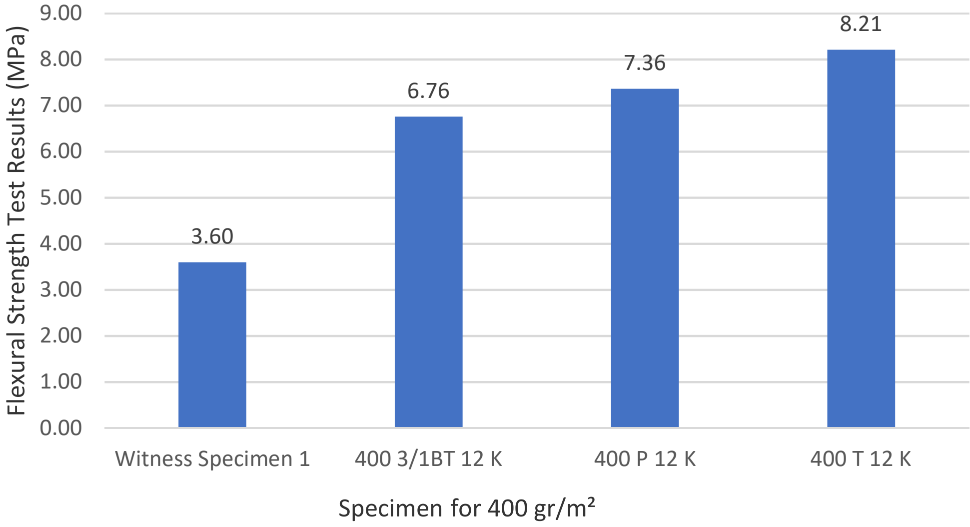

Figure 6. Test Results for 400g/m²

For 600 gr/m² fabrics, the plain sample is 5.33 MPa, satin 7.45 MPa and 2/2 twill 5.47 MPa, while the witness sample is 3.98 MPa. When viewed on a proportional basis, an increase of 52% is observed. The highest measurement value was obtained as a result of the reinforcement application made with 4/1 satin fabrics in double-sided 12 K 600 gr/m² fabrics.

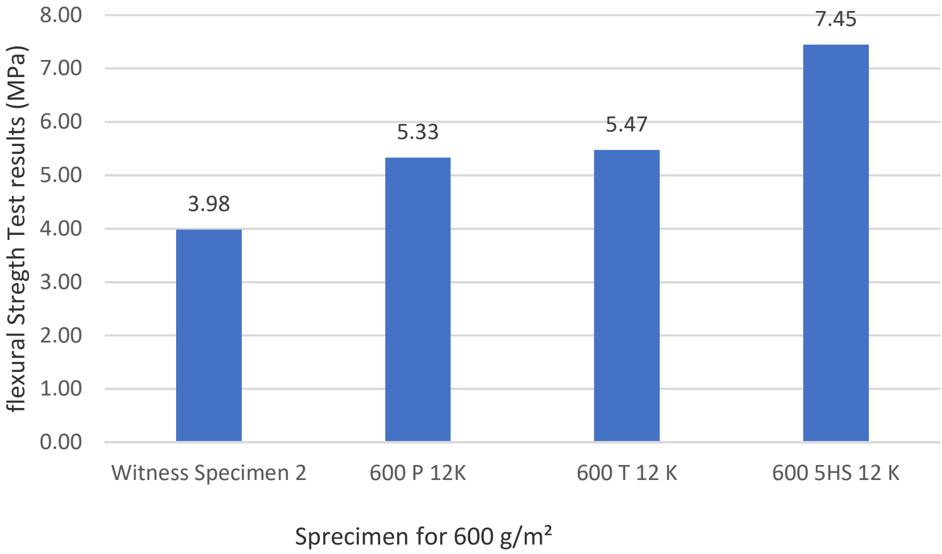

Figure 7. Test Results For 600g/m²

4. CONCLUSION

In reinforcement studies for beam flexural strength with carbon fiber woven fabrics, the average flexural strength of all fabric types increased by 79%. The flexural strength increases according to fabric types were between 34% and 128%. Although this value changes in different types of concrete, the reinforcement made with woven carbon fabric will contribute to the strengthening works in countries experiencing intense earthquakes.

According to test result performance when we compare 400g/m² and 600g/m², both results improve flexural strength of beam. But 400g/m² has a better performance than 600g/m² for each plain and twill 2/2. This should be investigated as a new study if it is related to absorbing epoxy performance.

ACKNOWLEDGEMENT

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5. REFERENCES

[1] BYRNE, C., "Technical textiles market-an overview", (eds. A.R. Horrocks an S.C. Anand), *Handbook of Technical Textiles*, Cambridge: Woodhead Publishing Limited and CRC Press LLC, 1-23, (2000).

[2] DURUR, G. , VARAN, N. "İnşaat Tekstilleri ve Yeni Uygulamalar", Tekstil Mühendis, 2007, vol. 68, pp 13-19,

[3] TÜRK STANDARTLARI, TS EN 206:2013+A1-Beton-özellik, Performans, Imalat Ve Uygunluk, 2017

[4] MALLICK, P.K., Reinforced Composites Materials Manufacturing and Design, U.S.A.: CRC Press Taylor Francis Group, 3-126, (2007).

[5] MUKHOPADYAY, S., K.,"High-Performance Fibres", Tekstile Progress, 25, 1–85, (1993).

[6] CHUNG, D. D. L., Carbon Fiber Composites, U.S.A.: Butterworth-Heinemann, 1-129, (1994).

[7] PARK, S., Carbon Fiber, Dordrecht, Heidelberg, New York, London: Springer, 1-63, (2015)

[8] WALSH, P.J., "Carbon Fibers", (eds. D.B.Miracle and S.L.Donaldson), Composites,21, U.S.A.:ASM, 92-107, (2001

[9] AKYILDIZ, A. , AĞIRGAN A.Ö., "Karbon Elyaf ile Sargılanmış Betonların Dayanımın İncelenmesi", Electronic Journal of Vocational Colleges, 2016, vol. 6(3), pp 99-107.

[10] BUKHARI, I.A., VOLLUM, R.L., AHMAD, S., AND SAGASETA, J., "Shear strengthening of concrete beams with CFRP", Magazine of Concrete Research, 2010, vol 62(1), pp 65-77

[11] HAWILEH, R.A., HAYDER, A., RASHEED, A., JAMAL, A.A., AND AL-TAMIMI, A.K., "Behavior of reinforced concrete beams strengthened with externally bonded hybrid reinforced polymer systems", Material and Design, 2014, vol 53, pp 972-982.

[12] DONG, J., WANG., Q., AND GUAN, Z., "Structural behavior of RC beams with external flexural and flexural shear strengthening FRP sheets", Composites Part B, 2013, vol 44, pp 604-612

[13] KÖKSAL, O.H., ALTINSOY, F., AKTAN., S., KARAHAN VE Ş. ÇANKAYA, R., "Üç Noktalı Eğilme Altında Betonarme Kirişlerde Karbon Lifli Polimerin Etkin ve Ekonomik Kullanımı", Çanakkale Onsekiz Mart Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 2017, vol 3(2), pp 1-16

[14] KAYA, T., ARAS, M., ve ÇALIŞKAN, Ö., "Beton Basınç ve Eğilme Dayanımlarına CFRP'nin Etkisi", KSU Mühendislik Bilimleri Dergisi, 20(3)

[15] AL-KHAFAJI, A. AND SALIM, A., "Flexural Strengthening of RC Continuous T-Beams Using CFRP", Fibers, 2020, vol 8(41), pp 1-18

[16] BAŞEV, S., A Research On The Use Of Textile Structures In Building Reinforcement, MSc Thesis, Pamukkale University Institute Of Science, 2021, pp 67-85

[17] TÜRK STANDARTLARI, TS 12390-5, Testing Hardened Concrete Part: 5 Flexural Strengths of Test Specimens: 2019

THE EFFECT OF YARNS MADE FROM DIFFERENT FIBER BLENDS ON QUALITY VALUES

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ABSTRACT

In this study, yarn quality parameters of yarns produced using recycled cotton, virgin cotton and virgin viscose fibers produced in the open-end spinning system in the textile industry, which has an important place in the world, were investigated. As a result, it has been seen that the yarns produced with viscose fiber used have better quality values than cotton due to the loss of existing fiber properties in recycling processes.

Key Words: Sustainability, recycled cotton, virgin fiber, open-end

1. INTRODUCTION

Clothing, which is one of the basic needs of human beings, is met by the textile sector, which is an important sector covering the whole world. Textile products are among the sectors that show that the best solution is recycling, by becoming the sector where sustainable important steps should be taken at the point of recycling, by overconsumption due to the rapid growth of fashion and by overconsumption of textile products. Today, sustainability plays an important role in the textile industry. Clothes that are consumed and thrown away quickly cause environmental problems and waste of resources. Therefore, the use of recycled materials offers an opportunity to increase sustainability in textile production. Recycled cotton has become an important player in this context. Brands can capture the attention of consumers by emphasizing their sustainability efforts, and the use of recycled cotton can strengthen brands' eco-friendly images. The use of recycled cotton can reduce the environmental impact of production processes and require the integration of recycled materials for recycling in the supply chain.

2. EXPERIMENTAL

In this study, as shown in Table 1, three different raw materials (R-CO, V-CO, V-CV) and two different mixing ratios (50:50 and 60:40), 20/1 and 30/1 open end the yarns produced in the spinning system were examined. [1] [2] IPI quality tests of the upcoiled yarns were carried out on USTER Tester 6 and USTER Tensojet devices. Quality parameters such as unevenness, hairiness, strength, elongation were examined and the results were compared. [1]

Table 1. Trial systematic

No	Yarn Ne	Composition	Explanation	Ratio
1	20/1	R-CO / CO	Recycled cotton + Cotton	%50-%50
2	30/1	R-CO / CO	Recycled cotton + Cotton	%50-%50
3	20/1	R-CO / CV	Recycled cotton + Viscose	%50-%50
4	30/1	R-CO / CV	Recycled cotton + Viscose	%50-%50
5	20/1	R-CO / CO	Recycled cotton + Cotton	%60-%40
6	30/1	R-CO / CO	Recycled cotton + Cotton	%60-%40

3. RESULTS AND DISCUSSION

When the quality parameters of the yarns produced were examined, it was observed that the unevenness, strength and elongation values were bad in the thin yarns produced with 60:40, 50:50 ratios, using R-CO, V-CO, V-CV cotton raw materials. The reason for this is thought to have a negative impact on the quality values of the recycled cotton fiber used in the blends.

Table 2. Yarn Quality IPI Values

No	Yarn Ne	Composition	Ratio	%U	%U CV	Hairiness	CN/tex	Elongation
1	20/1	R-CO / CO	%50-%50	10,65	13,43	4,74	14,94	5,4
2	30/1	R-CO / CO	%50-%50	12,52	15,82	4,09	13,47	4,74
3	20/1	R-CO / CV	%50-%50	9,59	12,12	4,46	12,5	6,7
4	30/1	R-CO / CV	%50-%50	11,56	14,6	3,92	11,7	5,36
5	20/1	R-CO / CO	%60-%40	11,04	13,93	4,9	14,31	5,52
6	30/1	R-CO / CO	%60-%40	12,71	16,04	4,28	13,49	4,46

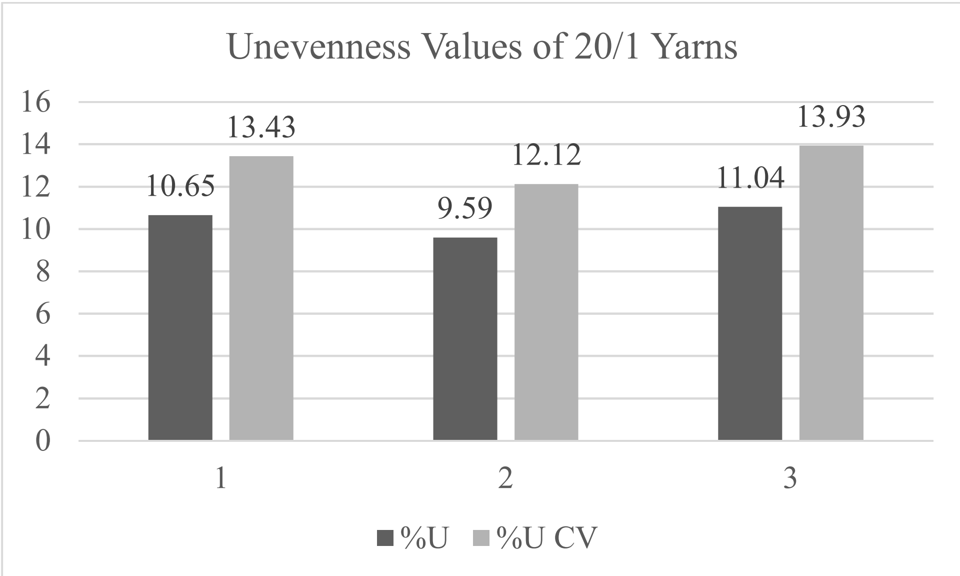

Figure 1. 20/1 Open-End Yarn Unevenness Chart

As seen in the chart, when the yarns numbered 1, 2 and 3 with Ne 20/1 (yarns numbered 1,3 and 5 in Table 1.) were examined, it was seen that the best result in terms of %U and %U CVm value was in the number 2 R-CO / CV yarn. This is thought to be due to the viscose fiber used in the blend. The reason why the number 1 yarn has a better value than the number 3 yarn is that the R-CO / CO mixing ratio is 50:50.

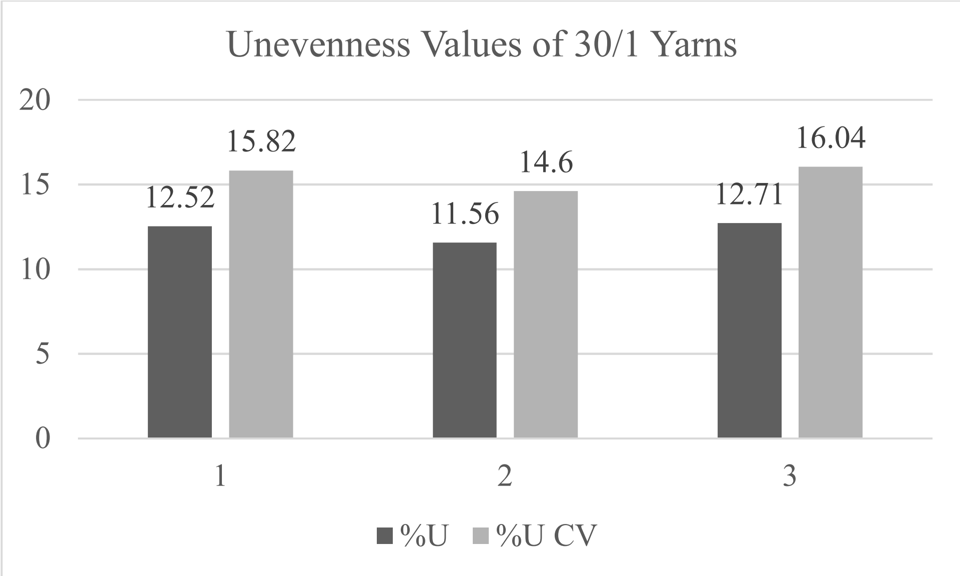

Figure 2. 30/1 Open-End Yarn Unevenness Chart

As seen in the chart, when the yarns numbered 1, 2 and 3 with Ne 30/1 (yarns numbered 2,4 and 6 in Table 1.) were examined, it was seen that the best result in terms of %U and %U CVm value was in the number 2 R-CO / CV yarn. The use of viscose fiber as in 20/1 yarn has been effective in this quality parameter. According to the blend ratio, the number 1 yarn is better than number 3 yarn because it is 50:50 as in 20/1 Ne yarn.

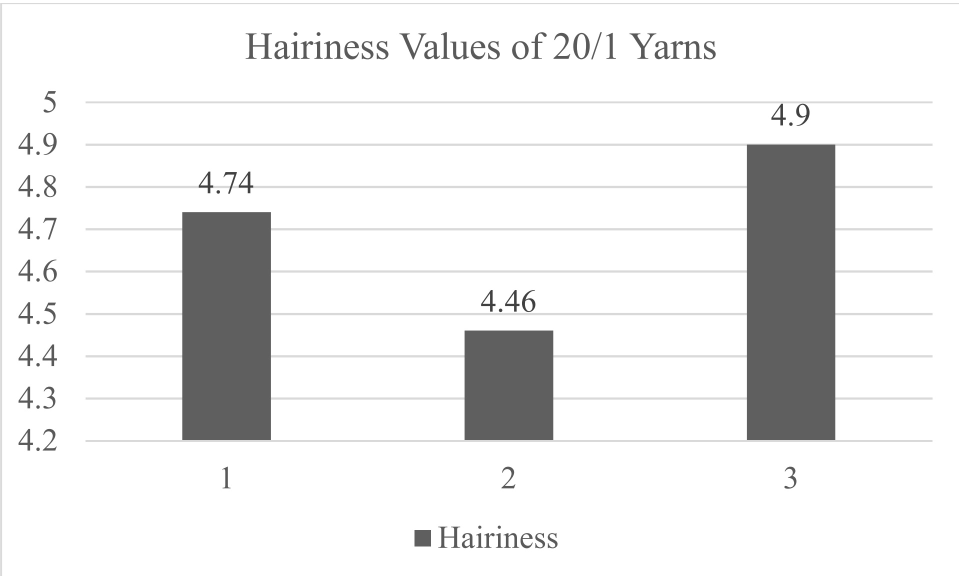

Figure 3. 20/1 Open-End Yarn Hairiness Chart

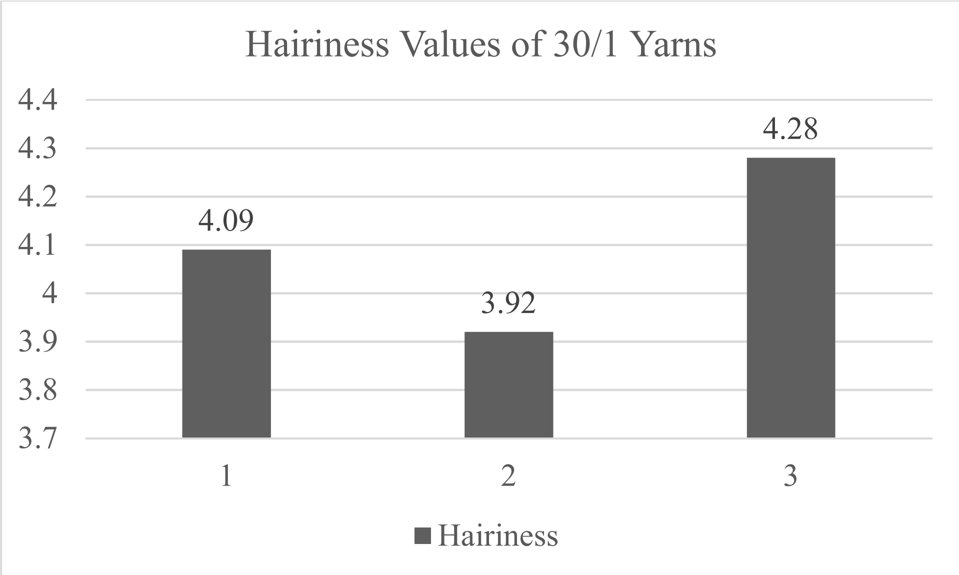

Figure 4. 30/1 Open-End Yarn Hairiness Chart

As can be seen in Figure 3 and Figure 4, it has been observed that the hairiness value of the yarns produced in the 20/1 and 30/1 OE spinning system is better in the number 2 R-CO-CV (50:50) As mentioned in the unevenness quality parameter, the reason for this is that the viscose fiber has a different structure compared to the virgin-cotton fiber used in other trials.

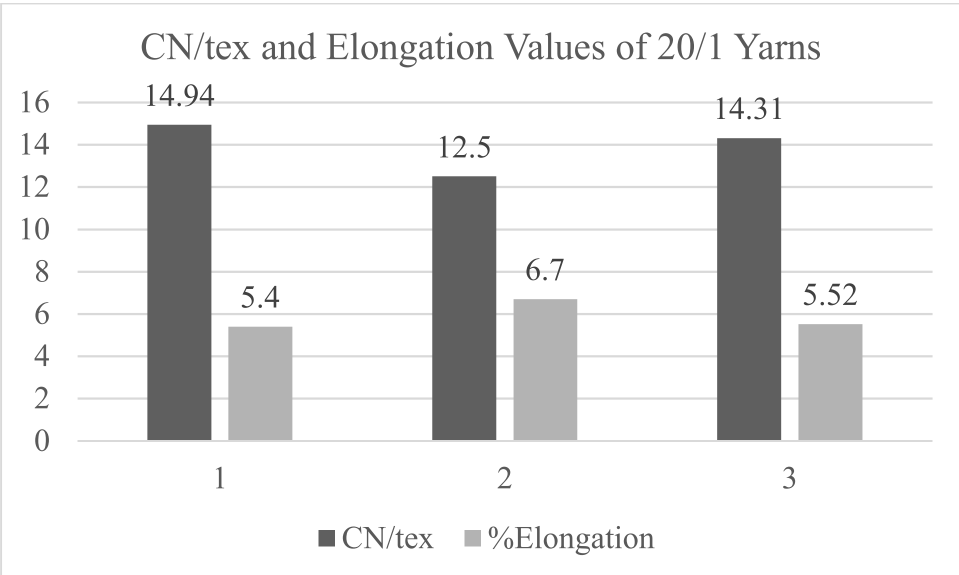

Figure 5. 20/1 Open-End Yarn CN/tex and Elongation Chart

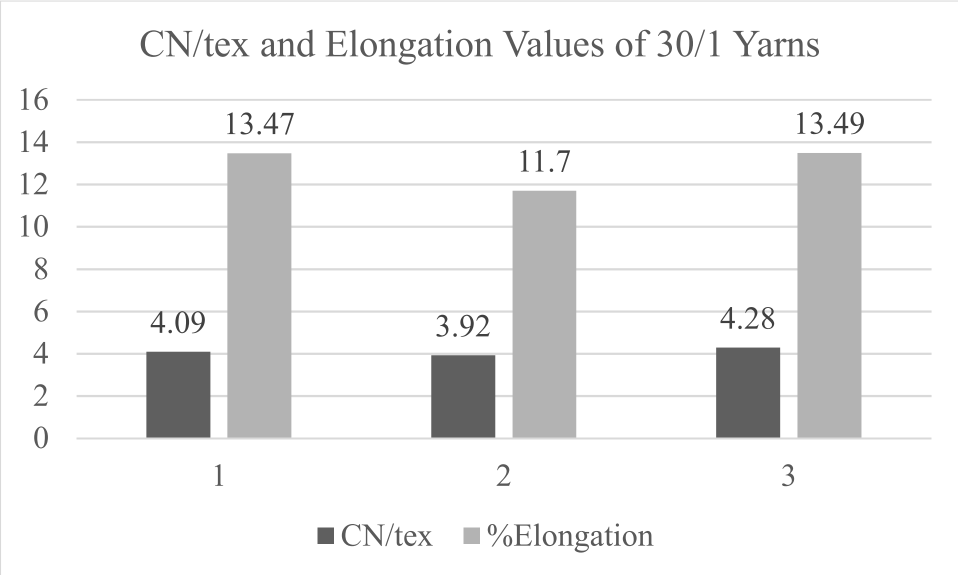

Figure 6. 30/1 Open-End Yarn CN/tex and Elongation Chart

The CN/tex and elongation values of the yarns produced in Figure 5 and Figure 6 were examined. As can be seen in Figure 5, it is seen that it is the number 1 OE yarn with a 50:50 blending ratio among the R-CO and CO fibers with the highest strength. As seen in Figure 6, when examined in 30/1 yarns, it was seen that yarn number 1 with the same blending ratio had high strenght. It is thought that the reason for this is the virgin cotton used in the yarn content. When the elongation value was examined, it was seen that the yarns made with 20/1 yarns and 30/1 yarn using virgin-cotton with 50:50 and 60:40 ratios had the lowest elongation value. These results have been achieved because cotton is a natural fiber.

4. CONCLUSIONS

In this study, the quality values of the yarns produced by using recycled cotton fiber with 50:50 and 60:40 ratios and virgin cotton and virgin viscose fibers with two different yarn counts in terms of sustainability in the textile sector were investigated. It is thought that this study will contribute to recycling research in the textile sector. The reason why recycled cotton fiber gives lower quality values compared to virgin cotton and virgin viscose fiber can be considered as the fiber losing its properties in recycling processes. Within the scope of this study, it is aimed to examine the fabric performance parameters of the yarns whose quality values are examined by making knitted fabric in the future [3] [4].

5. REFERENCES

[1] KAYNAK, .. K., & KILIC, G. B. (2019). Effects of waste cotton usage on properties of OE-rotor yarns. industia textila.
[2] TELLI, A., & BABAARSLAN, O. (2017). Usage of recycled cotton and polyester fibers for sustainable staple yarn technology. Tekstil ve konfeksiyon .
[3] VADICHERLA, T., & SARAVANAN, D. (2017). Effect of Blend Ratio on the Quality Characteristics of Recycled Polyester/Cotton Blended Ring Spun Yarn. FIBRES & TEXTILES.
[4] YÜKSEKKAYA, M. E., & CELEP, G. (2016). A Comparative Study of Physical Properties of Yarns and Fabrics Produced From Virgin and Recycled Fibers. Journal of Engineered Fibers and Fabrics.

INFLUENCE OF COPET DISSOLUTION AND DYEING PROCESSES ON PHYSICAL PERFORMANCE OF BLACKOUTS FROM PET/COPET BICOMPONENT YARNS

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ABSTRACT

This paper investigates the tensile and tear strength, air permeability and abrasion behavior of a bicomponent fabric made with PET/CoPET yarns in its loom state, after the dissolution of the CoPET from the yarn structure, and in its final form after it has been dyed. Finally, a comparative study of the sound absorption of the fabrics in their different forms with that of a commercial one was conducted. The results showed that both dissolution and dyeing have an influence on the physical and acoustic properties of the fabric and the dyed bicomponent fabric had comparable physical properties to those of the commercial product while it performed better acoustic properties than the commercial one.

Key Words: Blackout, bicomponent fiber, pet, copet, dissolution

1. INTRODUCTION

The quality of a building's indoor environment in relation to the health and well-being of those who occupy space within it is referred to as indoor environmental quality (IEQ) [1, 2]. The most common application of textiles that impact the IEQ are textiles for the control of acoustics. Wall coverings, ceilings, curtains, chairs, carpets, etc. are designed to absorb sound and prevent echoes inside a room. The application of curtains as sound absorbers for room acoustical purposes has considerable advantages like being relatively cost-effective, lightweight, flexible, and easy to handle. Acoustic performance of home textiles, such as curtains, carpets, sofa covers, etc., can be improved by accurate selection of suitable textile materials, appropriate physical and processing parameters, layering and placement of acoustical textiles [3]. Sound absorbing properties of textile curtains are under ongoing interest of researchers [4-6]. Bicomponent and hollow fibers not only have a lower density than their solid profile fibers, have better thermal insulation but also favor acoustic properties. Textile materials from hollow fibers also have been widely used in sound absorption and noise reduction applications [7, 8].

In this study, effect of CoPET dissolution and dyeing processes on physical properties of acoustic blackouts from C-shape PET/CoPET bicomponent yarns was investigated. Sound absorption performance of the samples were also presented.

2. EXPERIMENTAL

A woven blackout from textured PET warp and C-shape bicomponent PET/CoPET weft yarns with a weft-faced satin construction have been produced. The fabrics were tested for their physical and sound absorption properties in the loom state, after dissolving CoPET component to form the C-shape yarn in the weft direction and at the final state after dying. Additionally, a blackout curtain fabric sample that is being used commercially that does not have bicomponent yarns inside its structure was also taken to be used as a reference to observe the effect of the bicomponent yarn presence on the acoustic properties.

A representative image of the bicomponent yarn after the dissolving process is given in Figure 1.

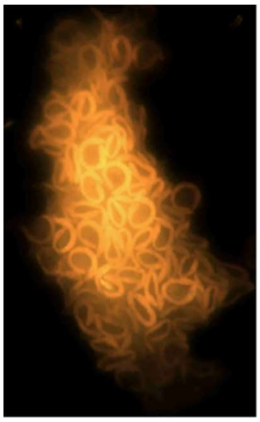


Figure 1. Cross-section of the dissolved PET/CoPET yarn

2.1 Physical Tests

The tensile and tear strength of the samples were tested according to ISO 13934-1 and ISO 13937-2 standards, respectively. Both tests were conducted both in the warp and weft direction of the fabrics. The pre-tension was set to 0,1 N and the rate of extension was set to 100 mm/min for all samples. The air permeability of the samples was tested according to DIN EN ISO 9237 standard. The Martindale abrasion of the samples were tested according to the ISO 12947-2. All the abrasion test cycles were started with cycles of 10,000 and continued with 500 cycles with inspection of the fabric surface in between the cycles. The tests were finished when a broken fiber on the sample surface was observed or when the samples reached a targeted level without any abrasion.

2.2 Acoustic Tests

The sound absorption coefficient of all samples was measured by using a TestSense impedance tube between the frequencies of 0 Hz - 6400 Hz according to TS EN ISO 10534-2:2003 standard.

3. RESULTS AND DISCUSSION

Some constructional properties of the samples are presented in Table 1. Since these fabrics are intended to be used as blackout fabrics, they are woven with a double warp yarn set, hence have high warp density.

Table 1. Some constructional properties of the samples

	Loom State Fabric Sample	Dissolved Fabric Sample	Dyed Fabric Sample	Reference Fabric
Warp Density x Weft Density (yarns per cm)	125 x 47 5875	152 x 59 8968	164 x 57 9348	128 x 39 4992
Thickness (mm)	0,45	0,68	0,54	0,54
Weight (g/m^2)	213,04	255,67	223,68	192
Fabric density (g/m^3)	469,24	375,99	414,21	355,55

As may be seen from Table 1, the warp and weft density, thickness and weight of the samples increased after the dissolving process. The dissolution process has decreased the thickness of the yarn, which in turn allows for more threads to be packed in the same unit of length. Dyeing has also increased the warp density of the samples. The fabric density has decreased with the removal of the CoPET component and later increased back up after the dye intake.

The tensile and tear strength results of the three samples in warp and weft directions can be found in Table 2.

Table 2. Tensile strength and tear strength results

	Loom	Dissolved	Dyed
Tensile Strength – Warp (N)	2144	1992	1910
Tensile Strength – Weft (N)	1082	820	761,4
Tear Strength –Warp (N)	71	36	30
Tear Strength –Weft (N)	46,7	20,4	16,7

Both tests have yielded better results in the warp direction since there is a significantly higher warp density compared to the weft density. As expected, dissolving and dyeing processes has decreased the tensile strength and tear strength values of the fabric. This result is consistent with the fabric density values of the samples in Table 1. This is to be expected, since alkali treatment to remove the CoPET component and dyeing are both chemical processes that will inevitably cause a decrease in the fabric strength. Nevertheless, the test results for the final dyed and finished fabric are acceptable to be used as a blackout fabric in a commercial use.

The air permeability results of the fabrics can be found in Table 3.

Table 3. Air permeability results

	Loom	Dissolved	Dyed
Air Permeability ($l/m^2/s$)	174,39	287,37	207,45

The loom fabric has yielded the highest air permeability resistance compared to its dissolved and dyed counterparts, since it has the densest structure compared to the others. The dissolution of the CoPET component has loosened up the fabric tightness and allowed for air to pass through the newly formed channels inside the structure, thus causes an increase in the air permeability. Dyeing, afterwards, has tightened the structure to an extent, which led to a decrease in the permeability.

Table 4 shows the abrasion test results of the samples.

Table 4. Martindale abrasion results

	Loom	Dissolved	Dyed
Martindale Abrasion (revolutions)	13,000	13,000	13,000

It should be noted that none of the samples has demonstrated a significant abrasion on their surface. Some pills were observed at 13,000 cycles, and the test was stopped afterwards. The microscope photos of the sample surfaces at 13,000 cycles are presented in Figure 2. The photos show that, although the samples show a level of abrasion and some pilling, none of the samples has had a completely broken yarn. A high level of abrasion resistance is the expected result, since the fabrics were made from synthetic yarns in both directions. Also, the fact that the fabrics have two sets of warp yarns will cause a tighter than normal structure, which will make it harder for the yarns to pill and stick out of the fabric structure. The fact that all samples have withstood 13,000 cycles demonstrates that processes such as chemically dissolving a component from the warp yarns and dyeing the fabric doesn't cause a significant increase in the abrasing and pilling tendency of the fabrics.

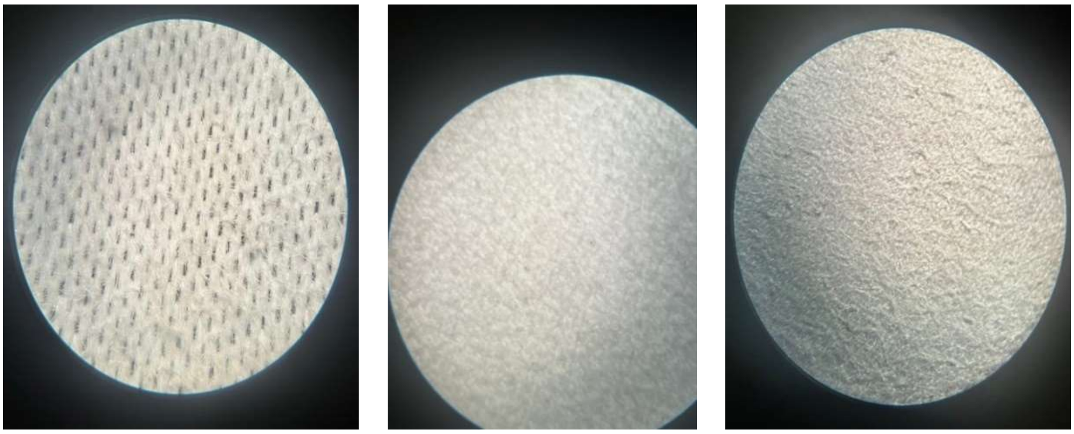
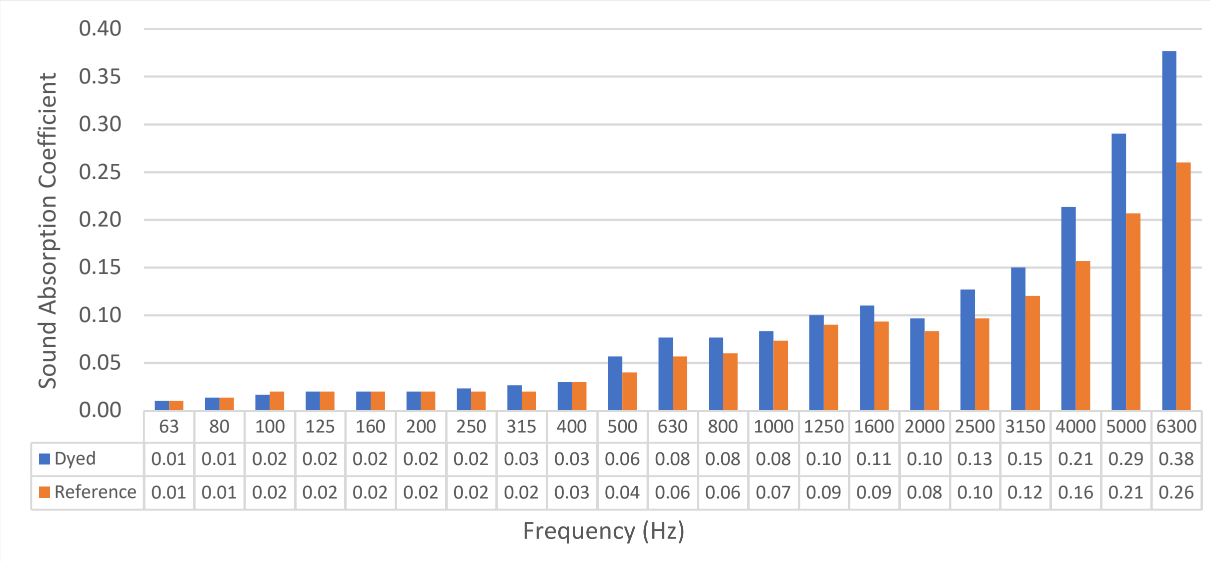


Figure 2. Loom, dissolved, and dyed samples (left to right) after 13,000 cycles.

The sound absorption coefficients of the dyed sample fabric and the commercial reference fabric is given in Figure 3.



	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300
Dyed	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.06	0.08	0.08	0.08	0.10	0.11	0.10	0.13	0.15	0.21	0.29	0.38
Reference	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.06	0.06	0.07	0.09	0.09	0.08	0.10	0.12	0.16	0.21	0.26

Figure 3. Sound absorption coefficient results

The results show that at frequencies 500 Hz and above, the bicomponent fabric has shown the better performance compared to the reference fabric. This indicates that using bicomponent yarns inside the fabric structure has resulted in a structure that has better sound insulating property. The fabrics made from bicomponent yarns are denser fabrics and have more threads per cm^2. This results in a higher fabric cover, which in turn increases the sound absorption of the fabrics since there is less space for soundwaves to be able to pass through.

4. CONCLUSION

In this study, the mechanical and physical properties of a PET/CoPET bicomponent fabric in its loom stage, dissolved stage, and dyed staged were investigated and compared. The results showed that alkali treatment applied to dissolve CoPET in the bicomponent yarns for obtaining C-shape fibers influenced constructional, mechanical and air permeability properties of the blackout curtains. In addition, the sound absorption coefficients of these samples, as well as a commercially available blackout fabric sample as a reference, were measured and compared. The dissolved and dyed sample has shown comparable, and in some frequencies better, sound absorbing properties with the commercial blackout fabric.

The recorded physical and acoustic properties of the bicomponent fabric were found to be satisfactory in terms of the expectations from commercial blackout curtains, thus it is concluded that it can be studied as an alternative with the addition of enhanced sound absorbing properties. Using a blackout fabric made from bicomponent yarns will not only provide the required darkness but will also provide sound insulation to a room. Both parameters are important for the IEQ of a room, and they are both vital for a good sleep quality.

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5. REFERENCES

[1] PRINIOTAKIS, Georgios; STACHEWICZ, Urszula; VAN HOOF, Joost. Smart textiles and the indoor environment of buildings. Indoor and Built Environment, 2022, 31.6: 1443-1446.
[2] PIEREN, Reto; HEUTSCHI, Kurt. Predicting sound absorption coefficients of lightweight multilayer curtains using the equivalent circuit method. Applied Acoustics, 2015, 92: 27-41.
[3] MEMON, Hafeezullah, et al. Considerations while designing acoustic home textiles: A review. Journal of Textile and Apparel, Technology and Management, 2015, 9.3.
[4] DEMIRYÜREK, Oğuz; AYDEMIR, Hüsnü. Sound absorbing properties of roller blind curtain fabrics. *Journal of Industrial Textiles*, 2017, 47.1: 3-19.
[5] PIEREN, Reto, et al. Sound absorption of textile curtains–theoretical models and validations by experiments and simulations. *Textile Research Journal*, 2018, 88.1: 36-48.
[6] BULUT, Hacer Merve, et al. A STUDY ON ACOUSTIC PERFOMANCE OF BLACKOUT CURTAINS.
[7] LIU, Xueting, et al. Sound absorption of hollow polyester woven fabric with honeycomb weave. *Applied Acoustics*, 2021, 180: 108148.
[8] VEIT, Dieter. Bicomponent Fibers. In: *Fibers: History, Production, Properties, Market*. Cham: Springer International Publishing, 2023. p. 569-583.

ARTIFICIAL INTELLIGENCE BASED ASSESSMENT AND OPTIMISATION OF KNITTED FABRICS SUITABLE FOR ALLERGIC INDIVIDUALS

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ABSTRACT

The porous breathability of knitted fabrics allows for better air circulation, keeping the skin dry and minimizing discomfort. However, people with chronic skin diseases are especially prone to skin irritation or rashes and require additional attention, where innovative textile materials have shown great potential. In this ongoing research, the flow, thermal, and moisture behaviour, as well as the properties of various standard knitted fabrics, such as single jersey, made from environmentally friendly fibres, including collagen peptide-enriched fibres like Umorfil viscose, Umorfil polyester (filament/staple), and Umorfil nylon, are being assessed using a combination of traditional methods such as 3D Computational Fluid Dynamics (CFD) and analytical tools such as TOPSIS. Experimental measurements provide input and validation data for comparison purposes. Artificial Intelligence-based analyses are used to determine and optimize the performance of alternative knitted assemblies, providing improved comfort for allergic individuals. The results reveal the significant potential of using the investigated materials and structures in layered combinations, which have been precisely calculated and demonstrated through detailed proof-of-concept studies.

Keywords: Atopic dermatitis, collagen-peptide, computational fluid dynamics, artificial intelligence, knitted fabric

1. INTRODUCTION

Thermal comfort is deemed crucial for human health and can potentially pose a life-threatening situation when core body temperatures exceed 37.5°C–38.3°C or drop below 35.0°C [1]. When combined with optimal breathability, thermal comfort also assumes significance for individuals with allergies. Immune responses can be triggered by allergic skin reactions, potentially enhancing, or suppressing various effects [2]. Unique advantages are offered by knitted fabrics for the creation of anti-allergic fabrics, primarily due to their intricate looped structures. However, individuals with chronic skin conditions are particularly susceptible to skin irritation or rashes, necessitating special attention and effective thermal management, an area where textiles have demonstrated significant potential [3]. Stretching and recovery properties are possessed by knitted fabrics ensuring a snug fit without restricting movement, thereby enhancing overall comfort. Flexibility, stretchability, and fabric permeability are directly influenced by the choice of stitch combinations, impacting thermal and moisture management. Material properties are of equal importance. People prone to chronic issues are advised to limit the use of synthetic materials that often utilize dispersing dye substances. Careful consideration is needed when selecting materials for different clothing layers [4,5]. Understanding of thermofluid and moisture transport behaviours of various knitted fabric plies is vital for optimizing thermal comfort. Each layer is influenced by operational conditions, significantly impacting thermofluid flow and moisture transport due to varying relative humidity and thermofluid conditions, necessitating consideration for achieving optimal solutions. Traditional methods like 3D Computational Fluid Dynamics (CFD) simulations have been extensively employed in previous studies [6,7] and remain essential for the analysis of fluid flow and thermal behaviour in different knitted fabrics. The rapid advancement of physics-based Artificial Intelligence (AI) applications has transformed research across diverse domains, offering advanced numerical modelling techniques with exceptional scalability and predictive capabilities. AI models efficiently manage extensive datasets resulting from experimentally validated complex multiphysics models. An advantage of AI lies in its ability to comprehend intricate procedures and interactions, reducing the need for individual analysis of massive datasets. The authors have successfully employed these techniques to gain a deep understanding of materials, components, and complex processes while enhancing efficiency and cost-effectiveness [8-11]. Hence, in this ongoing research, the thermal and moisture management properties of various knitted fabric structures made from environmentally friendly fibres, including collagen peptide-enriched fibres such as Umorfil viscose are systematically assessed. Analytical tools like TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) are utilized to facilitate decision-making processes. Experimental measurements help characterize the thermofluid flow behaviour of knitted fabrics, providing essential input for numerical simulations and validating developed models. The goal has been to optimize the performance of alternative knitted fabric assemblies through AI-based analyses.

2. EXPERIMENTAL MEASUREMENTS

In the present study, three stitch types of fabrics, i.e., single jersey, rib knit, and interlock, have been used as reference fabrics. Each fabric type has been knitted under commercial conditions with nine different types of yarns including Umorfil viscose, Umorfil Polyester and Umorfil Polyamide yarns. The stitch length for each knitting type was kept constant, considering the fabric's technical specifications in accordance with the literature and the targeted use area. Tests for yarn and fabric specifications were conducted in accordance with the standards TS 244 EN ISO 2060, TS 256, TS EN 12127, TS 7128 EN ISO 5084, ISO 6330, ASTM E96-00, ASTM D737-18, and DIN 53924 after they were acclimated one day under standard atmospheric conditions (20 ± 2°C and 65 ± 2% relative humidity). The produced fabrics were partitioned into half, pre-washed, and left for drying followed by an additional two days of acclimatisation before measuring the relevant properties. Furthermore, the porosity values for the samples were approximated by geometrical means as it doesn't rely on the absorption and release of a liquid, which can introduce variability and inaccuracies in the measurement, as is the case with the gravimetric method for absorbent materials and could be evaluated using dry-wet fabric sample mass comparisons. Based on the acquired data from the 27 combinations of samples and the targeted assessment, an initial screening process using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS-AHP) has been employed. Considering the alternatives and their relative importance, a multi-criteria decision-making method has been applied. The criteria of "air permeability, porosity, water vapour permeability, and capillarity rise" have been determined. Table 1 provides an indication of the ranking of the first three samples to initiate a preliminary data-based identification for potential candidates that can be further assessed.

Table 1. Sample data of the TOPSIS analysis

Fabric	d+	d-	Relative closeness
Sample1 (Rib-lyocel)	0.0273	0.0820	0.75
Sample 2 (Plain J-PET)	0.0300	0.0829	0.73
Sample 3 (Plain Jersey-Umorfil Viscose)	0.0304	0.0773	0.72

However, it should be noted that the thermofluid performance of the fabrics also considers the thermal exchange and moisture transport of fabrics. Therefore, the dynamic liquid transport properties and thermal exchange of all samples were measured. To assess how effectively the sample fabrics can manage moisture, MMT (AATCC 195-2017) has been used. Water vapour resistance values have been determined using the Permetest (ISO 11092). The thermal conductivity/thermal resistance values were determined using the Alambeta (ISO EN 31092) device. Generally, the liquid moisture management performance of the fabrics has been ranging from 0.44 to 0.85. These values correspond to the "good to excellent" classifications of the relevant AATCC 195-2017 standard. Similarly, the range of water vapour resistance for the fabrics was determined between 2-6 (Pa.m2.W^{-1}), whereas the thermal conductivities were in the range of 0.04-0.06 W/m.K. The literature reveals that these recommended values for AD (Atopic Dermatitis) patients could only be achieved with the use of additional finishing processes or phase-changing materials.

3. NUMERICAL ASSESSMENT

The numerical modelling and simulation of the knitted fabrics were initially used to computationally replicate the experimental measurements and support characterisation. The experimentally determined permeability and thermal properties data have been used to derive data for the mathematical characterisation of the fabrics to integrate for numerical predictions. Another point has been the digital design and 3D representation of existing fabrics being used in the experiments. This enables careful assessment and calibration of the experimental results, complementing the experiments for systematic predictions. This ensures a direct comparison with the same fabric thicknesses, and the characteristics can be implemented and solved for specified different materials. To predict the permeability of the fabrics, the permeability test has been replicated. The developed computational model depicts a 20 cm^2 sample size and the specified thickness of the knitted fabric samples. The operating condition data has been derived from the experimental measurements and implemented into the numerical modelling. Based on the continuum theory of porous media, the model has been successfully used and validated by determined flow resistance data and an applied experimental pressure drop of 125Pa and 200 Pa for specified materials and labelled such as A, B, and C, as demonstrated in Figure 1. The efficient computational tool has the advantage of having integrated all necessary material data, flow-thermal characteristic behaviour of the samples as well and containing its geometrical information. The reduced geometrical complexity aids in the efficient use of integrated physical complexity which is at the pre-development stage essential for systematic assessment. The geometrical construction details of the knitted samples are used in the individual design stages of the optimised fabrics.

Likewise, the model has successfully replicated the Alambeta test to depict detailed temperature distributions within the fabric samples. The added value of virtual experiments is particularly crucial for providing insight into temperature distribution across the fabric thickness, rather than solely depicting the temperature values of both fabric sides obtained through physical measurements. This approach significantly enhances computational and experimental efficiency during the calculation phase. Consequently, it becomes possible to assess various samples and scenarios. For instance, the single jersey fabric with face knit stitches on the front side and back knit stitches on the rear side demonstrates good extensibility in both the length and width directions but exhibits curling at the free edges.

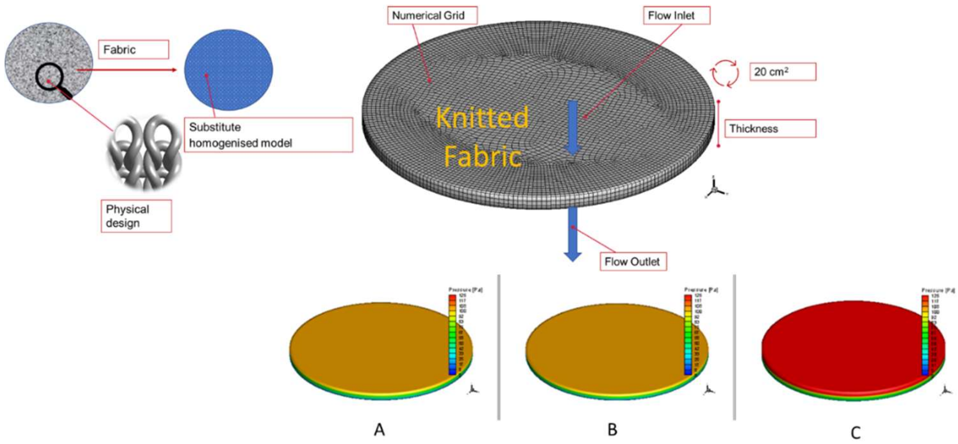

Figure 1. 3D CFD model and utilised continuum theory of porous media: The homogenised model is used to predict the permeability full-sized samples

Therefore, alternative structures, apart from single jersey, rib, or interlock, are currently under consideration.

4. AI-MODEL DEVELOPMENT AND OPTIMISATION OF FABRICS

The optimisation of knitted fabrics suitable for allergic people has been a complex integrated approach where the comfort behaviour and optimisation capacity of various fabric characteristics have been assessed. The current research has leveraged cutting-edge machine learning techniques to enhance the comfort properties of knitted fabrics, focusing on factors such as flow and thermal characteristics. For the AI model development, reliable data has been generated by the extended use of the validated CFD model through executing virtual numerical experiments. These have been systematically solved using the design of experiments (DoE) that increased solution efficiency and kept the output data moderate for meaningful AI predictions. This approach also facilitates addressing the scalability of the problem as large-scale computations using GPUs (Graphics Processing Units), or specialised hardware like TPUs (Tensor Processing Units) are mitigated. By employing machine learning (ML) techniques rooted in artificial intelligence (AI), it has been possible to navigate the intricacies of material and geometric complexities and invest this complexity in further development stages where powerful detailed multiphysics analyses including time-dependent moisture transport could be utilised. Thus, supervised learning has been used to establish a connection between various process, material, and geometrical parameters to predict the optimal thermofluid performance. As the investigated response parameters are known, the approach has been more predictable compared to alternative methods such as deep learning. The approach provides more solution clarity by directly showing the relationship between input features and the output; it mitigates the use of large amounts of data to learn meaningful patterns; training complexities are reduced; but most importantly manual feature engineering ensures the required understanding of our data and possibly engineering relevant features that still might entail improvement potential. The problem type being regression as well as the moderate size of data and parameters supports the efficient choice. The model training process involves the division of input data into training and testing datasets. The initial set of obtained data, serves as the basis for shaping the training dataset, used for model training, while the testing dataset is utilised to assess the model's accuracy. A cross-validation procedure is employed to partition the data for training purposes.

The evaluation criteria for machine learning results have been conducted using the typical Mean Squared Error (MSE) and Root Mean Squared Error (RMSE). Figure 2 demonstrates a graphical representation highlighting the relationship between material, fabrics, and process parameters as categorical using data aggregation.

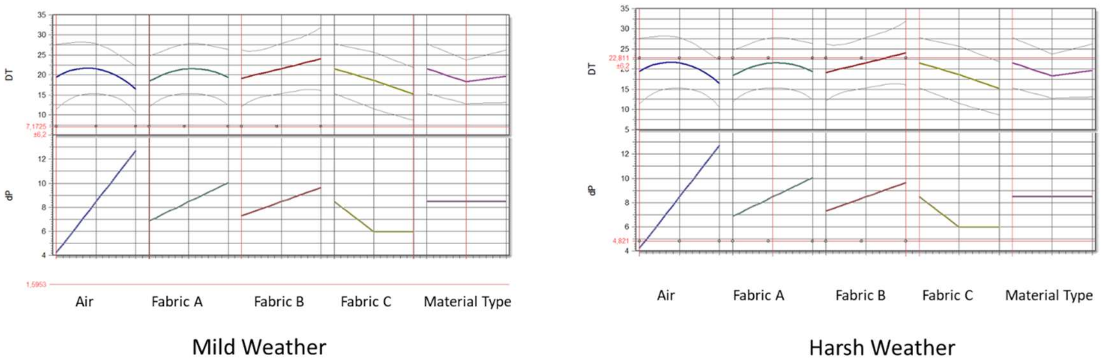

Figure 2. Artificial Intelligence-based optimization: The optimal configuration between various parameters and thermofluid levels has been predicted by AI to determine comfortable fabric properties for allergic people.

The machine learning algorithm has been used to predict the optimal comfort zone for a suitable combination of knitted fabrics satisfying both mild and harsh weather conditions. The target has been keeping the pressure drop as low as possible. The temperature difference DT between boundaries has been targeted for mild weather conditions as low as possible for rapid heat exchange, whereas for harsh conditions to keep the difference larger aiming for insulation but maintaining a low-value pressure drop for good breathability performance. Different process and material properties have been considered where the nonlinear behaviour from low to high factors has been depicted for demonstrative purposes.

5. PROOF OF CONCEPT (POF)

Carefully assessing the AI-driven predictions, the detailed CFD model has been employed to delve into the intricate multiphysics behaviour and solve the thermofluid flow and moisture transport within an enhanced knitted fabric assembly case. This case is constructed from a variety of materials and knitted fabrics suggested by the AI algorithm. The simulation encompasses the interaction of knitted fabric assemblies exposed to real-life ambient weather conditions. It relies on data collected from the Izmir Adnan Menderes Airport Meteorological Station for a true representation of environmental influences. Various weather-related data, including the temperature, humidity, wind speed and direction, precipitation, and atmospheric pressure for a specified month, day and hour in summer have been implemented to solve the complex problem. The moisture transport considers factors like moisture storage and capillarity and accounts for fabric properties determined through experimentation, such as permeability, porosity, diffusivity, and an irreducible liquid phase saturation. In addition, the conjugate heat transfer incorporates data on ambient air velocities and temperatures sourced from the weather station. The experimentally determined thermal properties of the fabrics have been implemented as well. The transient behaviour of the drying process of the wetted knitted fabric has been solved for the coupled, flow, heat, and moisture transport. Figure 3 illustrates the relative humidity of the fabric predicted over time. Inside the fabric sample, the relative humidity decreases from the initial 98% at the beginning of the simulation to 49% at 29°C at time t6, approaching the ambient relative humidity for the climate zone in which the fabric is being virtually tested.

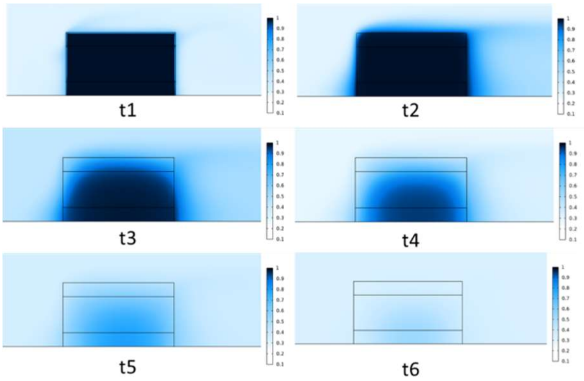

Figure 3. Change in relative humidity during drying of the fabric over time

The fabric is evidently moist, slowly beginning to release moisture into the environment as it undergoes slight cooling due to the convection effect, as shown in the velocity and temperature distributions in Figure 4.

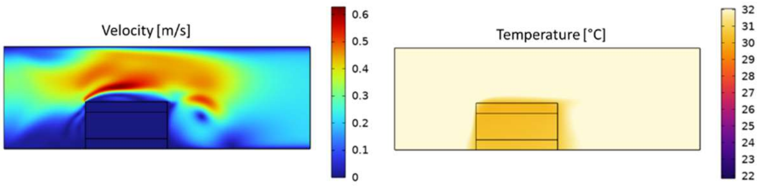

Figure 4. Conjugate heat transfer process at the initial stages of the drying process: convective forces around the fabric and the lower velocities due to the porous structure of the fabric are visible. Fabric cools while exchanging moisture and heat with the environment.

In other words, the air is initially not very humid, with the capacity to hold more moisture. The relatively warm temperature and the difference in relative humidity between the fabric and the surrounding air favour the drying process. The ambient air's relative humidity of 0.37 at t6 indicates that the air is relatively dry. In contrast, the knitted fabric has some interior local regions with a relative humidity of 0.49, suggesting the presence of spots with more moisture than the surrounding air, indicating it is still in the drying process. As the fabric dries, it can contribute to increased comfort and release moisture into the air, which can result in a slight increase in humidity immediately around the fabric. This can be beneficial for skin comfort, especially in dry conditions, as depicted for time instants t2-t3. For optimal comfort, it's essential to strike a balance between moisture levels in clothing and the surrounding environment. Slightly moist fabric in warm conditions can provide a cooling effect, but excessively wet clothing can lead to discomfort. As the knitted fabric approaches the relative humidity of the ambient air, comfort is likely to improve. It should be noted that maintaining an irreducible liquid phase saturation is beneficial for the fabric. Since moisture consists of both vapor and liquid water in the knitted fabric, a good indicator of the drying process is the liquid saturation of the fabric. At t6, there is a liquid fraction of 0.05-0.064 remaining, compared to t1 where it varied between 0.51-0.69.

6. CONCLUSIONS

The AI-based optimisation of fabrics suitable for individuals with allergies has proven to be an invaluable accelerator in the design process, leading to more efficient enhancements of knitted fabrics. Consequently, specific parameters could be assigned, and optimal dimensions could be generated. These efforts have allowed us to take a step further and implement precise fabric development, harnessing the power of detailed multiphysics analyses to showcase the transient behaviour of a preliminary demonstration design of a textile knitted fabric that exhibits improved thermofluid flow and moisture transport properties. The results highlight the substantial potential of utilising the investigated materials and structures in layered combinations, which have been precisely calculated and validated using the AI-based optimisation approach. This suggests the utilisation and expansion of its enhanced capabilities for future research.

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REFERENCES

[1] AXELROD, Y. K., DİRİNGER, M. N. (2008). Temperature Management in Acute Neurologic Disorders. Neurologic Clinics 26, (2), 585-603.
[2] ELMAS, Ö.F., AKDENİZ, N., ATASOY, M., KARADAG, A.S. (2020). Contact dermatitis: A great imitator. Clinics in Dermatology 38 (2) 176-192.
[3] HUİ, X., ZHU, H., SUN, G. (2016). Antimicrobial textiles for treating skin infections and atopic dermatitis. Gang Sun (Ed.), Antimicrobial Textiles. 287-303.8
[4] MOBOLAJİ-LAWAL M., NEDOROST S. (2015). The Role of Textiles in Dermatitis: An Update. Curr Allergy Asthma Rep. 15: 17, 1-7. DOI 10.1007/s11882-015-0518-0.
[5] RICCI, G., PATRIZI, A., BELLINI, F., MEDRI, M. (2006). Use of textiles in atopic dermatitis: care of atopic dermatitis. Curr Probl Dermatol. 33:127-43. doi 10.1159/000093940. PMID: 16766885.
[6] PEKSEN, M. ACAR, M., MALALASEKERA, W. (2018) Optimisation of machine components in thermal bonding process of nonwovens: Effect of the conveyer belt on the porous web performance. Journal of Industrial Textiles 47 (5) 978 – 990.
[7] PEKSEN, M. (2018). Multiphysics Modelling-Materials, Components, and Systems. London, England: Ed. Academic Press. ISBN 978-0-12-811824-5
[8] PEKSEN, M., CANDAN, C., NERGİS, B., KOYUNCU, B (2023). Digitalised R&D and Production in the Textile Industry for Reduced Energy Consumption and Efficient Production Rates. International Textile & Fashion Congress, 42-47.
[9] PEKSEN, M., (2023) Material and Performance Optimisation for Syngas Preparation Using Artificial Intelligence (AI)-Based Machine Learning (ML), Hydrogen 2023, 4(3), 474-492; https://doi.org/10.3390/hydrogen4030032
[10] PEKSEN, M., SPLİETHOFF, H., (2023) Optimising pre-reforming for quality r-SOC syngas preparation using artificial intelligence (AI) based machine learning (ML), International Journal of Hydrogen Energy, https://doi.org/10.1016/j.ijhydene.2023.03.223.

[11] PEKSEN, M., (2022) Artificial Intelligence-based machine learning toward the solution of climate-friendly hydrogen fuel cell electric vehicles. Vehicles 4(3):663-680 DOI: 10.3390/vehicles4030038.

ECO-FRIENDLY DENIM THROUGH THE COLORS OF NATURE

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ABSTRACT

Natural dyeing has been used for centuries to color textiles, yet it lost its ground to synthetic dyes due to its inability to adapt to industrial production, cost, and unpredictability. With the understanding of the harm synthetic dyes pose to both humans and the environment, the industry has been shifted to alternative solutions. Clay dyeing has emerged as an environmentally friendly alternative due to its natural composition, suitability for industrial processes, and its capacity to save energy and water. In the context of this study, the environmental impact of a clay-dyed denim collection was examined through a case study.

Key Words: Sustainable denim, natural dye, clay dye, bio-mordant, sustainable textiles

1. INTRODUCTION

The process of industrialization began with the Industrial Revolution in the late 18th century and has exerted a profound influence worldwide since the 20th century. Consequently, the adverse impacts have become visibly apparent in the ecosystem, characterized by environmental degradation, depletion of natural resources due to increased production, escalating waste generation, the extinction of certain species, and climate change [1]. One of the pioneers of the Industrial Revolution, textiles, occupies a prominent position among sectors in need of improvement. The textile industry is characterized by the use of various hazardous chemicals and petrochemicals in the production of fibers and fabrics, carbon emissions generated throughout the production, usage, and consumption phases, substantial water and energy consumption throughout the entire process, and the accumulation of factory and textile waste [2, 3]. The concept of sustainability, which emerged as a result of efforts initiated in the 1960s to comprehend the adverse environmental impacts, was defined in the late 1980s as meeting the needs of the present without compromising the ability of future generations to meet their own needs [3]. Within the context of the textile sector, sustainability encompasses environmentally friendly raw materials, the use of chemicals in production that do not harm the environment or human health, responsible behaviors towards post-production and post-usage waste, and the incorporation of concepts such as recycling and upcycling into the process [4]. While in the sector, approaches that align closely with this sustainability definition are exhibited by almost all stakeholders, it is particularly the finishing processes, notably printing/dyeing and washing, that stand out as the most polluting and containing toxic substances [1, 5].

In the early 18th century, the emergence of synthetic dyes in the textile industry replaced natural dyes, which were obtained from various plants, animals, and minerals. These natural dyes were characterized as costly, unpredictable, limited, and variable [6, 7]. Yet, in the 1980s, the rediscovery of natural dyeing gained significance as it was established that many synthetic dyes had adverse effects on human health and the environment [7]. Nonetheless, challenges such as the inability to achieve color consistency due to factors like seasonality and geographic limitations, as well as issues related to fastness values, durability, efficiency, and cost, necessitate solutions in the realm of natural dyeing.

Within the context of recent technological developments and perspectives, there are studies that propose innovative solutions. Research exists regarding the positive aspects of natural dyes, in addition to being renewable sources [8]. Some of these include UV protection, antimicrobial and hypoallergenic properties, as well as odor control. Environmental-friendly and alternative modern technologies such as ozone treatment, enzymes, ultrasonics, enable improvements in fastness properties and a reduction in the usage of metal mordants with these methods [9].

Clay dyeing emerges as a method that addresses the primary challenges of traditional natural dyeing, such as limited resources, small-scale production capacity, stability, color consistency, color intensity, and the necessity for harmful substances to human health, specifically metal mordants [10].

The Mavi brand, which began its journey locally with denim in the 1990s in Turkey and has since expanded globally with lifestyle product groups, holds a pioneering position among sustainability-focused brands in Turkey. The brand's sustainability approach, resulting in the All Blue Collection, demonstrates ongoing development each season, characterized by the incorporation of environmentally friendly new raw materials, improvements in existing materials and practices, and the effective utilization of technology. Within the scope of this study, the brand's approach in line with the All Blue philosophy, which includes the development of a clay dyeing method referred to as "Natural Dye" and its collection implementing various sustainability approaches, have been evaluated [11].

2. EXPERIMENTAL

The chosen method for this study, namely case study, is a frequently employed qualitative research approach within the field of social sciences. It is applied with the aim of conducting an in-depth research on a particular case and contributing insights that enhance the understanding of similar cases. Case studies can encompass both quantitative and qualitative approaches [12]. In this study, both quantitative data were employed to assess the positive environmental impact of clay dyeing, and a qualitative approach was utilized to compare it with conventional (synthetic dyeing) and traditional natural dyeing methods.

A case study, defined as an in-depth examination of a single case to elucidate it further, can also be referred to as a multiple case study when it encompasses more than one case. In such multiple case studies, the focal point is the sample selection. In the present study, the focus is on evaluating both the sustainability initiatives undertaken through clay dyeing in the selected collection and the environmentally friendly approaches adopted for the accessories used. Thus, the method can also be termed as a multiple case study [13].

The steps to be followed through the research method can be outlined as follows:

- Explanation of the clay dyeing method, its process and advantages.
- Quantitative presentation of the positive environmental impact of clay dyeing.
- Comparison of the characteristics of clay dyeing, conventional dyeing, and traditional natural dyeing.
- Evaluation of the other environmentally friendly approaches in the Natural Dye collection.

3. RESULTS

3.1 Clay Dye

Clay is a fine-grained natural mineral composed of rock, soil and plant residues. It exhibits a wide range of colors and tones, influenced by natural factors such as sunlight, wind, humidity, pressure, or heat, without the need for any chemical components, thus providing an extensive spectrum of colors and shades. In the coloration of textile fibers using clay dyeing, metal mordants are required. Preference is given to bio-mordants and organic enzymes. This approach allows for both chemical control and addresses the durability issues associated with traditional natural dyeing, such as fastness properties [10].

Clays and clay minerals hold a significant position as a crucial raw material for various industries due to their ease of procurement and low costs [14]. Consequently, they provide a solution to the high-cost issue associated with traditional natural dyeing. The clay chosen for coloring the products in the Natural Dye collection is sourced locally, which has a positive impact on carbon footprint [10].

The additional advantages that clay dyeing can offer are listed as follows [10]:

- Non-toxicity: Clay dyeing is non-toxic and possesses purifying properties.
- UV resistance: It provides a protective barrier against solar radiation, safeguarding the skin from UV rays.
- Dispersal of negative energy: Clay dyeing is believed to dispel negative energy.
- Biodegradability: It is biodegradable, making it environmentally friendly.
- Antibacterial properties: Clay dyeing prevents the proliferation of bacteria due to its antibacterial characteristics.

3.2 Clay Dye and Environment

Studies in the literature have demonstrated the use of clay minerals for the adsorption of hazardous substances, such as heavy metals, dyes, antibiotics, and other organic chemicals [14]. One of these studies revealed that clay minerals effectively adsorb fragments of indigo dye released into wastewater during washing processes of denim fabric [15]. Through the sustainable and efficient processes of clay dyeing in the Natural Dye collection, a water savings of 72.6% has been achieved [10].

Clay, being locally sourced and utilizing an efficient production method while requiring no additional washes for chemical purification, results in a carbon dioxide savings of 42.5% compared to similar collections [10].

Clay dyeing also offers an 82% space saving advantage over conventional dyeing units, owing to its compact unit size [10].

3.3 Comparison of Clay Dyeing with Other Natural Dye Systems and Conventional Dyes

In traditional natural dyeing practices, it is acknowledged that the choice of dyeing recipes and conditions can significantly affect the obtained color, clarity, intensity, and the fastness properties (such as wash, light, and friction fastness) [9]. Recent technological advancements and methods offer the possibility of addressing these disadvantages when compared to conventional dyeing by formulating new recipes to ensure consistency. Clay dyeing provides solutions to these issues, achieving optimization and consistency through developed recipes and methods. Table 1 compares Traditional Natural Dyeing, Conventional Dyeing, and Clay Dyeing [10] . As evident from the table, clay dyeing exhibits positive aspects compared to conventional and traditional natural dyeing methods.

Table 1. Comparison of Clay Dyeing Method with Other Natural Dyes and Conventional Dyeing Methods

PROPERTIES	CLAY DYE	CONVENTIONAL DYE	TRADITIONAL NATURAL DYE
Wide Range of Colors	✓	✓	✗
Color Fatness	✓	✓	✗
Durability	✓	✓	✗
Naturality	✓	✗	✓
Water & Energy Effiency	✓	✗	✓
Clean Waste Water	✓	✗	✓

3.4 Natural Dye Collection

The Natural Dye Collection established within the denim category of the Mavi brand comprises 18 products designed for both female and male users, suitable for combination with shirts and trousers. Specific recipes have been applied in the collection, incorporating various types of clay colorants and in different proportions for each color used in the products.

The recent sustainability approach in the textile industry has redirected the companies towards new-generation materials, with agricultural residues prominently emerging as raw materials for these materials [16, 17]. In the collection, a preference for buttons containing hazelnut shells and the use of olive pit content for back labels have provided a vegan alternative to leather. To improve the performance in terms of sustainability, the collection incorporates recycled-content yarns and labels made from basil seeds (Figure 1).

Figure 1. Natural Dye Collection

4. DISCUSSION

The products designed within the Natural Dye collection using clay dyeing method have yielded positive environmental outcomes in terms of energy and water conservation, reduced chemical usage, and a decrease in carbon footprint.

Textiles dyed with natural dyes are preferred by environmentally conscious consumers and have found a niche market for themselves [1]. An example of how natural dyeing, when conducted in an industrially suitable manner by a global ready-to-wear clothing brand, can reach a wider audience is highlighted by the Natural Dye collection.

5. CONCLUSIONS

Natural Dye Collection examined within the scope of this study will contribute both to the existing literature on natural dyeing and alternative environmentally friendly materials for eco-friendly denim and inspire the industry to explore different methods.

The choice of clay dyeing and clay as the primary raw material in the Natural Dye collection has resulted in a positive environmental impact through water conservation. The collection received recognition for its sustainability efforts by winning the Sustainable Collection Award from the Rivet + Project Awards based in the United States, thereby making its contributions to the field visible [17].

6. REFERENCES

[1] AYVAZ, K. M. and TEKER, M. S. Türkiye'de doğal boya kullanan tekstil işletmeleri ve bitki atıkları ile sürdürülebilir bir yaklaşım önerisi. Yüzüncü Yıl Üniversitesi Sosyal Bilimler Enstitüsü Dergisi, 2023, no. 59, pp 348-362.
[2] GWILT, A. A practical guide to sustainable fashion, London: Bloomsbury publishing, 2020.
[3] Sürdürülebilir Moda, Accessed: 26.11.2022. Available on https://www.surdurulebilirmodalisani.com/sozluk
[4] CAN, Ö. and AYVAZ, K. M. Tekstil ve modada sürdürülebilirlik. Akademia Sosyal Bilimler Dergisi, 2017, vol. 3, no. 1, pp 110-119.
[5] ODABAŞI, S. Sürdürülebilir moda tasarımı- kavramlar ve uygulamalar, Ankara: Nobel akademik yayıncılık, 2022.
[6] HODGE, S. Sanatın kısa öyküsü, Translator by DÖ. İstanbul: Hep kitap, 2020, pp 169.
[7] SUNERLİ, E. and ÇAKIR AYDIN, M. Doğal boyamanın farklı tekstil lifleri ile oluşturulan yüzeylere etkisi. The Journal of International Lingual Social and Educational Sciences, 2019, vol. 5, no. 1, pp 196-203.
[8] ÖZEN, Ö and ERDEM İŞMAL, Ö. Tekstil tasarımına ekolojik bir yaklaşım: lyocell üzerine doğal boyama ve eko baskı. Yedi, 2021, no. 26, pp 109-130.
[9] ERDEM İŞMAL, Ö. Doğal boya uygulamalarının değişen yüzü ve yenilikçi yaklaşımlar. Yedi, 2019, no. 22, pp 41-58.
[10] Terra Denim, Accessed: 26.11.2022. Available on http://www.maritasdenim.com/terra.html
[11] Mavi All Blue, Accessed: 27.08.2023. Available on https://www.mavi.com/

[12] YILDIRIM, A. and ŞİMŞEK, H. Sosyal bilimlerde nitel araştırma yöntemleri, Ankara: Seçkin, 2018, pp 73-74.
[13] SUBAŞI, M. and OKUMUŞ, K. Bir araştırma yöntemi olarak durum çalışması. Atatürk Üniversitesi Sosyal Bilimler Enstitüsü Dergisi, 2017, vol. 21, no. 2, pp 419-426.
[14] ISMADJI, S., SOETAREDJO F. E. and AYUCITRA, A. Chapter 2: Natural clay minerals as environmental cleaning agents, Clay materials for environmental remediation, United States: Springer, 2015, pp 5-37.
[15] MARYAN, A. S., MONTAZER, M. and DAMERCHELYC, R. Discoloration of denim garment with color free effluent using montmorillonite based nano clay and enzymes: nano bio-treatment on denim garment. Journal of Cleaner Production, 2015, no. 91, pp 208-215.
[16] BAHÇE, H. T. Kayısı çekirdeği ve kabuklu meyvelerin kompozit malzemelerde kullanımı: Master Thesis, İnönü University, 2019.
[17] Natural Dye, Accessed: 26.11.2022. Available on https://sourcingjournal.com/denim/

NEW APPROACH FOR DYE EXTRACTION FROM *RUBIA TINCTORUM* AND *RESEDA LUTEOLA* PLANTS

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ABSTRACT

In this study, three current extraction methods were applied for two plant species: *Rubia tinctorum L.* (common madder) and *Reseda luteola L.* (weld), as natural sources of dyes. Ultrasound-assisted extraction (UAE) and microwave-assisted extraction (MAE) were studied and compared with conventional heat reflux extraction (HRE). The impact of various operational parameters, including time and solvent composition, on the MAE and UAE techniques was examined. Under optimal conditions, the MAE and UAE approaches showed significantly higher recoveries than the conventional extraction methodology. Additionally, the use of the MAE method resulted in a significant reduction in extraction time. The extracted dyes were characterized by ultra-performance liquid chromatography photodiode array detection and Fourier-transform infrared spectroscopy.

Key Words: Natural dye, *Rubia tinctorum*, extraction, *Reseda luteola*, UV protection.

1. INTRODUCTION

Natural dyes offer an environmentally friendly alternative to synthetic dyes, avoiding the use of harmful chemicals. Synthetic dyes have major drawbacks, not least their toxicity. Their use can cause allergic skin reactions in humans, in addition to generating environmentally polluting, non-biodegradable waste. Replacing synthetic colorants with natural ones is therefore imperative [1]. *Rubia tinctorum L.*, from the Rubiaceae family, also known as madder, is a plant that has played an essential role in the history of natural dyeing and has traditional medicinal uses. This plant has contributed to the creation of a variety of shades of red appreciated for their resistance to fading. *Reseda luteola L.,* more commonly known as weld, is a member of the Resedaceae family recognized for its yellow color palette with high fastness proprieties [2]. The colorants present in natural sources are very limited in quantity. To efficiently separate the coloring components from their original sources, an efficient extraction technique using the optimal conditions is required [3]. Among the many conventional techniques for extracting colored ingredients are aqueous extraction [4], acid and alkaline extraction processes [5], and solvent extraction. To improve extraction, various advanced technologies are used, such as ultrasonic [6] and microwave extraction [7], fermentation, enzymatic extraction and supercritical fluid extraction [3].

We carried out the present study to explore the extraction of natural dyes from tinctorial plants, employing two prominent extraction techniques, Ultrasound-assisted extraction (UAE) and microwave-assisted extraction (MAE) in order to enhance the extraction efficiency and reduce the extraction cost. We have analyzed various influencing factors in depth to find the optimal extraction conditions for the most efficient extraction technique.

2. EXPERIMENTAL

Materials

The rhizomes of *R. tinctorum* and the aerial parts of *R. luteola* were used in this study. The first plant was provided from the herbal stores in Casablanca city, and the second one was collected during the flowering period (Avril/May) in the region of Ouarzazate (Southern/Morocco). These plants were dried in an oven at 60°C, then ground to obtain a powder with an average diameter of 0.5 mm.

Ultrasonic-assisted extraction

An ultrasonic generator with a power of 130 W (Vibra Cell 75186 sonicator) and a titanium ultrasonic probe (6 mm in diameter) was positioned in the center of the mixture, with an amplitude of 80%. The nominal frequency was 20 kHz. Ground plant material (10 g) was mixed with 100 ml of ethanol and water, using a solid/solvent ratio of 1:10 (g/mL). The beaker was placed in a temperature-controlled water bath. The extract was then filtered and dried in an oven.

Microwave-assisted extraction

The microwave-assisted extraction (MAE) experiments were carried out on a microwave-accelerated reaction system (Speedwave Xpert. Berghof. Germany. 2.45 GHz). MAE recoveries can be influenced by the solvent and extraction time. These effects were studied; dyes were extracted by adding 3 g of dried plants in 30 ml of solvent. For all experiments, the output power was 900 W and the temperature was 60°C. After microwave irradiation, the solution was filtered through filter paper and dried.

Reflux extraction

For one hour, 10 g of each plant was refluxed with 100 ml of water at 90°C. The final extract was filtered and evaporated.

Ultra-High-performance liquid chromatography - detection by photodiode array (UHPLC-PDA)

The dye powder (100 mg) was dissolved in 10 ml of ethanol/water mixture (4:6. v/v). The dissolved extract was then filtered through a 0.2 µm filter. High-performance liquid chromatography (HPLC) analyses were carried out for 35 minutes at a constant flow rate of 1 ml/min. The column was thermostated at 35°C, and the binary elution solvent consisted of acetonitrile (A) and Millipore distilled water (B) acidified with 0.01% trifluoroacetic acid (TFA). The sample injection volume was 10 µl. This method was performed using an UHPLC system from PerkinElmer, equipped with a diode array detector.

3. RESULTS AND DISCUSSION

Optimization of UAE conditions

<u>Effect of extraction time:</u>

For both plants, the effects of extraction time on yields were studied by adjusting the mass/volume ratio of the liquid (1:10) and the composition of the solvent with 40% ethanol, varying the time (30, 35, 40, 45 min) to obtain the maximum yield of dye extract (Figure 1a). Experiments were carried out at room temperature.

As shown in figure 1, for *R. tinctorum*, the recovery percentage increases with the duration of ultrasonic treatment, as the contact time between liquid and solid plant material increases, for the first 40 minutes, then decreases considerably thereafter. These results may be linked to dye decomposition caused by extraction times that are too long, as plant phenols such as anthraquinone are most often degraded or undergo undesirable reactions such as enzymatic oxidation [8]. These phenomena could also be explained by Fick's second law of diffusion, according to which a final equilibrium between solute concentrations in the solid matrix (plant matrix) and in the bulk solution (solvent) could be reached after a certain time, leading to a deceleration in extraction yield [8]. For the *R. luteola* plant, the amount of dye leaving the plant increased also with time, but this increase was quite evident only up to 35 min. Further, there was not much change in the extraction rate, as longer times represent more energy and can break down the recovered compounds (Figure 1a), so an extraction time of 35 min was set for the next step.

Effect of solvent composition :
The extraction process was carried out with different solvent compositions (0, 20, 60, 80, 100) % ethanol when the other three factors namely, solid/liquid ratio, extraction time and temperature were set at 1:10, 35 min for *R. tinctorum* plant and 40 min for *R. luteola* plant , at room temperature, respectively.

In the case of ultrasound-assisted extraction of *R. tinctorum*, the yield increases and reached 11.91% rate with the ethanol content to 60%, then decreases (Figure 1b). This was probably due to the relative polarity that matched the extracted dyes and increased their solvability in ethanol than in water [9]. In fact, at higher water concentrations, as in 0% ethanol, product recovery was lowest, as high water content increased the polarity of the mixture to the point where it was no longer favorable for anthraquinone extraction. In contrast, for the *R. luteola* plant, the addition of water increases the extraction efficiency, giving a maximum rate of 24.18% with 100% water. This can be explained by effective swelling of the plant in water, which increased the contact surface between the plant composition of flavonoids and the solvent, and release the dyes from plant [9] altough the flavonoids have less polarity than water. The optimum values of parameters affecting quantitative ultrasonic extraction are found to be 35 min for extraction time, 100% distilled water for extraction solvent and a mesh size of 0.5 mm.

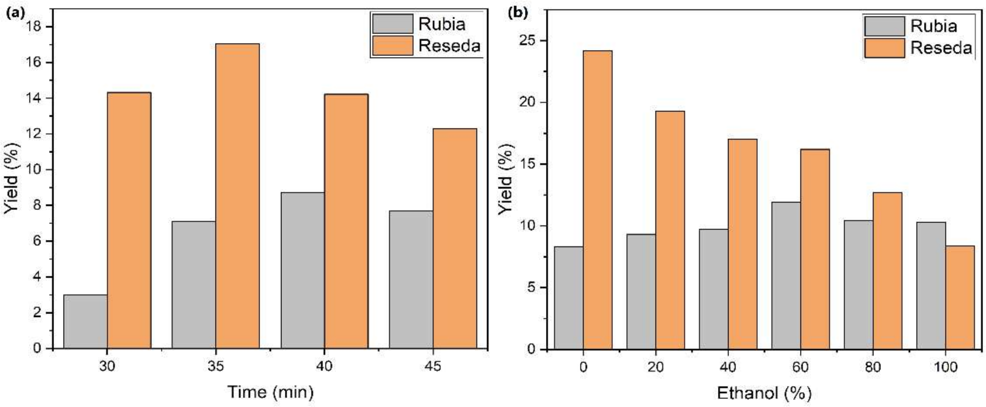

Figure 4. The effect of (a) UAE time and (b) solvent composition on extraction yield

Optimization of MAE conditions

Effect of extraction time :

The duration of microwave irradiation was varied from 1, 2, 3, 4 to 5 minutes. The results indicate that yield increases with the duration of MAE at the start of extraction. Yields peaked for *R. tinctorum* and *R. luteola* plants, at 13% in 4 minutes and 22.66% in 3 minutes, respectively, during the MAE process (Figure 2a). However, if the MAE time exceeds 5 minutes, the extraction percentage decreases due to the extract decomposition [10] as mentioned above.

Effect of solvent composition :

The impact of ethanol concentration on extraction efficiency is shown in figure 2b. These results show that the use of microwaves clearly improves product recovery for the all investigated solvent compositions. The MAE technique using 20% ethanol in water gave the highest percentage recovery of dyes extract for the both plants. The presence of high amount of water in the solvent have prompted the swelling of the plant material, which increases the contact surface between the plant composition of dyes and the solvent [11].

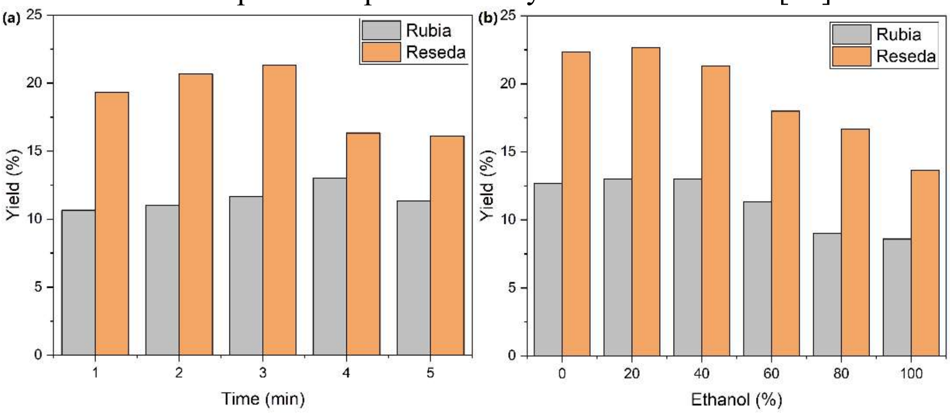

Figure 5. The effect of (a) MAE time and (b) solvent composition on extraction yield

Extraction yields comparison

The HRE, UAE and MAE extraction methods were investigated to determine the best dye extraction technique. Table 1 shows different extracts yields achieved with the three extraction techniques. The best yield was obtained with 13% using the MAE technique for *R. tinctorum* plant. In the case of *R. luteola* plant, the extract yield of the UAE technique (24.18%) was the highest among the three methods. The best results were achieved not only in terms of the higher extract yields but also in terms of economic benefit since the extraction process was carried out at room temperature.

Table 1. Comparison of yields for the three extraction processes

Plant	Extraction mode	Parameter			Yield (%)
		Solvent ($EtOH/H_2O$)	Temperature [°C]	Extraction time [min]	
Rubia tinctorum L.	**UAE**	60/40	Ambient	40	11.91
	MAE	20/80	60	4	13
	HRE	0/100	90	60	10.12
Reseda luteola L.	**UAE**	0/100	Ambient	35	24.18
	MAE	20/80	60	3	22.66
	HRE	0/100	90	60	13.51

Caracterization of extract dyes by HPLC

Figure 3 illustrates HPLC chromatogram of *R. tinctorium* rhizomes extract, reveals the presence of three major peaks. According to *Derksen GCH et al.*'s work [12], the similar result has been found, it was considered that the main peaks at 2.848mn, 4.546mn and 5.660nm could be assigned to lucidin primeveroside, ruberythric acid and alizarin, respectively. As the result, ruberythric acid is the most abundant compound in the *R. tinctorium* rhizoms extract. But it could be transformed easily to alizarine by a simple hydrolyse reaction.

Figure 4 demonstrates the HPLC chromatogram of *R. luteola* extract dyes. The chromatogram discloses the presence of three peaks at 1.441mn, 1.829nm and 3.118nm. Comparing this result to the previous works such as *van der Klift E et al.*'s research, these peaks could be attributed to ellagic acid, apigenin and luteolin, respectively [13]. This result confirms the presence of the most abundant compound, luteolin, in *R. luteola* extract as it was mentioned in literature.

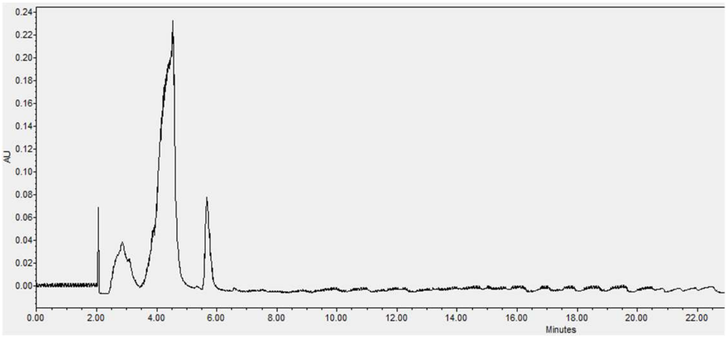

Figure 6. HPLC chromatogram of *R. tinctorum* extract at 450nm

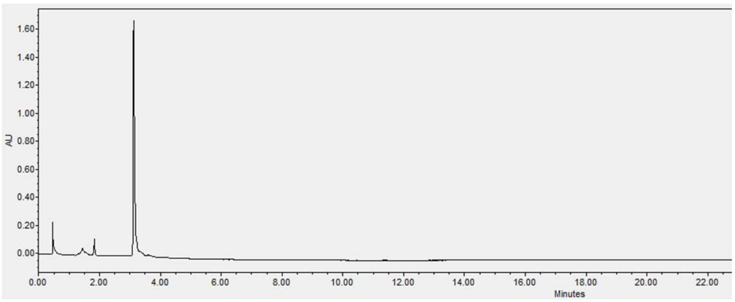

Figure 7. HPLC chromatogram of *R. Luteola* extract at 350nm

4. CONCLUSIONS

The study has developed and optimized two main recent technics of dyes extraction, mainly ultrasound- and microwave-assisted extraction methods for extracting the natural dyes existing in the aerial parts of *R. Luteola* and the rhizomes of *R. tinctorum*, taking into account the effect of two extraction parameters: extraction time and solvent composition. The optimal extrcation conditions for the *R. tinctoria* plant using MAE were obtained at 900 W in 4 minutes of treatment at 60°C, with an ethanol/water solvent mixture (20/80, v/v). On the other hand, the optimal extraction conditions using ultrasonic-assisted extraction (UAE), were achieved in 40 minutes with ethanol/water (60/40, v/v). The extraction yields achieved by the both techniques, MAE and UAE were 13% and 11.91%, respectively. For *R. Luteola* plant, the optimal conditions using the UAE technique were obtained with 100% water as a solvent and 35 minutes of treatment, realizing a higher yield of 24.18%. The MAE method has achieved an extract yield of 22.66% using ethanol/water (60/40, v/v) for 3 minutes.

5. REFERENCES

[1] W. RASOOL, S. ADEEL, F. BATOOL, S. AHMAD, S. MUMTAZ, M. HUSSAAN, Environmental friendly silk and cotton dyeing using natural colorant of Bougainvillea (Bougainvillea glabra) flowers: the sustainable approach towards textile industry, Environmental Science and Pollution Research. 30 (2022). https://doi.org/10.1007/s11356-022-23417-7.

[2] O. CHAJII, A. ZOURIF, Y. CHEMCHAME, A. BENBIYI, M. EL GUENDOUZI, F.Z. MOURID, A. EL BOUARI, Ethnobotanical, geographical, phytochemical and dyeing study of the main tinctorial plants in Morocco, Sustainable Chemistry and Pharmacy. 36 (2023) 101200. https://doi.org/10.1016/j.scp.2023.101200.

[3] W. HADDAR, S. ADEEL, M. SALMAN, A. GHAFFAR, M. NASEER, M. USAMA, M. BENTICHA, Ecological Applications of Enzymes in Plants Based Textile Dyeing, in: 2023. https://doi.org/10.5772/intechopen.108603.

[4] K. SINHA, P.D. SAHA, S. DATTA, Extraction of natural dye from petals of Flame of forest (Butea monosperma) flower: Process optimization using response surface methodology (RSM), Dyes and Pigments. 94 (2012) 212–216. https://doi.org/10.1016/j.dyepig.2012.01.008.

[5] S. ALI, T. HUSSAIN, R. NAWAZ, Optimization of alkaline extraction of natural dye from Henna leaves and its dyeing on cotton by exhaust method, Journal of Cleaner Production. 17 (2009) 61–66. https://doi.org/10.1016/j.jclepro.2008.03.002.

[6] V. SIVAKUMAR, J.L. ANNA, J. VIJAYEESWARRI, G. SWAMINATHAN, Ultrasound assisted enhancement in natural dye extraction from beetroot for industrial applications and natural dyeing of leather, Ultrason Sonochem. 16 (2009) 782–789. https://doi.org/10.1016/j.ultsonch.2009.03.009.

[7] K. SINHA, S. CHOWDHURY, P.D. SAHA, S. DATTA, Modeling of microwave-assisted extraction of natural dye from seeds of Bixa orellana (Annatto) using response surface methodology (RSM) and artificial neural network (ANN), Industrial Crops and Products. 41 (2013) 165–171. https://doi.org/10.1016/j.indcrop.2012.04.004.

[8] J. NURUL AIN, A.M. Mimi Sakinah, A.W. Zularisam, Effects of Different Extraction Conditions on The Production of Anthraquinone, (n.d.).

[9] H. LI, L. PORDESIMO, J. WEISS, High intensity ultrasound-assisted extraction of oil from soybeans, Food Research International. 37 (2004) 731–738. https://doi.org/10.1016/j.foodres.2004.02.016.

[10] K. SUKTHAM, P. DAISUK, A. SHOTIPRUK, Microwave-assisted extraction of antioxidative anthraquinones from roots of Morinda citrifolia L. (Rubiaceae): Errata and review of technological development and prospects, Separation and Purification Technology. 256 (2021) 117844. https://doi.org/10.1016/j.seppur.2020.117844.

[11] S. HEMWIMON, P. PAVASANT, A. Shotipruk, Microwave-assisted extraction of antioxidative anthraquinones from roots of Morinda citrifolia, Separation and Purification Technology. 54 (2007) 44–50. https://doi.org/10.1016/j.seppur.2006.08.014.

[12] G.C.H. DERKSEN, T.A. VAN BEEK, Æ. DE GROOT, A. CAPELLE, High-performance liquid chromatographic method for the analysis of anthraquinone glycosides and aglycones in madder root (Rubia tinctorum L.), Journal of Chromatography A. 816 (1998) 277–281. https://doi.org/10.1016/S0021-9673(98)00492-0.

[13] E. VAN DER KLIFT, A. VILLELA, G.C.H. DERKSEN, P.P. LANKHORST, T.A. VAN BEEK, Microextraction of Reseda luteola-Dyed Wool and Qualitative Analysis of Its Flavones by UHPLC-UV, NMR and MS, Molecules. 26 (2021) 3787. https://doi.org/10.3390/molecules26133787.

EXPLORING EDUCATION FOR SUSTAINABLE DEVELOPMENT (ESD) IN FASHION DESIGN STUDIES IN GERMANY AND IRAN – A COMPARISON

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ABSTRACT

Education for Sustainable Development (ESD) has been increasingly becoming part of the curriculum of higher education in fashion design (HEFD). Thus, a structured, systematic literature review for ESD in HEFD and an exploratory, qualitative comparison between curricula in Germany and Iran were conducted to explore how far this educational approach with its relevant sustainability aspects for fashion design has been implemented in the curricula of B.A. and M.A. programs in the two countries. The findings of this paper demonstrate a high difference between the state of implementation of ESD in HEFD in the two countries.

Keywords: ESD, sustainable fashion, higher education, Germany, Iran

1. INTRODUCTION

ESD is an educational approach that concerns everybody. The ESD concept has evolved as an independent field of educational research since the 1990s. It contributes to empirical educational research by focusing on evidence-based development and empirical validation of educational initiatives [1]. Especially in fashion and textile design, ESD offers the potential to transform the industry [2], providing students with the essential tools to overcome creative challenges for sustainable development (SD) by e.g., incorporating ESD as a guiding principle. These changes in education potentially contribute to a more sustainable fashion industry [3]. Hence, considering the various approaches to the sustainable transformation of the fashion system, product design is particularly important. It is, therefore, necessary to begin at this stage in education to effect long-term changes in the system and educate in a manner that promotes sustainability. To achieve this goal, introducing new educational paradigms is necessary [4].

This paper compares fashion design programs in Germany and Iran in terms of sustainability related competencies, as both economies contribute to the global fashion market in different ways. Germany is one of the leading fashion markets in Europe, ranking second in terms of the number of companies and total sales [5-6]. Meanwhile, in Iran, local fashion brands are experiencing unprecedented growth despite economic sanctions [7]. Starting from product design, the fashion system has a significant impact on the environment and society worldwide. [8]. Therefore, it is essential to transform fashion design education in line with the ESD approach, which is considered an integral element of sustainable development and a crucial facilitator for all relevant professional fields to tackle global challenges. This approach is reflected in UNESCO's ESD 2030 program, which also encompasses higher education curricula and aims to integrate sustainable development and the SDGs into education and learning [9]. Furthermore, UNESCO's roadmap requires a curriculum that is focused on sustainability, which places new challenges on universities, researchers, and higher education institutions in their efforts toward sustainable development [10]. Therefore, universities that offer fashion design degrees should incorporate ESD into their curricula as a guiding principle. Thus, the aim of this paper is to explore the question of how far ESD and sustainability aspects are already anchored in fashion design studies in Germany and Iran. To explore this question, the research comprises two parts: A) a systematic literature review of the implementation of ESD in HEFD in both countries, as well as B) a qualitative content analysis of curricula for Bachelor of Arts (B.A.) and Master of Arts (M.A.) in fashion design regarding the implementation of ESD in HEFD in the two countries.

2. METHODS

2.1. Systematic Literature Review (SLR)

Following Paul and Criado's SLR guidelines, the current state of ESD in HEFD was reviewed alongside four primary parameters: material collection, descriptive analysis, category selection, and material evaluation [11-12]. Publications on ESD in higher education and ESD in HEFD in both Germany and Iran, as well as in other countries, were searched for between January to June 2023. The search was conducted in three languages: German, Persian, and English. In Table 1, the databases and publishers used for literature searches are classified based on how they were employed for each country's literature search.

Table 1. Classified databases and publishers for literature searches

Countries	Databases and publishers
Germany and Iran (German and English)	BNELIT OS/ PH-Katalog Plus/ Freiburg General Catalog/ FIS Bildung/ KVK - Karlsruher Virtueller Kat/ BASE/ HAW Hamburg REPOSIT Education Source/ Springer/ Academic Search Premier/ OAIster/ Wiley/ DOAB/ DOAJ/ WorldCat/ ERIC/ Taylor and Francis Online/ Emerald/ Science Direct/ Google Scholar
Iran (Persian)	The National Library of Iran/ The Library of Alzahra University/ IRANDOC/ Journal of Environmental Education and Sustainable Development of Iran/ The Scientific Information Database

The search methods were pearl growing, snowballing, and citation search [13], as well as Boolean operators, phrase search, and truncation [14]. Initially, a search term matrix was created, which comprises search terms of "sustainable fashion education, education for sustainable development, Germany, and Iran" and their synonyms (e.g., sustainable apparel design education or ESD), broader (e.g., sustainability), narrower (e.g., eco-clothing), and related terms (e.g., environmental education in fashion), which were chosen based on the research question. Then, to evaluate the results, a table of inclusion and exclusion criteria was created based on the research question and scope.

Table 2. Inclusion and exclusion criteria of the systematic literature review (SLR) on Education for Sustainable Development (ESD) in higher education of fashion design (HEFD) in Germany and Iran.

Inclusion	Exclusion
English, German, and Persian language resources	Other languages
Focuses on ESD for fashion and textiles design studies in higher education in Germany and Iran	Only focuses on ESD for other fields of study
Peer-reviewed journals; grey research including Ph.D. dissertation, M.A. and B.A. theses, and governmental reports; as well as conference papers	Focuses on ESD in fashion and textiles design but not on ESD in higher education

The publications underwent a three-phase screening process (see Figure 1), yielding 13 and 2 publications for Germany and Iran, respectively. Phase 1 involved screening the titles and abstracts of the results, whereas phase 2 involved eliminating duplications and irrelevant publications. In phase 3, the inclusion and exclusion criteria (refer to Table 2) were used to hone in on publications relevant to ESD implementation in HEFD in Germany and Iran.

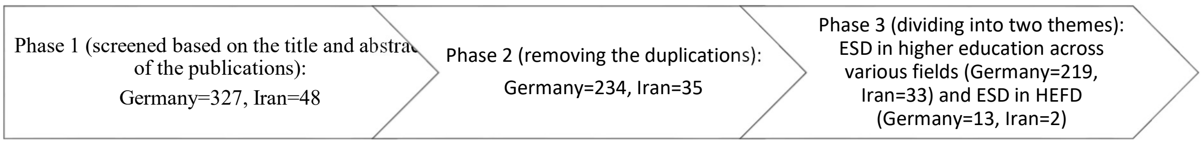

Figure 8. Three phases of screening the SLR results

2.2. Content Analysis of Fashion Design Curricula

In Germany, 13 universities (11 public and 2 private) were selected for the comparison, since they all offer B.A. and M.A. in fashion design programs[1] [15-27], while in Iran[2], 3 public universities[3], 9 technical and vocational universities, and 21 private universities [28-34] were explored[4]. The data collection for the curricula involved an internet search through the universities' websites. Following the deductive content analysis by Mayring [12], several keywords were selected based on the holistic learning model for developing sustainable fashion design education [35]. The keywords were employed as codes to scrutinize the content of

[1] Reutlingen University (B.A. in fashion and textile design), University of Applied Sciences and Arts Hannover (HSH) (B.A. in fashion design), University of Applied Sciences Berlin (HTW) (B.A. and M.A.in fashion design), Niederrhein University of Applied Sciences (bachelor of fashion design engineering), Pforzheim University (B.A. in fashion design), University of Applied Sciences Zwickau (B.A. and M.A. in fashion design), Burg Giebichenstein University of Art and Design Halle (B.A. in fashion design and M.A. in conceptual fashion design), Art Academy Berlin-Weissensee (B.A. and M.A. in fashion design), Bielefeld University of Applied Sciences and Arts (HSBI) (B.A. and M.A. in fashion design), Trier University of Applied Sciences (B.A. and M.A. in fashion design), Hamburg University of Applied Sciences (HAW) (B.A. and M.A. in fashion design), BSP Business & Law School (B.A. in sustainable fashion), and University of Art Berlin (UDK) (B.A. and M.A. in fashion design) [15-27].

[2]. Iran refers to the field as apparel and textile design, or separate fields of apparel design, sewing and design, as well as textile design and printing. The Iranian universities in each of the 16 provinces, both public and private, offer bachelor's degrees in these areas. The Ministry of Science, Research, and Technology publishes the curriculum for each field for universities. Despite of including courses related to fashion, none of the programs are called fashion design and this could be due to the political issues which has affected the status of fashion in Iran after the 1979 Islamic revolution [36].

[3]. Alzahra University (offering B.A. and M.A. in apparel and textile design), Tehran University of Art (offering B.A. and M.A. in textile design and printing), Semnan University (offering B.A. and M.A. in textile design), and technical and vocational universities [26-28].

[4]. These comprise of 3 Azad universities, 8 Gheirentefai universities, and 10 Elmikarbordi universities and provide various types of bachelor's degree programs, which includes a B.A. in apparel and textile design, B.A. in apparel design, B.A. in textile and printing design, Foghe-e-Diplom or Kardani (equivalent to 2 years of higher education) in sewing and design, and a discontinuous Undergraduate B.A. course (2 additional years of higher education) in sewing and design [28-34].

curricula and program descriptions. These codes include “socio-cultural, environmental and economic aspects of sustainability, sustainable design strategies, fashion design and apparel production for sustainable development, strategies in the textile change, innovative knowledge, ethical and social action, group work, working within local projects, co-operation with different disciplines, co-operation with industry partners, real-life learning, critical thinking, innovative thinking” [35, p 5]. German and Persian results were translated into English by the researcher.

3. RESULTS

3.1. Evaluation of ESD Implementation

Ermer [35] proposed a framework model of learning forms for a didactic-methodical concept for a holistic perspective on learning sustainability in fashion design. She presented the notions of sustainability and education for sustainable development in the fashion industry and discussed the status of sustainable design [37]. Furthermore, Ermer and Schwarzkopf [38] conducted a qualitative content analysis to examine the curricula of five German universities that offered a B.A. in fashion design by 2019. They found that only HTW Berlin directly incorporates sustainability aspects in its curricula [38]. However, the analysis does not include master’s programs and extracurricular sustainability-related activities. Additionally, the main objective of the EU-project Fashion Diet is the implementation of ESD as a guiding principle in fashion and textile study programs [39], using a mixed-methods research approach. The researchers from four partner universities in Germany, Romania, and Bulgaria created – as the main intellectual output – an ESD education module in the context of fashion and textiles that comprises 42 courses for higher education, which is provided as Open Educational Resource on the platform Glocal Campus [40-42].

For Iran, only two publications mentioned sustainability in the context of fashion and textiles, and one of them was focused on ESD. Davari et al. [43], by applying a survey of female students enrolled in B.A. and M.A. courses in textile, apparel, and industrial design, reported a lack of comprehensive awareness in the field among their peers, along with observed anti-sustainability attitudes. In contrast, Rezvani Ahangar Kolaee et al. [44] focused exclusively on female undergraduate students at Shariati Technical and Vocational University in Tehran. They designed courses to improve students’ cognitive abilities in designing sustainable clothing to minimize waste through knowledge of fibers, textiles, apparel life cycle, and their environmental impacts on their future careers. The study, however, did not cover the implementation of ESD into the university curriculum. A broader focus on different universities and a more concrete look at ESD implementation in HEFD is missing.

3.2. Engagement of Universities in ESD

In the fashion design study programs of German universities, a variety of topics and competencies related to sustainability could be found. The sustainability aspects included in the B.A. curricula as elective courses or relevant topics are “Sustainability in the Textile Industry” [15, p 14], “Design and Ecosystems, Materials and Innovation, Critical Fashion, Responsible Fashion”, seminars on “Responsible Fashion Business and Ecological Thinking” [19, p 6], “Sustainable Fashion” [17, p 5], innovative design [24, pp 4-5] and socio-cultural topics [24, pp 19-20], the knowledge of sustainability and ecology for the "Design Techniques" module [27, p 5], fashion as a reflection of social processes regarding gender, culture-specific clothing characteristics, as well as ethical and ecological aspects in the internship research [23, p 80]. Additionally, one university offers a Bachelor of Arts degree in sustainable fashion with two incorporated courses: “Sustainability in the Textile Supply Chain” and “Sustainability in Marketing” [26]. Moreover, two universities have offered elective courses such as “Greenwashing, Innovative Materials, Material World Making, Strategies for Sustainable Design, and Fashion Revolution” [16], “Contemporary Textile Design” to promote an understanding of sustainable textile design, and “Green and Sustainable Logistics” [18]. Two universities also claim that sustainability is emphasized across all program subjects [16, p 24; 17, p 2].

Besides, in the B.A. program description of universities, the topics of sustainable factors and recyclability as aspects of the program [18], sustainability solutions throughout the development process from material production and dyeing techniques to product design [21], and training students based on social and ecological standards [22] are stated. Concurrently, the sustainability aspects included in the M.A. curricula are innovative materials [17, p 2-3] and the socio-cultural system of fashion and clothing [24, pp 2 and 6], while the descriptions of M.A. programs claim to deepen students’ specializations in sustainability [17], to prepare graduates to handle cultural, societal, and technical challenges and to develop innovative, business-collaborative, and environmentally sustainable solutions [25], to enhance the student's comprehension of design across economic to ecological contexts [20], and to emphasize on the principles of sustainability, ecology, economy, and their global impacts [22].

In contrast, 34 universities in Iran did neither integrate any ESD aspects in their curricula nor mention sustainability in their program descriptions [28-34], while all 13 universities in Germany either incorporated at least one aspect of ESD (e.g., ecological thinking) in their HEFD curricula or stated in their program descriptions that they follow sustainability goals. In sum, regarding the research question, the findings provide the following answer: several sustainability aspects such as topics of sustainability in the textile chain, ecology, innovation in materials, responsible fashion and activism, critical fashion, innovative design, and sustainable solutions were found in the curricula and program descriptions of HEFD in Germany which is far ahead of ESD implementation in HEFD in Iran.

4. DISCUSSION

The qualitative content analysis of the curricula and program descriptions for universities revealed that, while in Germany, sustainability aspects were mentioned in both curricula and program descriptions, in Iran there is no indication of sustainability or ESD implementation. This is particularly concerning given the high number of universities offering higher education degrees in this field in Iran. Interestingly, the program descriptions of 6 out of 13 universities in Germany included various topics such as acquiring skills to handle cultural, societal, and technical challenges, discovering environmentally sustainable solutions, and specializing in sustainability. This is the crucial aspect of the curricular analysis as it highlights the progress in integrating sustainability aspects into the curricula of HEFD in Germany, compared to the results of past research on the curricula of five universities, showing only the University of Applied Sciences Berlin integrated sustainability into its curriculum by 2019 in Germany [38]. Furthermore, elective courses on sustainability were either integrated into curricula or were offered, and even a degree in sustainable fashion has been offered. However, it is necessary to further integrate sustainability issues into all fashion subjects and increase engagement with industry businesses to adjust the curriculum and equip students with the requisite knowledge, skills, and tools [2]. Besides, accelerating ESD integration in curricula requires professional development and changes in the discipline [45], which two out of selected German universities in this paper claim involving sustainability across all program subjects.

The SLR demonstrated that research on ESD in higher education of fashion and apparel design in Germany and Iran is limited. ESD implementation in HEFD has been considered in two projects in Germany: The Fashion DIET project with an online ESD module that can be used to integrate ESD into the curriculum, and the publications of Ermer which primarily focus on HEFD. In contrast, while two papers mentioned sustainability, with one organizing ESD courses, no papers on the integration of ESD into the HEFD curricula could be found for Iran, which is in line with previous research in 2021 pointing out that no research on ESD implementation in apparel and textile design education has been conducted [44], and sustainability has yet to be considered a significant factor in Iran's fashion industry [46]. This highlights a significant research gap related to this subject in Iran and offers potential for experts in this area to explore varied sustainability topics throughout the country. Hence, the status of ESD implementation needs more research including participant observation of the classes at universities or exploring extracurricular activities to find out what is being implemented by experts in the content of courses. Comparing the two countries, Germany is far ahead of Iran but still, in both countries, there are many research gaps in ESD implementation in HEFD such as integrating the current frameworks for ESD in all subjects of the curricula or developing ESD models for fashion design education at universities.

5. CONCLUSION

This study offers an overview of the current status of ESD in HEFD and compares Germany and Iran. While there are several publications regarding the implementation of ESD in HEFD curricula in Germany, only one publication from Iran has addressed the integration of ESD in higher education for apparel and textile design. Besides, all of the German universities selected for the study include varying levels of sustainability aspects in their curricula and program descriptions, while Iranian universities have not incorporated sustainability in either the curricula or program descriptions. In sum, the comparison demonstrated that Germany has made considerable progress in integrating sustainability aspects into the fashion design programs, whereas Iran has yet to include sustainability aspects in its programs.

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6. REFERENCES

[1] RIEß, W., MARTIN, M., MISCHO, C., KOTTHOFF, H.-G. AND WALTNER, E.-M. How can education for sustainable development (ESD) be effectively implemented in teaching and learning? An analysis of educational science recommendations of methods and procedures to promote ESD goals. Sustainability, 2022, vol. 14, no. 7, p 3708.

[2] WILLIAMS, D. Transition to transformation in fashion education for sustainability. In Engaging stakeholders in education for sustainable development at university level, Edited by Leal Filho, W. and Brandli, L. World Sustainability Series, Springer, Cham, 2016, pp 217-231.
[3] SALA, K. F. The new look: transforming sustainable fashion education. Doctoral dissertation. RMIT University: Australia, RMIT Library Homepage, 2019.
[4] FLETCHER, K., AND WILLIAMS, D. Fashion education in sustainability in practice. Research Journal of Textile and Apparel, 2013, vol. 17, no. 2, pp 81-88.
[5] Statista Research Department. Retail trade in Europe - Statistics and Facts [online], updated 31.08.2023. [cited 04.09.2023]. Available on https://www.statista.com/topics/4017/retail-trade-in-europe/#topicOverview
[6] The Status of German Fashion 2021. A report by Oxford Economics [online]. Updated 19.01.2021. [cited 04.09.2023]. Available on https://www.oxfordeconomics.com/resource/the-status-of-german-fashion/
[7] NABATI, P. Iranian fashion retailers pursue growth amid sanctions [online], updated 01.08.2022. [cited 04.09.2023]. Available on https://www.businessoffashion.com/news/global-markets/iranian-fashion-retailers-pursue-growth-amid-sanctions/
[8] MCKINSEY AND GLOBAL FASHION AGENDA (GFA), Fashion on Climate. How the Fashion Industry Can Urgently Act to Reduce its Greenhouse Gas Emissions [online], 2020 [cited 04.09.2023]. Available on https://www.mckinsey.com/~/media/mckinsey/industries/retail/our%20insights/fashion%20on%20climate/fashion-on-climate-full-report.pdf
[9] UNESCO. Education for sustainable development: a roadmap. The United Nations Educational, Scientific and Cultural Organization, 2020 [online], updated 2020. [cited 04.09.2023]. Available on https://unesdoc.unesco.org/ark:/48223/pf0000374802.
[10] LEICHT, A., HEISS, J. AND BYUN, W. J. Issues and trends in education for sustainable development. United Nations Educational, Scientific and Cultural Organization. Paris, 2018.
[11] PAUL, J. AND CRIADO, A.R. The art of writing literature review: What do we know and what do we need to know?. International Business Review, 2020, vol. 29, no. 4, p 101717.
[12] MAYRING, P. Qualitative content analysis: theoretical foundation, basic procedures and software solution [online], 2014 [cited 04.09.2023]. Available on https://nbn-resolving.org/urn:nbn:de:0168-ssoar-395173
[13] HIRT, J., NORDHAUSEN, TH., APPENZELLER-HERZOG, CH. AND EWALD., H. Citation tracking for systematic literature searching: a scoping review. Research Synthesis Methods, 2023, vol. 14, no. 3, pp 563-579.
[14] BRAMER, W.M., DE JONGE, G.B., RETHLEFSEN, M.L., MAST, F. AND KLEIJNEN, J. A systematic approach to searching: an efficient and complete method to develop literature searches. Trends and Tools, 2018, vol. 106, no. 4, pp 531-541.
[15] Reutlingen University, curricula and program description of B.A. in fashion and textile design [online], updated 11.05.2023 [cited 04.09.2023]. Available on https://www.tex.reutlingen-university.de/fileadmin/user_upload/Fakultaet_TD/Modulhandbuecher_ab_WiSe22-23/FTDB_Modulhandbuch_ab_WS_2022-23_2023_05_11.pdf and [cited 04.09.2023]. Available on https://www.tex.reutlingen-university.de/de/bachelor/fashion-and-textile-design/
[16] University of Applied Sciences and Arts Hannover, curriculum and program description of B.A. in fashion design [online], [cited 04.09.2023]. Available on https://f3.hs-hannover.de/en/courses/bachelor-studiengaenge/fashion-design-bmo and https://www.hs-hannover.de/internationales/weltweit-vernetzt/internationale-projekte/international-practice-cooperation-for-global-change-i-prac

[17] University of Applied Sciences Berlin (HTW), curricula and program descriptions of B.A. and M.A. in fashion design [online], [cited 04.09.2023]. Available on https://md-bachelor.htw-berlin.de/ and https://md-master.htw-berlin.de/, updated in January 2023. Available on https://md-bachelor.htw-berlin.de/fileadmin/HTW/Zentral/Rechtsstelle/Amtliche_Mitteilungsblaetter/Modulbeschreibungen/MD_BA_AM_41_09_Module_20130225.pdf, and curricula updated in July 2021. Available on https://www.htw-berlin.de/fileadmin/HTW/Zentral/ZHV_IIIA_-_Studienberatung/Studieninfos/Modedesign_MA.pdf

[18] Niederrhein University of Applied Sciences, curriculum and program description of bachelor of fashion design engineering [online], curriculum updated in 2017 [cited 04.09.2023]. Available on https://www.hs-niederrhein.de/fileadmin/dateien/FB07/Studium/Curriculum/studienverlaufsplan/PO_2017/studienverlaufsplan_BA-DI_2017.pdf, and on https://www.hs-niederrhein.de/textil-bekleidungstechnik/studieninteressierte/ba-studiengang-design-ingenieur/

[19] Pforzheim University, curriculum and program description of B.A. in fashion design [online], curriculum updated in 2021, [cited 04.09.2023]. Available on https://www.hs-pforzheim.de/studium/im_studium/modulhandbuecher and on https://designpf.hs-pforzheim.de/ba_m/studium

[20] University of Applied Sciences Zwickau, curricula and program descriptions of B.A. and M.A. in fashion design [online], [cited 04.09.2023]. Available on https://whz-zwickau.de/english/university/faculties/applied-arts-schneeberg/

[21] Burg Giebichenstein University of Art and Design Halle, curricula and program description of B.A. in fashion design and M.A. in conceptual fashion design [online], [cited 04.09.2023]. Available on https://www.burg-halle.de/design/modedesign/mode/

[22] Art Academy Berlin-Weissensee, curricula and program description of B.A. and M.A. in fashion design [online], [cited 04.09.2023]. Available on https://kh-berlin.de/studium/fachgebiete/bama-mode-design/bama-mode-design

[23] Bielefeld University of Applied Sciences and Arts (HSBI), curricula and program description of B.A. and M.A. in fashion design [online], curricula updated in 2019, [cited 04.09.2023]. Available on https://www.hsbi.de/gestaltung/mode/studienrichtung

[24] Trier University of Applied Sciences, curricula and program description of B.A. and M.A. in fashion design [online], curricula updated in 2013, [cited 04.09.2023]. Available on https://www.hochschule-trier.de/gestaltung/studiengang-modedesign/studium-bewerbung/bewerben/bewerbung-bachelor-modedesign-1 and on https://www.hochschule-trier.de/gestaltung/studiengang-modedesign/studium-bewerbung/studienangebot/modedesign-ma

[25] Hamburg University of Applied Sciences (HAW), curricula and program description of B.A. and M.A. in fashion design [online], curricula updated in 2021 and 2022, [cited 04.09.2023]. Available on https://www.haw-hamburg.de/studium/studiengaenge-a-z/studiengaenge-detail/course/courses/show/modedesign-kostuemdesign-textildesign/ and https://www.haw-hamburg.de/en/study/degree-courses-a-z/study-courses-in-detail/course/courses/show/fashion-costume-and-textile-product-design/Interested/

[26] BSP Business & Law School, curricula and program description of B.A. in sustainable fashion [online], [cited 04.09.2023]. Available on https://www.fakultaet-creative-business.de/sustainable-fashion/

[27] University of Art Berlin (UdK), curricula and program description of B.A. and M.A. in fashion design [online], curricula updated in 2014, [cited 04.09.2023]. Available on https://www.udk-berlin.de/en/courses/design-product-design-fashion-design/

[28] Alzahra University, curricula and program description of B.A. and M.A. in apparel and textile design [online], [cited 04.09.2023]. Available on https://www.alzahra.ac.ir/page-Textile/fa/14/form/pId12232
[29] Tehran University of Art, curricula and program description of B.A. and M.A. in textile design and printing [online], [cited 04.09.2023]. Available on https://applied.art.ac.ir/fa/
[30] Semnan University, curricula and program description of B.A. and M.A. in textile design [online], [cited 04.09.2023]. Available on https://art.semnan.ac.ir/
[31] Technical and Vocational Universities, Shariati University, curricula and program description of none-continuous bachelor in Sewing and design [online], [cited 04.09.2023]. Available on https://www.shariaty.ac.ir/textile-design/fa/
[32] Azad Universities, Azad University of Science and Art Yazd, curricula and program description of B.A. and M.A. in apparel and textile design [online], [cited 04.09.2023]. Available on https://yazd.iau.ir/fa/page/59
[33] Gheirentefai Universities, University of Science and Culture, curricula and program description of B.A. and M.A. in apparel and textile design [online], [cited 04.09.2023]. Available on http://td.aa.usc.ac.ir/news/5870808703e89e31048b4592/staticpage
[34] Elmikarbordi Universities, curricula and program description of B.A. in apparel and textile design, and sewing and design [online], [cited 04.09.2023]. Available on https://www.uast.ac.ir/fa
[35] ERMER, C. Implementing sustainable thinking and acting into design- and textile education – a holistic and interdisciplinary learning model. Trends in Textile Engineering & Fashion Technology, 2018, vol. 1, no. 2, pp 47-50.
[36] SHIRAZI, F. The veiling issue in 20th century Iran in fashion and society, religion, and government. Religions, 2019, vol. 10, no. 8, p 461.
[37] ERMER, C. Modedesign neu denken. Nachhaltigkeit in einer kreativen Disziplin. Hamburg: Diplomica Verlag, 2019.
[38] ERMER, C. AND SCHWARZKOPF, J. Critical thinking in fashion design education – new learning approaches for a systemic change in the fashion industry. In Design Culture(s). Cumulus Conference Proceedings Roma: Cumulus the Global Association of Art and Design Education and Research, Edited by Di Lucchio, L., Imbesi, L., Giambattista, A. and Malakuczi, V. Rome, July, 2021, vol. 2, pp 3963 - 3979.
[39] GRUNDMEIER, A.-M. AND HÖFER, D. Sustainable fashion curriculum at textile universities in Europe – development, implementation and evaluation of a teaching module for educators. OPUS-PHFR, 2023, [cited 04.09.2023]. Available on https://phfr.bsz-bw.de/frontdoor/index/index/year/2023/docId/2213
[40] BLAGA, M., GRUNDMEIER, A.-M., HÖFER, D., KAZLACHEVA, Z., KÖKSAL, D., STRÄHLE, J. AND ZLATEV, Z. D. A new curriculum for sustainable fashion at textile universities in Europe – preliminary results of the European Project Fashion Diet. Advances in Science and Technology, Trans Tech Publications Ltd, Switzerland, July, 2022, vol. 113, pp 209-215.
[41] GRUNDMEIER, A.-M., HÖFER, D., KAZLACHEVA, Z., ZLATEV, Z., BLAGA, M., KÖKSAL, D. AND STRÄHLE, J. On the importance of fashion design within a sustainable fashion curriculum at textile universities in Europe – preliminary results of the European research project Fashion DIET. In International Conference on Technics, Technologies and Education ICTTE, at Trakia University Stara Zagora, Bulgaria, November, 2021, pp 1-11.
[42] HÖFER D., GRUNDMEIER A.-M., KÖKSAL, D., STRÄHLE, J., BLAGA, M., KAZLACHEVA, Z. AND ZLATEV, Z. D. How to implement a sustainable fashion curriculum at textile universities via e-learning – preliminary results of the European research project

Fashion DIET. In International Conference Fashioning Resurgence – Our Time is Now, International Foundation of Fashion Technology Institutes 2021(IFFTI), Pearl Academy, India, August, 2021, pp 55-60.
[43] DAVARI, R., TALEBPOOR, F., DADVAR, A. AND AFHAMI, R. Female students' awareness toward sustainable purchase consumption of clothing (Case study: Art faculty of Alzahra University). Journal of Woman in Culture Arts, 2016, vol. 8, no. 2, pp 281-300.
[44] REZVANI AHANGAR KOLAEE, H., TALEBPOUR, F. AND JAVADI, S. The impact of Teaching Sustainable Development Principles on the Design Performance of Students Studying Fashion Design. Program and Development Research, 2021, vol. 2, no. 1, pp 143-164.
[45] ARMSTRONG, C. M. AND LEHEW, M. Barriers and mechanisms for the integration of sustainability in textile and apparel education: stories from the front line. Fashion Practice, 2014, vol. 6, no.1, pp 59-85.
[46] DAVARI, R. Stating a sustainable development model for garments (Case Study: Iran) Doctoral dissertation, Alzahra University, Tehran: Iran. The library of Alzahra University, 2017.

THE EFFECTS OF STORE WINDOW DESIGN ON CLOTHING BUYING BEHAVIOR

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ABSTRACT

Store window, which is one of the prominent store atmosphere factors, is the first point where consumers and brands interact with each other. A store window, which is attractively designed and possesses a high visual quality, attracts the consumers to the store and causes them to shop from this store. In this context, this research aims to analyze the effects of store window design on clothing buying behavior. In accordance with this aim, a survey is conducted to consumers whose ages are 18 and over and who live in three biggest cities of Türkiye (İstanbul, Ankara and İzmir). According to the obtained results within the scope of research; consumers are more affected from store window designs, which has bright design, in which price information are given and which possess a theme or tell a story. Besides, they are affected from color use within the store window design and they indicate that store window design is effective on their entrance to clothing stores and on their clothing product selections.

Keywords: Store window design, store atmosphere, clothing sector, buying behavior, consumer

1. INTRODUCTION

Store atmosphere is one the significant factors, which affect the buying decisions and therefore buying behaviors. Store atmosphere, which consists of the factors like used colors, odors, music, shelves and store window, affects the consumers' perceptions and their buying decisions. At this point, store window, which is one of the prominent store atmosphere factors, is the first point where consumers and brands interact with each other. A store window, which is attractively designed and possesses a high visual quality, attracts the consumers to the store and causes them to shop from this store. Therefore, store window design becomes a significant factor for brands and retailers that operate in clothing sector in which visual design is very important. In this context, this research aims to analyze the effects of store window design on clothing buying behavior.

There are studies in the literature, which analyze the effects of store window design on buying behavior and preferences of consumers on the basis of clothing sector. These studies [1 – 5] focus on a specific brand or brand identity, a specific behavior, the importance of store window design in clothing sector and how it should be. However, this research focuses on the effects of store window design on clothing buying behavior generally without taken into consideration a specific brand or a behavior. Thus, this research alters from other studies within the literature.

2. STORE WINDOW CONCEPT AND ITS EFFECTS ON CONSUMERS' BUYING BEHAVIORS

When consumers would like to shop from retail stores, they first see the store windows [6,7]. Store windows are used for convincing consumers [7]. Researches have shown that store windows could affect the consumers' buying behaviors [6]. A store window, which possesses a beautiful presentation and high visual quality, positively affects the consumers' emotions and increases the sales. A store window helps to differentiate from rivals, attracts more consumers and increases consumers' attention to products within the store [7].

A store window is the first place, when a consumer looks just before entering a store. Store windows are used for gathering information about stores and the products that they involve. Potential customers decide whether to enter or not to a store by using store windows. Stores with store windows possess higher sales according to stores, which do not have store windows. Successful store windows aesthetically please consumers, possess a theme, use warm colors, use perspective successfully, own a good lighting and contain accessories that are related with products [8]. More creative store windows attract more consumers [6]. Besides, store windows, which demonstrate new products, increase sales [8].

First factor, which is used in store window design to attract consumers' attention, is colors. If background colors, which highlight the product, are used, the product attracts more attention. Second factor is lighting and it especially attracts attention when it is used properly. It provides an attractive, interesting and comfortable store window. Lighting of a store window positively or negatively affects the views of consumers about the demonstrated products. Third factor is the materials (auxiliary materials, accessories, mannequins etc.) that are used in a store window. Materials can increase consumers' interest towards store and products [9].

The store windows, in which mannequins are used, are found to be more aesthetic and attractive by consumers with regard to store windows without mannequins [9]. The mannequins, which are used in store windows, help consumers to estimate the fit of product on their own body [7]. A store window with a composition / story / theme attracts more attention from consumers [9]. Besides, large store windows attract more attention with regard to narrow store windows [6,8]. Briefly, clothed mannequins, a proper lighting and product-centered designs are used and the important features of products are emphasized by use of proper light and colors in order to create attractive store windows [5,10].

3. METHOD OF THE RESEARCH

In accordance with this aim, a survey is conducted to consumers whose ages are 18 and over and who live in three biggest cities of Türkiye (İstanbul, Ankara and İzmir). Consumers whose ages are 18 and over are incorporated in the research because the age of legal majority is 18 in Türkiye. Besides, İstanbul, Ankara and İzmir provinces are selected because they can represent the country-wide due to their cosmopolite structures and population densities.

According to data of Turkish Statistical Institute [11], Türkiye's population is 84.680.273 by 31.12.2021. The number of individuals, whose ages are 18 and over, is 61.941.973. Sample size is calculated as 384 at 95% confidence interval with 5% error margin. The individuals, who constitute the sample, are determined according to simple random sampling.

The surveys are carried out between February 2023 and May 2023. Online survey technique is used. Survey form consists of 9 main and 32 sub-questions. Ege University's Ethical Board of Social and Human Sciences Scientific Research and Publication has ethically approved the survey in 26.10.2022 with 1643 protocol number. 433 survey forms are incorporated in the research. The obtained findings are analyzed by using SPSS program.

4. ANALYSIS OF THE RESEARCH FINDINGS

The questionnaire's reliability is calculated and the reliability co-efficient α is found as 0,962. According to this, the scale of the questionnaire is found to be highly reliable. Besides, the participants are found that they are generally well-educated young consumers who possess low or middle-low incomes (Table 1). 79% of the participants separate 20% or less from their monthly budgets for clothing expense. In addition to these, the clothing brands, which are mostly bought by participants, can be respectively listed as; LC Waikiki, Zara, Mavi, Koton and DeFacto. However, the participants indicate that they mostly like the store window designs of Zara, Mavi, Koton, DeFacto, Beymen and LC Waikiki, respectively.

Table 1. Distribution of participants according to their demographic properties

Demographic Properties		Frequency	Valid Percent
Age	18-25	83	19,2
	26-33	152	35,1
	34-41	69	15,9
	42-49	63	14,5
	50 and over	66	15,2
Gender	Women	219	50,6
	Men	214	49,4
Education status	Primary school	23	5,3
	Secondary school	23	5,3
	High school	70	16,2
	University	253	58,4
	Postgraduate	64	14,8
Monthly income	525 $ and below	129	29,8
	526-1055 $	187	43,2
	1056-1600 $	62	14,3
	1601-2105 $	30	6,9
	2106 $ and over	25	5,8

The survey includes 24 statements, which analyze the effects of store window design on clothing buying behaviors and the participants are asked to select their agreement levels for each of these statements. In quinary likert scale I certainly agree was coded as 5, I agree as 4, I have no idea or I'm on the fence as 3, I don't agree as 2 and I certainly don't agree as 1. According to the obtained research results, consumers are mostly affected from the store window designs in which the prices of products are given (Table 2). Besides, they indicate that store window design is effective on their entrance to clothing stores and on their clothing product selections. In addition to these, the bright store window design is another important factor that affects the clothing buying behavior of consumers. Also, the consumers absolutely enter the clothing stores, which they like their store window designs. They can follow fashion and trends via store window designs and they are affected from the colors that are used in store window designs. Besides, they are more affected from store window designs, which possess a theme or tell a story.

Table 2. The descriptive statistics of the statements and the results of the exploratory factor analysis

Factors	Statements	Rotated Loadings	Average	Standard Deviation	Averages of the Factors
Store window properties of clothing stores	I am more affected from bright store window designs while I am buying clothes.	0,809	3,68	1,169	3,39
	I am more affected from large and wide store windows while I am buying clothes.	0,782	3,41	1,244	
	I am more affected from store window designs, in which products come into prominence, while I am buying clothes.	0,748	3,48	1,204	
	I am more affected from store window designs, which possess a theme/story, while I am buying clothes.	0,726	3,54	1,234	
	I am affected from decoration materials (accessories, furniture, mirror, flower etc.) within store windows while I am buying clothes.	0,715	3,34	1,303	
	I am affected from colors that are used in store window designs while I am buying clothes.	0,687	3,55	1,172	
	I am more affected from store window designs, in which product prices are given, while I am buying clothes.	0,664	3,76	1,130	
	I am more affected from store window designs, in which brand logo and symbols are used, while I am buying clothes.	0,610	3,12	1,238	
	I am more affected from store window designs, in which products come into prominence, while I am buying clothes.	0,587	3,11	1,324	
	I am more affected from store window designs, which include many different products, while I am buying clothes.	0,583	3,26	1,250	
	I am more affected from intense/full store window designs while I am buying clothes.	0,574	3,07	1,254	
The effects of store window design on clothing store entrances and clothing product buying	I definitely enter to a clothing store that I like its store window design.	0,796	3,64	1,200	3,57
	I frequently visit the clothing stores that I like their store window designs.	0,768	3,52	1,258	
	Store window design is effective on my entrance to a clothing store.	0,764	3,75	1,134	
	I enter to a clothing store if I like its store window design; even if I do not want buy a product.	0,739	3,36	1,330	
	Store window designs of clothing stores affect my clothing products choices.	0,705	3,70	1,114	
	I can follow fashion and trends via store window designs of clothing stores.	0,686	3,59	1,187	
	I am affected from store window designs while I am buying clothes.	0,580	3,40	1,236	
The effects of store window design on clothing shopping habits	I buy clothes from a clothing store if I like its store window design; even if I do not need clothes.	0,790	2,39	1,295	2,77
	I but clothes without examining in detail, if I see and like them in a store window.	0,777	2,58	1,330	
	I frequently shop from clothing stores, which frequently change their store window designs.	0,724	2,79	1,315	
	I frequently visit clothing stores, which frequently change their store window designs.	0,645	2,95	1,318	
	I usually buy clothes from stores, whose store windows designs are liked by me.	0,569	3,04	1,314	
	I visit shopping malls in order to see store window designs of clothing stores.	0,484	2,85	1,304	

On the other hand, most of the participants indicate that they are affected from store window designs, in which products come into prominence. Moreover, they are affected from large and wide store windows and decoration materials (accessories, furniture, mirror, flower etc.) that are used in store window design. In addition to these, consumers are affected from store window designs, which include many different clothing products. Also, they enter to a clothing store if they like its store window design; even if they do not want buy a product.

The statements, which analyze the effects of store window design on clothing buying behaviors, are gathered into three groups by using exploratory factor analysis. Exploratory factor analysis is actualized in order to obtain brief statements instead of 24 statements. It was found that the sample is suitable and reliable for factor analysis (Kaiser-Meyer-Olkin measure of sampling is equal to 0,957 and the significance of Bartlett's Test of Sphericity is equal to 0,000). Principal components extraction was used for extracting factors with eigenvalues over 1 and the rotation of factor loading matrix was chosen as varimax. The cumulative variance of three factors is equal to 67,5% (Table 2). The loadings (scores) of the statements within Table 2 are taken from rotated component matrix (only one loading is lower than 0,50 and it is equal to 0,484). The obtained three factors are renamed (Table 2). Afterwards, following hypotheses are suggested:

H_1: The effects of store window design on clothing buying behaviors alter according to women and men consumers.
H_2: The effects of store window design on clothing buying behaviors alter according to consumers' education levels.
H_3: The effects of store window design on clothing buying behaviors alter according to consumers' ages.
H_4: The effects of store window design on clothing buying behaviors alter according to consumers' monthly incomes.

Four main hypotheses involve 12 sub-hypotheses due to the 3 factors and 4 demographic features. All sub-hypotheses were tested at 95% confidence interval. According to the obtained results, 5 sub-hypotheses are accepted, whereas 7 sub-hypotheses are rejected.

Table 3. Differences between the effects of store window design on clothing buying behaviors of women and men consumers

Hypothesis 1a: The effects of store window design on clothing store entrances and clothing product buying differ according to women and men consumers.						
Gender	N	Average	Standard Deviation	t	df	p
Women	219	0,1495677	0,98470383	3,182	431	0,002
Men	214	-0,1530623	0,99459898			
Hypothesis 1b: The effects of store window design on clothing shopping habits differ according to women and men consumers.						
Gender	N	Average	Standard Deviation	t	df	p
Women	219	-0,1701703	1,02006703	-3,632	431	0,000
Men	214	0,1741462	0,95024397			

Table 4. Differences between the effects of store window design on clothing buying behaviors of consumers at different education levels

Hypothesis 2a: The effects of store window design on clothing store entrances and clothing product buying differ according to consumers at different education levels.						
Education Level	N	Average	Standard Deviation	t	df	p
High school or below	116	-0,2646248	1,05129654	-3,371	431	0,001
University or above	317	0,0968343	0,96423983			

Table 5. Differences between the effects of store window design on clothing buying behaviors of consumers at different ages

Hypothesis 3a: The effects of store window design on clothing shopping habits differ according to consumers' ages.						
Age	N	Average	Standard Deviation	t	df	p
41 or less	304	-0,0785159	0,98990339	-2,524	431	0,012
42 or more	129	0,1850297	1,00310898			

Table 6. Differences between the effects of store window design on clothing buying behaviors of consumers at different income groups

Hypothesis 4a: The effects of store window design on clothing shopping habits differ according to consumers' monthly incomes.						
Monthly Income	N	Average	Standard Deviation	t	df	p
1600 $ or less	378	0,0419439	1,00863883	2,299	431	0,022
1601 $ or more	55	-0,2882691	0,89466242			

Performed hypotheses tests indicate that the store window properties of clothing stores do not alter on the basis of gender, age, education level and income level. However, the effects of store window design on clothing store entrances and clothing product buying are much higher on women consumers and on consumers, who possess an education level of university or more (Table 3 and Table 4). Besides, the effects of store window design on clothing shopping habits are much higher on men consumers, on consumers, who are aged 42 or more and on consumers, who possess 1600 dollar monthly income or less (Table 3, Table 5 and Table 6).

5. RESULTS AND GENERAL EVALUATION

The important research results and the suggestions that can be made on the basis of these results can be summarized as followed:

1. According to the obtained research results, consumers mostly affected from store window designs, in which product prices are given. Therefore, clothing enterprises and brands should explicitly exhibit the product prices in a readable way.
2. Consumers indicate that store window design is effective on their entrance to clothing stores and their clothing product choices. At this point, clothing enterprises and brands should give the necessary importance to their store window designs and design attractive store windows.
3. Consumers are more affected from store window designs, which are bright and which possess a theme/story. Besides, colors, which are used at the design process of store windows, also affect the clothing buying behaviors. Therefore, clothing enterprises and brands should design bright and colored store windows, which possess a theme/story.

4. Consumers definitely enter to clothing stores that they liked their store window designs and also they frequently visit the clothing stores that they liked their store window designs. At this point, clothing enterprises and brands should give great importance to their store window designs and design interesting store windows.
5. Consumers indicate that they can follow fashion and trends via store windows. Therefore, clothing enterprises and brands should design window stores, which reflect the current fashion and trends.
6. Consumers indicate that they are affected from store window designs, in which products come into prominence. Moreover, they are affected from large and wide store windows and decoration materials that are used in store window design. In addition to these, consumers are affected from store window designs, which include many different clothing products. At this point, clothing enterprises and brands should design large and wide window stores, in which products come into prominence, and in which different decoration materials are used and many different clothing products are exhibited.
7. The effects of store window design on clothing store entrances and clothing product buying are much higher on women consumers and on consumers, who possess an education level of university or more. Therefore, clothing enterprises and brands, especially whose target groups consist of women and well-educated consumers, should give more importance to store window design.
8. Besides, the effects of store window design on clothing shopping habits are much higher on men consumers, on consumers, who are aged 42 or more and on consumers, who possess 1600-dollar monthly income or less. At this point, the clothing enterprises and brands, especially whose target groups consist of men, consumers at middle age or over and consumers possess low and middle-low incomes, should give great significance to store window design.

6. REFERENCES

[1] ZHOU, L., 2015, Research on the window display design on the modern brand clothing, Proceedings of the 2015 International Conference on Economics, Social Science, Arts, Education and Management Engineering, 38:441-446
[2] CHENG, S.Y. AND LIANG, J.F., 2014, Analysis on the influence of clothing window display to consumer behavior, Textile Bioengineering and Informatics Symposium Proceedings, 1-2:495:502
[3] OH, H. AND PETRIE, J., 2012, How do storefront window displays influence entering decisions of clothing stores?, Journal of Retailing and Consumer Services, 19:27-35
[4] SUN, M.Q. AND MA, D.L., 2010, Signifying interpretation of clothing window display design, Proceedings of the 2010 International Conference on Information Technology and Scientific Management, 1-2:196-198
[5] SOMOON, K. AND SAHACHAISAEREE, N., 2010, Factors determining window display conveying merchandise’s positioning and style: a case of shopping mall clothing display targeting undergraduate students, Procedia Social and Behavioral Sciences, 5:1236-1240
[6] LANGE, F., ROSENGREN, S. AND BLOM, A., 2016, Store-window creativity’s impact on shopper behavior, Journal of Business Research, 69:1014-1021
[7] ABIDIN, N.A.Z.Z. AND AZIZ, A.A., 2012, Window display compositions: its influences on youths in Malaysia, Procedia Social and Behavioral Sciences, 38:355-361
[8] MOWER, J.M., KIM, M. AND CHILDS, M.L., 2012, Exterior atmospherics and consumer behavior: influence on landscaping and window display, Journal of Fashion Marketing and Management, 16(4):442-453
[9] KERNSOM, T. AND SAHACHAISAEREE, N., 2010, Determinant of design elements and compositional settings of window display on the corporate strategic merchandising of large scale

department store: a case of central world department store, Procedia Social and Behavioral Sciences, 5:1351-1356
[10] SOMOON, K. AND SAHACHAISAEREE, N., 2012, Design elements and users' perceptual response: a case of window display design for adolescent merchandising, Procedia Social and Behavioral Sciences, 50:685-690
[11] Turkish Statistical Institute, Address Based Population Registration Statistics 2021, Population by Province, Single Age and Gender, Available on https://data.tuik.gov.tr/Kategori/GetKategori?p=Nufus-ve-Demografi-109 (Date of access: September 2022)

SUSTAINABLE FASHION: A HISTORICAL REVIEW

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ABSTRACT

The history of sustainable Fashion traces the evolution of an industry that has undergone significant transformations in response to growing environmental and social concerns. This paper provides an overview of the key milestones and developments in sustainable Fashion, highlighting the motivations, challenges, and achievements that have shaped its trajectory, clarifying the phases of Sustainable Fashion development by dividing them into clearly defined periods.

Key Words: Sustainability trend, sustainable fashion, fashion, eco-design, textile industry

1. INTRODUCTION

Sustainability has become ingrained within all creative industry sectors today, including textiles. Sustainable Fashion represents a growing design philosophy and a prevailing trend with a mission to diminish the carbon footprint of the world's second-largest economy. This sustainability movement seeks to establish fresh frameworks and mechanisms for the ever-expanding textile and fashion sector. With roots extending back several decades, this movement engages significant entities of the fashion world through its well-structured platforms. Consequently, the global industry now directs heightened attention toward sustainability in textile and fashion design. This shift toward environmentally conscious production of textiles and garments is growing in intensity, spurred by the increasingly evident signs of climate change. Notably, the environmentally-conscious Y and Alpha generations display rising interest in ecologically produced textile and apparel items. After approximately three decades of dedicated efforts, the global textile and fashion industry has successfully pursued its objective of operating within a sustainable, ethical, and transparent framework. This article researches the history of this revolution.

2. METHODOLOGY: OVERVIEW OF THE KEY EVENTS AND DEVELOPMENTS IN THE HISTORY OF SUSTAINABLE FASHION

The history of sustainable Fashion can be traced back to various movements and milestones that have shaped the industry's environmental and social responsibility approach. This research's methodology is based on summarising and reviewing the Author's previous articles and complementing them with new information gained from renewed authors' available sources and some prominent literature. The goal was to clarify the phases of Sustainable Fashion development by dividing them into clear periods. The overview of the key events and developments in the history of sustainable Fashion can be divided into four phases:

- Early Awareness
- Emergence of Environmental Concerns
- Ethical Fashion Movement
- Mainstreaming Sustainable Fashion.

2.1 Early Awareness (19th-20th Century)

The Industrial Revolution and the rise of mass production and mechanisation in the 19th Century led to increased environmental and social impacts on the textile industry. The nineteenth-century European landscape witnessed a profound shift in textile production and consumption, primarily propelled by the monumental influence of the Industrial Revolution. The pivotal role of textile industries in shaping the evolution of the factory system cannot be emphasised enough. Numerous ground-breaking inventions from this era found direct or indirect applications within the textile sector, solidifying its central position in the transformative processes of the time. In 1801, Joseph Marie Jacquard, a pioneering inventor from France (1752–1834), revolutionised the production of intricate woven textiles by introducing a ground-breaking mechanical system. Advances brought about by the Industrial Revolution paved the way for greater production of goods that exceeded consumer demand. This shift meant conspicuous consumption was no longer confined solely to the upper classes. The impact of the International Exhibitions was also significant, fuelling the competition between French and English textile manufacturers, while design quality has suffered from concept to mass production. This trend was one of the reasons for the development of the Art and Craft Movement (a movement which spanned the transition from the Nineteenth Century to the twentieth), one of whose leading figures was William Morris. (Watt, 2004) At the same time, labour rights movements, such as early unions, emerged to address issues such as poor working conditions and low wages in the textile and garment industry.

2.2 Emergence of Environmental Concerns (1960s-1980s)

The growing awareness of environmental issues in the 1960s and 1970s laid the sustainable fashion movement's first environmental movements and foundation. The initial recycling ideas emerged in the 1960s, coinciding with the era of the hippies. However, the specific objectives associated with this movement, as we recognise them today, were still being defined. (Fig 1)

Figure 1. Fashion of the Hippie Era

2.3 The Ethical Fashion Movement (1990s-2000s)

Visionary designers laid down the foundations of sustainable Fashion in the early 1990s as the movement to address environmental concerns arising from the expanding fashion industry and the use of eco-friendly materials began to regain momentum. The notable designers of the movement were Belgian designer Martin Margiela and Italian designers Franco Moschino and Giorgio Armani. The Slow Fashion Concept, the idea of slowing down consumption and promoting quality over quantity, gained traction in response to the fast fashion culture. (Csanák, 2014) In 1990, the March edition of Vogue highlighted the new environmental trend in Fashion. Its Author, Carol Leggett, emphasises, *"As the ecological movement gathers force, designers are finding that fashion can be environmentally responsible."* (Leggett, 1990) In the same year, the initial article addressing this subject, *"The Environmental Movement in the Fashion Industry,"* debuted in The New York Times, authored by Woody Hochswender. (Hochswender, 1990.) (Fig 2)

Figure 2. (Left to right) Manifest of Martin Margiela, a campaign of Franco Moschino, a screenshot of the runway of Giorgio Armani SS95 collection, and an image from the 1990 issue of the Vogue

In this period, the first fair trade initiatives arose: fair trade organisations began to address labour rights and social justice issues by promoting fair wages and better working conditions for garment workers. At the same period, demand for organic cotton and other eco-friendly fibres increased, driven by concerns about pesticide use and the environmental impact of synthetic fibres. In 2001, designer Stella McCartney introduced her independent fashion label, renowned for its animal-friendly design ethos. 2004, Rogan Gregory and Scott Hahn established the Loomstate brand and unveiled their inaugural line of organic designer products. Their brand's mission is to foster interest in certified organic cotton through socially and environmentally responsible production techniques, crafting eco-conscious clothing collections.

In the same year, the Author of this article introduced her inaugural sustainable private-label Spring-Summer '05 collection, named *"All My Eye! by edita Q'ray."* This collection, featuring organic denim and flax materials, earned recognition as a finalist for the 2005 Industrial Design Award, and it was showcased at the Museum of Applied Arts in Budapest in 2005. (Fig 3)

Figure 3. Edit Csanák (2004): *"All my eye! by edit a Q'ray"* SS05 - Industrial Design Award finalist, 2005

Around 2007, the fashion market underwent a significant transformation, embracing sustainability as a fundamental principle. Despite some experts expressing scepticism about whether environmentalism could instigate substantial shifts in style and dismissing it as a mere "one-season trend," it rapidly gained global traction. The inaugural green fashion weeks came to fruition, with esteemed designers like Versace, Calvin Klein, and Yves Saint Laurent incorporating eco-conscious fashion trends into their collections. Robert Sullivan's article, featured in the May 2007 issue of Vogue, also delved into the realm of sustainable fashion topics. *"We are getting the message: The eco-friendly trend is good for the planet. But, (...) there is much more to this conscientious clothing movement."* (Sullivan, 2007.) The new trend, the eco-phenomenon, has been characterised as not a short-term trend and can last for several seasons. In 2007, the Earth Pledge Foundation released a comprehensive collection of essays addressing the fashion industry's sustainability, featuring contributions from various authors. This ground-breaking publication marked the inaugural book on the subject, offering valuable insights that elucidated the progression toward a more sustainable fashion industry. (Earth Pledge Foundation, 2008.) (Fig 4)

Figure 4. (Left and middle) Article of Robert Sullivan in the May 2007 issue of Vogue; (right) Book cover of the Future Fashion White Papers of the Earth Pledge Foundation

It's crucial to emphasise the profound shift in the fashion industry around 2007 when it encountered a game-changing phenomenon: Fast Fashion, significantly bolstered by the rapid growth of e-commerce. While there were inklings of this trend, its immense impact on the fashion world was difficult to anticipate. Some experts foresaw that this new market channel would bring a seismic transformation in the industry. The first comprehensive article on sustainability in this context had been published just a year earlier, featuring contributions from multiple authors. (Csanák, 2014)

2.4 Mainstreaming Sustainable Fashion (2010s to present)

The period from the 2010s was an era of collaboration and awareness: various stakeholders, including fashion brands, NGOs, and consumers, began working together to raise awareness and promote sustainable practices. (Black, Eco-chic: The Fashion Paradox, 2008.) (Black, The Sustainable Fashion Handbook, 2013.)

Fast Fashion catalysed consolidating the sustainability trend, sparking a surge in the number of movements, a proliferation of their participants, and forming various associations. Table 1 provides an overview of key players in the global sustainable fashion landscape. These organisations have significantly promoted fashion sustainability by facilitating online courses, hosting panel discussions, conducting webinars, organising fashion expos, and training emerging fashion brands. The pivotal year of 2013 united the revolutionary forces within the movement in response to the Rana Plaza disaster in Bangladesh. Subsequently, in 2014, the organisation known as Fashion Revolution was established, emerging as a central entity in the Sustainable Fashion movement.

Table 1. Organisations of Sustainable Fashion with the year and location of their establishment

Year of Establishment	Name of the Organisation	Country
1987	EPEA (Environmental Protection Encouragement Agency)	Germany
1989	Clean Clothing Campaign	Bangladesh
1995	Verite	France
1996	Textile Environment Design (TED)	United Kingdom
1998	Ethical Trading Initiative	United Kingdom
2002	Ethical Trading Organisation	United Kingdom
2006	Ethical Fashion Forum	United Kingdom
2007	Fashion Takes Action	Canada
2008	National Association of Sustainable Fashion Designers (SFD)	United States
2009	Eco-Age	United Kingdom
2009	Sustainable Apparel Coalition	United States
2014	Fashion Revolution	United Kingdom
2016	Mistra Future Fashion	Sweden
2016	Eco Team of the National Fashion League	Hungary

The interplay of environmental and ethical concerns arising from the moral and economic challenges within the fashion industry gave rise to a distinct sector within the fashion market, commonly referred to as the eco-design textile and fashion products segment. Around the 2010s, a new market segment was born: Sustainable Fashion. This transformation brought about new employment opportunities, shifts in power dynamics, and evolving interests within the industry. Designers focused on sustainable and ethical practices gained recognition and brought the issue to the forefront of the fashion industry. Concurrently, conceptual education modules and specialised training programs emerged, leading to the establishment of sustainable fashion education as a relatively recent discipline.

The Sustainable Circular Economy (SCE) approach gained popularity, emphasising resource efficiency, recycling, and minimising waste in the fashion supply chain. The call for transparency, supply chain traceability and ethical sourcing led to increased examination of supply chains and the introduction of certifications and standards to verify sustainable practices. Advancements in technology and innovation, smart textiles and new materials, such as recycled fabrics, bio-based materials, and 3D printing, have contributed to the growth of sustainable Fashion.

3. RESULTS AND DISCUSSION

As the 21st Century progressed, sustainable Fashion gained momentum through various initiatives. Establishing certification systems and standards, such as Global Organic Textile Standard (GOTS) and Fairtrade, helped consumers identify and support sustainable products. Collaborations between fashion brands, NGOs, and governmental bodies further bolstered sustainable practices, promoting responsible sourcing, reducing carbon footprint, and supporting worker welfare. Technological advancements have been pivotal in fostering sustainability within the fashion industry in recent years. Innovations like 3D printing, upcycling, and digital design tools have opened new avenues for creative expression while minimising waste and reducing reliance on virgin resources. Furthermore, the rise of digital platforms has facilitated the movement's growth, making sustainable Fashion more accessible to a broader audience. (Cline, 2013.) As stakeholders continue to collaborate, innovate, and educate, sustainable Fashion has the potential to transform the entire industry, promoting a future where style and ethics go hand in hand (Minney, 2016).

4. CONCLUSION

Hence, sustainable Fashion is commonly mentioned as a trend that emerged due to the fast fashion industry's detrimental environmental and social impacts; it has deeper roots. It is essential to highlight that sustainable Fashion is still an ongoing movement, and its history continues evolving as new challenges and solutions emerge. Scaling up sustainable practices, overcoming supply chain complexities, and changing consumer mindsets remain ongoing obstacles. Looking ahead, the history of sustainable Fashion serves as a testament to the power of collective action and innovation in addressing the environmental and social impacts of the fashion industry. The article attempted to present and explore this history.

5. REFERENCES

[1] M. WATT, "Nineteenth-Century European Textile Production." In Heilbrunn Timeline of Art History. New York: The Metropolitan Museum of Art, 2000," October 2004. [Online]. Available: http://www.metmuseum.org/toah/hd/txtn/hd_txtn.htm. [Accessed 13. September 2023.].

[2] E. CSANÁK, "ECO-FRIENDLY CONCEPTS AND ETHICAL MOVEMENTS IN THE FASHION INDUSTRY," in *University of Zagreb*, Zagreb, 2014.

[3] C. LEGGETT, "Natural Selection," 1990.

[4] W. HOCHSWENDER, "The Green Movement in the Fashion World," *The New York Times,* p. 1., 25. March 1990.

[5] R. SULLIVAN, "Sustainable Style-Eco-ethical Chic: Earth to Fashion," *Vogue,* May 2007.

[6] Earth Pledge Foundation, Future Fashion White Papers, New York: Earth Pledge Foundation, 2008.

[7] S. BLACK, Eco-chic: The Fashion Paradox, London: Black Dog Press, 2008.

[8] S. BLACK, The Sustainable Fashion Handbook, New York: Thames & Hudson, 2013.

[9] E. L. CLINE, Overdressed: The Shockingly High Cost of Cheap Fashion, New York: Portfolio, 2013.

[10] S. MINNEY, Slow Fashion: Aesthetics Meets Ethics, New Internationalist, 2016.

ADVANCED DIGITAL TECHNOLOGIES IN FASHION DESIGN

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ABSTRACT

Innovative ideas emerging from global challenges have contributed to reshaping societies with new systems. With the progression of technology, these systems have transitioned into a digitized structure, enhancing the overall quality of human life. Having said that, this study aims to elucidate how the collaboration between fashion design education and the textile industry can shape fashion innovation and sustainability, and contribute to digital transformation. It presents a future scenario that sheds light on the contributions of digital transformation to fashion design students and professionals, unveiling the potential it holds. In that respect, the fashion design students created their digital designs using tools such as CLO3D and Blender in an attempt to explore the intersection of fashion education and industry applications from a professional perspective and culminate in a digital fashion show demonstrating the combined digital skills fueled by imagination. Not only does this study ensure continuity in the remote learning process, but it also highlights the impact of seamless digital integration in response to evolving industry demands through collaborative efforts.

Key Words: Digital fashion, virtual fashion, CAD, 3D fashion, CLO3D, blender, digitalization, sustainability

1. INTRODUCTION

Innovations that shape and advance societies have brought forth new thought systems. With the progression of technology, these thought systems have transitioned into a digitized structure, enhancing the overall quality of human life. Notably, amid the global challenges posed by the COVID-19 pandemic, this digital transformation emerged as an effective coping strategy and rapidly catalyzed various sectors, most notably the fashion industry. The pandemic-induced restrictions on physical interactions have necessitated innovative educational solutions, especially in fashion and textile design departments [1], [2]. These constraints have directed the globally recognized fashion industry towards embracing sustainable principles and consequently led to the emergence of new concepts such as virtual stores, computer-aided software, interactive three-dimensional fashion exhibitions, and the Metaverse [3]. The developments, on the other hand, have triggered the exploration of digital tools and increased collaborations between academic institutions and industry partners. Factors such as sustainability, advancing technology, consumer expectations, and environmental awareness have prompted progressive brands to embrace digitalization within the fashion industry. One can witness the initial instances of this initiative in the collection released by the world-renowned fashion brand Balenciaga in December 2020. The brand launched its Autumn 2021 collection, titled 'Afterworld: The Age of Tomorrow,' by transforming realistic avatars into a gaming format. This collection, which brought together virtual reality, fashion, and gaming worlds, offered viewers a new-generation fashion show experience [4]. This innovative and eco-friendly step into the fashion world signifies a rapid transformation of the future of fashion, emphasizing sustainability.

Regarding the discussion above, in the project under discussion, fashion design students ' collections were digitally brought to life through computer-aided design programs, namely CLO3D and Blender. By doing so, it was demonstrated that unique digital fashion collections and catwalk shows can be realized by getting the most benefit of the amalgamation of technology and fashion education, and that the digital resources, with the help of the university and industry collaboration, can be efficiently employed for digital transformation in the industry. As is well known, balancing technological advancement while preserving artistic essence is a crucial step in maintaining the identity of fashion. Achieving this balance is essential in seamlessly combining fashion's creativity with digital transformation. The study also suggested that the fusion of traditional design aesthetics with contemporary digital solutions has opened up new possibilities for reshaping the future of fashion in an environment where technology and sustainability converge.

As a final word, the study under discussion did suggest that digital showcases can be an additional option to reduce the carbon footprint of fashion companies. The comparative study between the previous years ’fashion show activities with the effort invested in the current digital fashion show pointed at positive impact in terms of various parameters such as transportation, production, material sourcing, electricity consumption, and organization.

2. EXPERIMENTAL

The foundation of this study encompasses the process of creating a digital fashion collection that reflects the symbiotic relationship between traditional design and digitization. The adopted methodology involves collaboration among students, academic institutions, and industry partners through computer-aided design software.

2.1 Design Process

The process commenced with students presenting their clothing designs and mood boards, marking the inception of their creative journey. Students who defined their themes produced two design sketches. These designs were subsequently transformed into tangible patterns using computer-aided design software, constituting the foundation of the digital collection. A versatile three-dimensional digital fashion design software, CLO3D, was employed to meticulously position garment patterns on virtual models and carry out the tailoring process. This facilitated a visualization within the designs, bridging the tactile realm of traditional design with the virtual world of digitization. Following this stage, digital representations of the fabrics chosen by students to align with their themes were assigned to the garments. Subsequently, colors, patterns, and accessories that complemented the themes were incorporated to establish the holistic aesthetic of the design. This stage is illustrated in Figure 1.

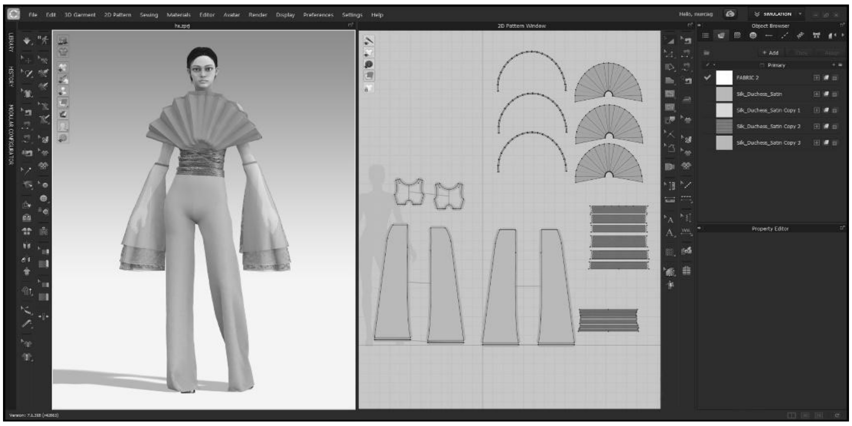

Figure 1. Pattern and model application in the CLO3D program

2.2 Digital Fashion Show

In order to imbue the designed avatars with vitality and realism, a set of poses and movements were defined within the program. During the showcase phase, collaboration was established with a 3D designer to further enhance students' designs and create a professional presentation. This original three-dimensional modeling and animation process was successfully executed through the use of the software Blender. To achieve the best results from the runway show, the models carrying the digital garments were placed in three-dimensional environments designed to match the concept, integrated with lighting and sound elements. The resulting models were skillfully combined with video editing and graphic design techniques to complete the project. An exemplary image from the prepared video work is shown in Figure 2.

Figure 2. Captured image from digital fashion show video

This process not only enriched the students' learning experiences but also strengthened the connection between theoretical education and practical application, emphasizing the potential of digital tools in contemporary fashion design.

3. RESULTS AND DISCUSSION

The digital fashion show has presented a series of outcomes demonstrating its potential to reshape sustainability in fashion education and industry practices. Students have created designs that combine traditional aesthetics with digital dynamism through programs such as CLO3D and Blender. In this context, this study anticipates that students will be equipped with skills; furthermore, they will gain innovative advantages in their careers after graduation.

The fashion industry, known for its artistic expression and cultural impact, has raised environmental concerns due to its intensive use of resources and carbon emissions in physical fashion shows. In this sense, shifting towards virtual exhibitions and digital platforms reflects a proactive approach to sustainability. This digital leap offers a responsible alternative to mitigate the environmental damage caused by traditional fashion events, effectively reducing the time, cost, and workload involved [2]. According to a report by Ordre, travel by fashion buyers and designers to major fashion weeks in cities like Paris, Milan, London, and New York results in the emission of 241,000 tons of carbon annually [5]. Transitioning to digital fashion events not only transcends geographical boundaries but also minimizes the carbon footprint. Digital fashion events not only serve to mitigate emissions arising from transportation but also have the potential to reduce emissions stemming from the transportation of raw materials and products, production processes, and catering services provided to participants in physical events. In our study, we present a carbon footprint equivalent calculation by delineating emission sources [URL 1-6] and comparing two scenarios occurring in physical and digital contexts. For these calculations, the figures related to ITU Fashion Show 2019 such as the number of attendees (500) and of designs (40) as well as the emissions resulting from transportation and catering services approximated on a per-person basis were taken into account. During the digital fashion showcases, 26 looks designed by 13 students were showcased at the launching event attended by 45 individuals. As shown in Table 1, the emissions stemming from transportation, catering services, and clothing production during the physical event amounted to 1,323.6 kgCO2e, while those in the digital showcase, including electricity consumption from blender and rendering, transportation, and catering services, were calculated to be 254.16 kgCO2e. It is evident that the emissions generated in the digital showcase have decreased by approximately 81% compared to the physical show. Based on these findings, it can be concluded that the digital showcase has significantly reduced emission values, equivalent to the carbon sequestration capacity of 18 trees over 10 years, resulting in a reduction of 1,069.45 kgCO2e in emissions.

Table 1. The emission values resulting from the comparison of digital and physical fashion shows

Emission Source	Physical Fashion Show	Digital Fashion Show
Event and Meeting Transportation	152,7 kgCO2e	20,18 kgCO2e
Catering Service	1.128,9 kgCO2e	80,63 kgCO2e
Designed Garments	42 kgCO2e	0
Blender and Render Electricity Consumption	X	153,34 kgCO2e
Total	1.323,6 kgCO2e	254,15 kgCO2e

The collaboration at hand presents a mutual dynamic for us: the adaptation of the academic world to industrial needs and the inspiration drawn by industry from fresh academic perspectives. The creative skills and digital competencies acquired as a result of this collaborative effort prepare graduates for a rapidly evolving professional landscape. However, as this digital evolution unfolds, preserving the artistic spirit of fashion becomes imperative. Balancing technological progress with the artistry of industry plays a significant role in defining the identity of the field. Achieving this equilibrium within a digital transformation will serve as a testament to the enduring essence of this transformation.

In summary, this collaboration highlights how digitalization and sustainability intertwine within the narrative of fashion. It offers us a path where innovation, responsibility, and creativity converge, shaping the future while embracing the potential of technology, all while respecting the heritage of the past.

4. CONCLUSION

The collaboration between the academic world and the industry has yielded outcomes that illuminate the process of reshaping fashion education and industry practices through digitization and sustainability. The combination of powerful digital tools such as CLO3D and Blender has enabled fashion design students to transcend traditional boundaries and create a digital fashion show. Through this fashion show, students have become prepared to work in contemporary professional life with technological finesse while also embodying a sustainable and creative approach. The prepared digital fashion showcase redefines fashion presentation, serving as a symbol of sensitivity to the fashion industry. The adoption of virtual exhibitions is of vital importance as it demonstrates compatibility with sustainability and innovation, contributing to the reduction of consumption habits and carbon footprint.

In summary, the findings of the study emphasize the vital role of sustainability, innovation, responsibility, and artistic originality in shaping the future of the textile and fashion context. It furthermore shows that it could be possible to reduce environmental negative impacts of fashion industry by integrating human creativity and digital innovation while maintaining aesthetic value and artistic authenticity and to steer the fashion world towards a more sustainable and ethical path for future generations.

5. REFERENCES

[1] D'LTRIA, E., VACCA, F. Fashion Design for Sustainability. A transformative challenge across the European fashion education system. 7th International Conference on Higher Education Advances (HEAd'21), Edited by DOMENECH, J. MERELLO, P. DE LA POZA, E. Valencia: Editorial Universitat Politècnica de València, June 2021, pp 680-681.
[2] BERTOLA, P., TEUNISSEN, J. Fashion 4.0. Innovating fashion industry through digital transformation. Research Journal of Textile and Apparel, 2018, 22(4), pp 352-369.
[3] SAYEM, A. S. M., Digital fashion innovations for the real world and metaverse. International Journal of Fashion Design, Technology and Education, (2022), 15(2), 139-141.
[4] ÀLA.HAUSSE. Balenciaga's "Afterworld: The Age of Tomorrow" Could be the Future of Fashion [online], updated 04.09.2023 [cited 02.09.2023]. Available on https://hackernoon.com/balenciagas-afterworld-the-age-of-tomorrow-could-be-the-future-of-fashion
[5] CARBON TRUST AND ORDRE. Zero to Market The Carbon Cost of Travel Associated with the Ready-to-Wear Wholesale Buying Process. London: Carbon Trust [online], updated

04.09.2023 [cited 02.09.2023]. Available on https://www.ordre.com/en/static/pdf/ZeroToMarket.pdf

URL PAGES

URL 1: http://www.global-sci.org/uploads/Issue/JFBI/v11n1/111_1.pdf, Access Date: 04.09.2023
URL 2: 111_1.pdf (global-sci.org), Access Date: 04.09.2023
URL 3: https://8billiontrees.com/carbon-offsets-credits/carbon-footprint-of-polyester/#ref-22, Access Date: 04.09.2023
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URL 5: https://www.collectivefashionjustice.org/articles/carbon-cost-leather-goods, Access Date: 04.09.2023
URL 6: Pınar Erdoğan_Yüksek Lisans Tezi.pdf (hacettepe.edu.tr), Access Date: 04.09.2023

AN INVESTIGATION ON THE EFFICIENCY OF AN IN-HOUSE FABRIC RECYCLING LINE UTILISATION FOR PRE-CONSUMER DENIM WASTES

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ABSTRACT
This paper investigates the efficiency of an in-house fabric waste recycling line to recycle the pre-consumer denim fabric wastes. The results gave satisfying performances in OE spinning with recycled cotton fibers; so it was possible to contribute an sustainable process example in denim industry.

Keyword: Denim, recycling, OE yarn

1. INTRODUCTION

Denim is a type of cotton woven fabric which is characterized by thick, indigo dyed warp yarns, ecru weft yarns, high sett, weight and abrasion resistance. The global denim market was valued at around 70 Billion USD in 2021 and expected to reach a value of around 107 Billion USD in 2023. This huge market resulted with sustainable process applications. Denim industry has various sustainable process approaches to reduce water consumption, environmental-friendly chemical and dye usage, to reduce the air pollution during production and recycling of wastes [1-3]. Since denim fabrics have quite higher weight, tensile and tearing strength compared to non-denim fabrics, conventional fabric waste recycle lines have difficulty to obtain good quality recycled cotton fibers at final.

This study includes the utilisation of an in-house fabric waste recycling line. Pre-consumer denim apparel wastes are subjected to recycling by that in-house line for the very first time and recycled fibers are than characterized by means of the HVI along with virgin cotton fibers. Than, Ne 10 virgin : recycled cotton (from spinning and denim wastes separately) 80:20 blend OE yarns were produced. The produced yarns were used as weft in denim fabric sample production; the standard quality control tests were applied to the samples. The results showed that the proposed line would be successfully used to recycle denim fabric wastes to produce OE yarns and denim fabrics at industrial scale.

2. MATERIALS AND METHODS

Denim apparel line wastes (%100 cotton) were collected in Baykan Denim facilities (Malatya / Turkiye) and subjected to physical recycling by fabric waste recycling line. The line is in-house designed by Erbağcı Recycling (Gaziantep / Turkiye) with higher number of pulling stations and different garneting wire cross-section than conventional lines. The recycled fibers are as given in Figure 1.

Figure 1. Recycled cotton fibers from denim fabric wastes

The fiber samples were characterized by the means of HVI and the average of the analysis results are given in Table 1. Table 1 shows that in-house recycling line obtained white, short staple (good enough for spinning), clean, mature fibers with moderate fineness, and average strength.

Table 1. HVI results of the fibers obtained

	SCI	Mic	Length (inch)	Maturity (%)	Strength (g/tex)	Elongation (%)	Rd	b	Trash Area (%)
Mean	69	4,3	0,83	86	27,7	5,8	91,8	3,3	0,04
CV %	9,6	1,7	1	0,7	2,2	12,3	0,4	7,6	19,9

The fibers were used to produce Ne 10/1 OE yarn with 80:20 virgin : recycled fiber blend. For comparison, identical yarn was also produced including recycled fiber from yarn wastes in conventional process (standard recycled yarn). The mechanical properties were tested by the USTER and the results are given in Table 2. Table 2 showed that OE yarn with denim waste recycled fibers showed similar mechanical properties with standard recycled yarn.

Finally, denim fabric sample with 28 x 20 sett, 14 oz, was produced utilizing denim recycled yarn as weft and subjected to stone wash in Baykan Denim. The mechanical test results (Table 3) showed that denim fabric sample met almost all of the quality control limits of Baykan Denim; shrinkage after washing in weft direction was higher than limits as always observed in recycled yarn processing.

Table 2. Mechanical properties of yarn samples

	Denim waste	**Standard recycled yarn**
Yarn Count (Ne)	10,19	10,10
Twist (TPM)	537 (α_e:4,27)	532 (α_e:4,27)
U %	13,0	13,7
U% CV	16,60	17,40
-30	2410	2655
-40	233	218
-50	11	3
-60	0	1

+35	1490	1214
+50	395	267
+70	74	31
+100	13	5
Neps	148	49
Hairiness Index	9,13	9,35
Elongation %	6,57	6,37
Elongation CV	6,47	8,25
Tensile strength Cn/Tex	15.43	15.97
Tensile strength CV	8,4	7,35

Table 3. Mechanical properties of denim sample

Mechanical Property	**Average Value**	**Control / Acceptance Limit of Baykan Denim**	
		Minimum	**Maximum**
Weight (g/m2) (ASTM D 3776)	396.00	390.0	430.0
Elongation (%) (ASTM D3107)	13.20	9.0	13.0
Crocking fastness (Dry) (TS 423-2 EN 20105-A02)	4.50	3.0	-
Crocking fastness (Wet) (TS 423-2 EN 20105-A02)	2.00	1.5	-
Width (cm) (ASTM D 3774)	137.00	147.0	152.0
Width after wash (cm) (ASTM D 3774)	99.00	143.0	-
Weight after wash (g/m^2) (ASTM D 3776)	545.00	385.0	425.0
Tearing strength – Warp (N) (ASTM D1424)	8733.33	4300.0	-
Tearing strength – Weft (N) (ASTM D1424)	4396.66	3300.0	-
Tensile strength – Warp (N) (ASTM D1424)	91.23	65.0	-
Tensile strength – Weft (N) (ASTM D1424)	38.10	40.0	-
Shrinkage Weft (%) (TS EN ISO 5077)	-3.93	-1.0	-4.0
Shrinkage Warp (%) (TS EN ISO 5077)	-29.00	-2.0	-5.0
Skewness (%) (AATCC TM 179)	-1.00	-3.0	3.0
pH (TS EN ISO 3071)	6.00	5.0	7.5
Growth (%) (A-3LB)3HL (ASTM-D)3107	11.20	-	-

3. RESULTS AND DISCUSSIONS

This study investigates the efficiency of utilizing an in-house fabric recycling line for denim fabric wastes. As known, the fibers obtained by the conventional recycling lines are shorter than needed to be processed in spinning. We showed that with the proposed line, it is possible to process denim fabric wastes from OE spinning to weaving / dying and washing process successfully.

4. REFERENCES

[1] BUSCIO, V. et al. Sustainable dyeing of denim using indigo dye recovered with polyvinylidene difluoride ultrafiltration membranes. Journal of Cleaner Production, 1979, vol. 91, pp 201-207.
[2] NAYAKI, R. et al. Laser and ozone applications for circularity journey in denim manufacturing - A developing country perspective. Current Opinion in Green and Sustainable Chemistry, 2022, vol. 38, pp 100680.
[3] MEZARCIÖZ, S. et al. Effect of Sustainable Cotton Fibers on Denim Fabric Selected Properties. Journal of Natural Fibers, 2021, vol. 19, no. 15, pp 10345-10355.

DESIGN AND DEVELOPMENT OF MULTIFUNCTIONAL FABRIC USING COATING METHOD WITH DIFFERENT FINISHING PROCESSES

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ABSTRACT

The aim of this study is to produce multifunctional cotton woven fabric having water, oil and stain repellency properties by using different chemicals with coating method. In the scope of the study, the different chemicals with coating method were applied to 100% cotton fabrics. After the applications, the tests and analyzes of the untreated and treated fabrics were performed. The water repellency, oil repellency, stain repellency, contact angle, circular bending rigidity, air permeability, surface roughness, and tear strength test results were evaluated.

Key Words: Cotton, TiO_2, SiO_2 nano powder, water, oil and stain repellency, contact angle

1. INTRODUCTION

Nowadays, the design and production of multifunctional textiles and high added value products have started to gain importance with the changes in the textile industry. In this way, the market shares of multifunctional textiles with different and functional properties are increasing compared to conventional textiles. The mostly required properties of the textile materials are water, oil and stain repellency.

The basis of the water repellency process is to create a water-repellent layer on the surface of the yarns with chemicals having a long-chain water-repellent group by reducing the surface tension of the fabric against water. Cotton fibers have a hydrophilic structure to a greater or lesser extent. Since the water repellency process creates a water-repellent layer only on the surface of the yarns, the internal structure and pore structure of the fabric are not adversely affected in any way and remain the same [1]. As the structure of the dirt and the way it affects and adheres to the textile surface are very different, it is very difficult to obtain effective results for all dirts with a single treatment on dirt repellency. However, mainly dry and wet staining forms can be mentioned. In dry staining, it can be in the form of filtering all kinds of dust and pollutant particles by textiles (curtain), collapsing on it (upholstery) or attracting pollutants by electrostatic charge (synthetics). In wet soiling, wet dirt or oily, watery dirt are poured directly on textile and contaminates it. By applying stain repellency treatments to the fabrics, the textile materials are protected from getting dirty quickly during usage [1].

The superhydrophobicity on the cotton fabric can be achieved by constituting nano or micro roughness structures on the surface of the fabric with low surface energy materials by using different micro and nano particles such as SiO_2, ZnO, TiO_2, Ag_2O, CuO, fluoroalkyl silane and, polymers [2,3]. Silicon dioxide (SiO_2) is an inorganic material widely used in various fields, including nanocomposites, because of its unique properties. It is also used as construction materials, ceramics, textile coating materials, drugs, adsorbents, ion exchangers and catalysts [4]. TiO_2 has characteristics such as sound insulation, good mechanical properties, thermal and chemical stability and TiO_2 compounds are used in various fields such as electronics, biomedical, optics, dermatological and photocatalytic. TiO_2 is applied to fabrics by coating technique, sol-gel process and chemical deposition method [5]. TiO_2 nano particles are used in processes such as self-cleaning, UV protection, flame retardancy, antibacterial activity, especially of cotton and wool fabrics [6].

Lamination and coating are techniques applied to add functional properties to fabrics used in technical textile production and to increase their usage fields such as agricultural textiles, medical textiles and protective clothing. The functional properties of these fabrics may vary depending on the coating material used, the production technique applied, and the structure characteristic of the textile surface [7].

The aim of this study is to produce multifunctional 100% cotton woven fabrics by applying water, oil and stain repellency treatments. TiO_2 and SiO_2 nano powders [8] in different blended ratios, such as 100/0, 70/30, 50/50, 30/70, 0/100% were applied to cotton woven fabrics by coating method.

2. EXPERIMENTAL

2.1 Material

In the experiments, used 100% pre-treated cotton plain woven fabric was supplied from Batı Basma Company (In Turkey). The physical properties of the cotton fabric are given in Table 1.

Table 1. The physical properties of the cotton fabric

Weave construction	Plain	
Square mass (g/m^2)	260	
Yarn count (Nm)	Warp: 18.6	Weft: 18.4
Yarn density (threads/cm)	Warp: 22	Weft: 20
Breaking strength (N)	Warp: 692.7	Weft: 644.2

2.2 Method

In the study, water, oil and stain repellent multifunctional fabrics were produced with different chemicals by using coating method. The coating applications were carried out as one layer by using Mathis AG laboratory type coating machine. After the applications, drying and fixation were done in Ataç GK 40 brand laboratory type stenter.

Table 2 indicates the recipes of the coating applications. Since the best results were obtained with the recipe having the ratio of TiO_2/SiO_2 was 30/70, subsequent trials with this ratio was made by also adding fixator and fluorocarbon (Fabric 6,7,8), as given in Table 3.

Table 2. The recipes of the coating applications (Fabric 1-5)

Chemical type	TiO_2/ SiO_2 ratio					Unit
	100/0	70/30	50/50	30/70	0/100	
	Fabric 1	**Fabric 2**	**Fabric 3**	**Fabric 4**	**Fabric 5**	
Synthetic thickener	15	15	15	15	15	g/kg
Binder	150	150	150	150	150	g/kg
TiO_2	10	7	5	3	0	g/kg
SiO_2	0	3	5	7	10	g/kg
Ethanol	330	165	165	165	165	g/kg
HCl	-	165	165	165	165	g/kg
Water	X	X	X	X	X	g/kg
Total	1000 g	1000 g	1000 g	1000 g	1000 g	
Coating → Drying (80°C-10 min.) → Fixation (150°C-5 min.)						

Table 3. The recipes of the coating applications (Fabric 6,7,8)

Chemical type	**TiO_2/ SiO_2 ratio**			**Unit**
	30/70	30/70	30/70	
	Fabric 6	**Fabric 7**	**Fabric 8**	
Synthetic thickener	15	15	15	g/kg
Binder	100	100	100	g/kg
TiO_2	6	9	12	g/kg
SiO_2	14	21	28	g/kg
Fixator	10	10	10	g/kg
Fluorocarbon	20	20	20	g/kg
Ethanol	330	330	330	g/kg
HCl	165	165	165	g/kg
Water	X	X	X	g/kg
Total	1000 g	1000 g	1000 g	
Coating → Drying (80°C-10 min.) → Fixation (150°C-5 min.)				

2.3 Tests

After the applications, according to standard test methods various physical and chemical tests such as, water, oil, stain repellency, contact angle, circular bending rigidity, air permeability, surface roughness, and tear strength tests of the untreated and treated fabrics were carried out [9-15] (Table 4). Before the tests, the fabrics were conditioned under standard atmospheric conditions at 20±2ºC temperature and 65±4% relative humidity in laboratory.

Table 4. The physical and chemical tests applied to the fabrics

Test	**Standard**
Water stain repellency	AATCC TM 22
Oil repellency	AATCC TM 118
Stain repellency	AATCC TM 130
Contact angle	In house test
Circular bending rigidity	ASTM D 4032-08
Air permeability	TS 391 EN ISO 9237
Surface roughness	JIS B 0601
Tear strength	TS EN ISO 13937-1

3. RESULTS AND DISCUSSIONS

3.1 Evaluation of Water and Oil Repellency Test

In Table 5, the results of water and oil repellency tests of the untreated and treated fabrics are given. The best water repellency value was obtained with Fabric 1 and Fabric 2, while the lowest water repellency value was observed in Fabric 3 and Fabric 6. While the best oil repellency value was obtained with Fabric 6, 7 and 8, there was no oil repellency features of other fabrics.

Table 5. The water and oil repellency test results

Fabric code	**Water repellency value**	**Oil repellency value**
UT	0	0
Fabric 1	80	0
Fabric 2	80	0
Fabric 3	50	0
Fabric 4	75	0

Fabric 5	75	0
Fabric 6	50	4
Fabric 7	60	4
Fabric 8	60	4

3.2 Evaluation of Stain Repellency Test

In Table 6, the stain repellency test results of the untreated and treated fabrics are given. For tea stain, after 1 washing the best results were obtained with Fabric 6 and Fabric 8, while the worst results were achieved with the untreated, Fabric 1 and Fabric 2. After 5 washings, the best result was observed with Fabric 8, however the worst results were detected in Fabric 2 and 3. For coffee stain, after 1 washing the best result was found in Fabric 8, while the worst results were obtained with untreated fabric and Fabric 6. After 5 washings, the best results were found in Fabric 5 and Fabric 8, while the worst results were observed in the untreated fabric, Fabric 1 and Fabric 3. In terms of wine stain, after 1 washing the best results were found in the untreated fabric, Fabric 2 and Fabric 3, while the worst results were obtained with Fabric 6 and 7. After 5 washings, the best result was found in Fabric 1, while the worst result were obtained with Fabric 4, 6 and 7.

Table 6. The stain repellency test results of the untreated and treated fabrics

Fabric code	Tea stain		Coffee stain		Wine stain	
	1 washing	5 washings	1 washing	5 washings	1 washing	5 washings
UT	1.00	3.13	1.00	2.25	3.25	2.25
Fabric 1	2.13	1.83	2.88	2.25	2.88	2.63
Fabric 2	2.00	1.50	3.75	2.75	3.25	2.13
Fabric 3	2.25	1.67	2.00	2.00	3.00	2.13
Fabric 4	2.50	2.17	3.50	3.38	2.13	1.00
Fabric 5	3.63	2.33	4.25	4.75	2.63	2.25
Fabric 6	4.25	3.5	1.5	3.625	1.5	1.00
Fabric 7	3.125	3.5	1.625	4.25	1.25	1.00
Fabric 8	4.25	4.5	4.75	4.625	2.375	2.25

3.3 Evaluation of Contact Angle Test

In Table 7, the contact angle values of the untreated and treated fabrics are given. In the contact angle measurement, the highest angle values were obtained with Fabric 1, 2 and 3, while the lowest angle value was observed in the untreated fabric. Therefore, it can be stated that the coating applications were successful. Figure 1 shows the images of the drops falling on the fabric surface during the contact angle test. In Fabric 1, 2 and 3, the drops appear to be more spherical and not spreading compared to the others.

Table 7. The contact angle values of the untreated and treated fabrics

Fabric code	Contact angle (°)
UT	40.37
Fabric 1	131.22
Fabric 2	136.65
Fabric 3	132.57
Fabric 4	130.50
Fabric 5	113.17
Fabric 6	115.45
Fabric 7	117.97
Fabric 8	120.83

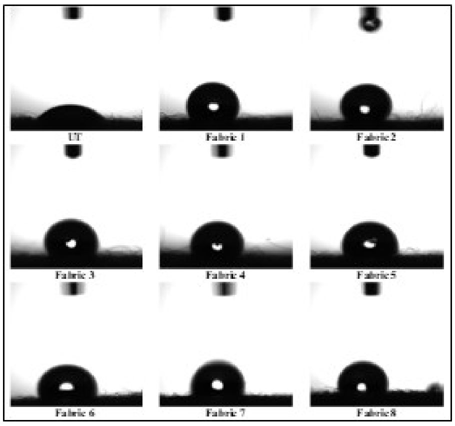

Figure 1. The images of the drops on fabrics

3.4 Evaluation of Circular Bending Rigidity Test

For the evaluation of the treatment effects on the handle characteristics of the fabrics, the circular bending rigidity values of the untreated and treated fabrics were measured, as given in Figure 2. The lowest circular bending rigidity values were obtained with Fabric 2 and 3, the highest circular bending rigidity values were obtained with Fabric 7 and 8. The stiffest fabrics among the coated fabrics were Fabric 7 and 8 due to the application recipes of these fabrics containing fixator and fluorocarbon. The higher the circular bending rigidity means the stiffer the fabric, so the coating process did not cause significant effect in terms of handle except Fabric 7 and Fabric 8.

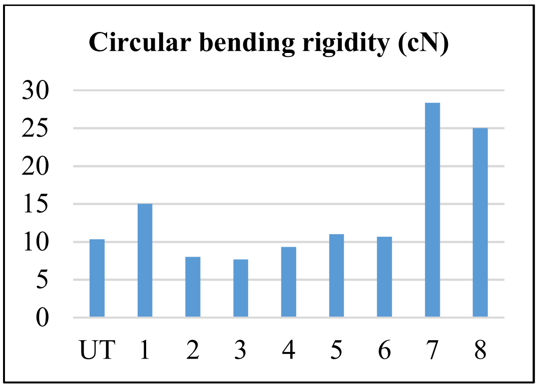

Figure 2. The circular bending rigidity values

3.5 Evaluation of Air Permeability Test

In Figure 3, the air permeability values of the untreated and treated fabrics are given. The air permeability values of all coated fabrics decreased much more than that of the untreated fabric due to filling of the pores inside the fabrics after coating applications. Among the treated fabrics, the air permeability values of Fabric 3 and Fabric 6 were slightly higher than the others.

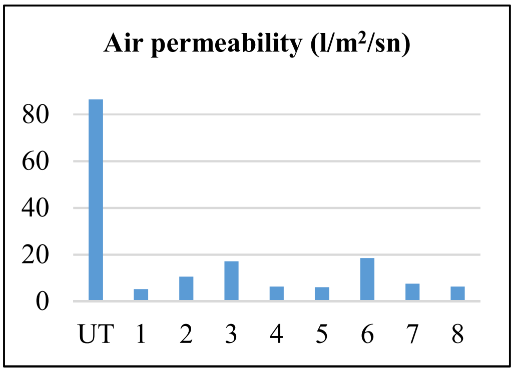

Figure 3. The air permeability values

3.6 Evaluation of Surface Roughness Test

In Figure 4, the surface roughness values of the untreated and treated fabrics are given. According to the results, it can be stated that the coating application did not cause significant effect on the surface roughness of the fabrics, except for Fabric 7 and 8.

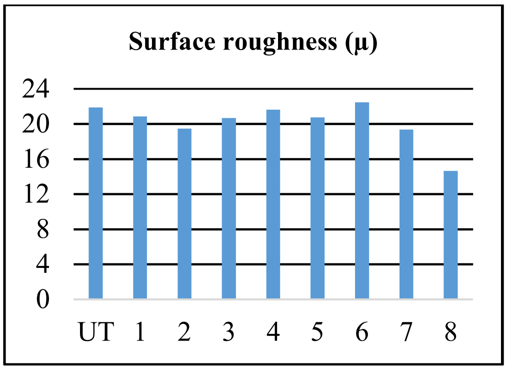

Figure 4. The surface roughness values

3.7 Evaluation of Tear Strength Test

Figure 5 indicates the tear strength values of the untreated and treated fabrics. The coating applications caused decreases in the tear strength values of the fabrics. When the treated fabrics were compared with each other, there were not notably differences. The fabric with the highest strength was Fabric 8, whereas the lowest tear strength values were observed with Fabric 1, 2 and 4.

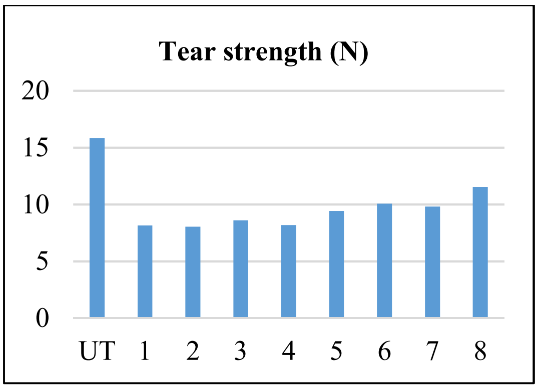

Figure 5. The tear strength values

4. CONCLUSIONS

As a result, Fabric 1 and 2 have the best results in terms of water repellency and contact angle. The concentration of TiO_2 used in these fabrics were higher than that of the other fabrics and this resulted in better water repellency characteristic. On the other hand, in terms of oil repellency, stain repellency and tear strength, Fabric 8 has the best results, because the concentration of TiO_2 and SiO_2 used in this fabric were higher than that of the other fabrics. Therefore, Fabric 8 provided the highest multifunctional performance among the coated fabrics, however the recipe of this fabric caused negatively the handle property of the cotton fabric. Since the multifunctional characteristics is required much more for the technical fabrics, Fabric 8 can be suggested especially for the outwear, upholstery, tent fabrics.

5. REFERENCES

[1] ÇOBAN, S. Genel Tekstil Terbiyesi ve Bitim İşlemleri (In Turkish), ISBN NO: 975-483-457-1, 1st edition. İzmir: Ege University Textile and Apparel Research Center, 1999.
[2] CHAUHAN, P., KUMAR, A., & BHUSHAN, B. Self-cleaning, stain-resistant and anti-bacterial superhydrophobic cotton fabric prepared by simple immersion technique. Journal of colloid and interface science. 2019, Vol.535, pp.66-74.
[3] PANDA, A., VARSHNEY, P., MOHAPATRA, S. S., & KUMAR, A. Development of liquid repellent coating on cotton fabric by simple binary silanization with excellent self-cleaning and oil-water separation properties. Carbohydrate Polymers, 2018, Vol.181, pp.1052-1060.
[4] GASHTI, P. M., ALIMOHAMMADI, F., SHAMEI, A. Preparation of water-repellent cellulose fibers using a polycarboxylic acid/ hydrophobic silica nanocomposite coating, Surface & Coatings Technology 206, 3208-3215, 2012
[5] ZHAN, J., ZHANG, H., ZHU, G. Preparation of photocatalytic cenosphere immobilized with TiO_2 nanoparticles by hydrothermal method. Journal of Industrial Textiles, 2014, Vol. 44(1), pp.99-114.
[6] DHINESHBABU, NR., ARUNMETHA, S., MANIVASAKAN, P., KARUNAKARAN, G., RAJENDRAN, V. Enhanced functional properties of cotton fabrics using TiO_2/SiO_2 nanocomposites. Journal of Industrial Textiles, 2016, Vol.45(5), pp.674-692.
[7] BULUT, Y., SÜLAR, V. Kaplama veya laminasyon teknikleri ile üretilen kumaşların genel özellikleri ve performans testleri(In Turkish), Tekstil ve Mühendis, 2008, Year.15, No.70-71, pp.5-16.
[8] http://nanografi.com.tr, 2023.
[9] AATCC TM 22-2017 standard, Water Repellency: Spray Test, 2017.
[10] AATCC TM 118-2020 standard, Oil Repellency: Hydrocarbon Resistance Test, 2020.
[11] AATCC TM 130-2018 standard, Soil Release: Oily Stain Release Method, 2018.
[12] ASTM D 4032-08 standard, Test Method for Stiffness of Fabric by the Circular Bend Procedure, 2012.
[13] EN ISO 9237 standard, Textiles-Determination of permeability of fabrics to air, 1996.
[14] JIS B 0601standard, Surface Texture: Profile Method-Terms, Definitions and Surface Texture Parameters, 2013.
[15] EN ISO 13937-1 standard, Textiles- Tear properties of fabrics- Part 1: Determination of tear force using ballistic pendulum method (Elmendorf), 2001.

OPTIMIZATION OF THE PARAMETERS INFLUENCE BLEACHING PROCESS FOR NETTLE/COTTON MIXED FABRICS BY TAGUCHI METHOD

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ABSTRACT

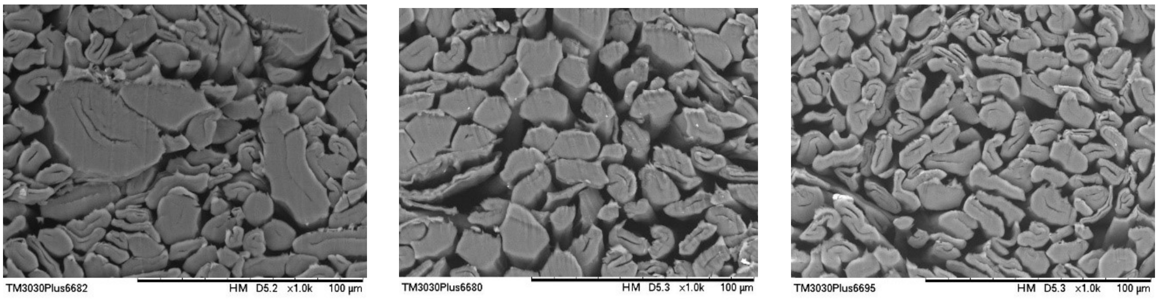
The use of natural fibers in the clothing industry has a long history. Natural fibers used within the scope of sustainability and circular economy; wool, silk, cotton, linen, jute, ramie, nettle, kapok etc. can be listed as. Nettle, one of the cellulosic fiber groups, has been used in many fields (medical, food, cosmetics, medicine and textile etc.) throughout history. Fabrics produced from nettle yarn provide well insulation due to the hollow structure of the characteristic cross-section of the fiber, while at the same time showing breathability. In the study, it is aimed to reveal the advantages of nettle-based woven fabrics, which are more environmentally friendly and have superior comfort properties, as an alternative to cotton and linen-containing woven fabrics, which are mainly used in women's upper clothing products. Within the scope of the study, the whiteness index, tear strength, color yield and hydrophilicity properties of cotton, cotton/linen and cotton/nettle blended woven fabrics were analyzed comparatively. Experiment plan was designed according to the L9 standard orthogonal array for three parameters (sodium hydroxide, hydrogen peroxide and weft yarn type) each with three different levels. When all the results are evaluated in general, it is concluded that cotton fiber provides a better whiteness index than nettle, while cotton/nettle blended fabrics are more durable. It has been determined that the color yield of the linen fiber blended fabric in medium-dark colors is better. Thanks to the applied method, time and cost savings were achieved.

Key Words: Nettle, bleaching, taguchi method, CIE whiteness, tear strength

1. INTRODUCTION

Textile fibers are classified as natural fibers and artificial fibers. Natural fibers are obtained from plants or animals, and artificial fibers are obtained from synthetic raw materials. Nettle, one of the cellulosic fiber groups, has been used in many fields (medical, food, cosmetics, medicine and textile etc.) throughout history. Nettle fiber, which is also a stalk fiber, is foreseen as an alternative to flax and cotton. Thanks to 17% high quality fibers, the nettle plant has a better strength value than other natural fiber types such as cotton and linen [1,2]. At the same time, nettle fiber has a high moisture absorption capacity. The fiber cross-section consists of its own characteristic hollow structure and thanks to this structure, it creates a natural air conditioning effect [3]. In order to keep cool in the summer months, the yarns are twisted to close the gaps in the center of the fiber and the insulation is reduced. In winter months, the hollow structure should be preserved by giving lower twist and the temperature should be kept constant. According to SEM images, the cross-section of the nettle plant has a more curved and hollow structure than the linen fiber (Figure 1).

Nettle fibers are naturally biodegradable, consist of renewable resources, and provide an ecological advantage because they require less energy in their production. With the need for sustainable natural resources, interest in the use of nettle is increasing. At the same time, the negative effects of excessive water consumption and pesticides used in cotton production have increased the demand for nettle fibers [4-7]. On the other hand, the nettle plant, which is widely grown in the Black Sea Region in our country, also creates a potential for domestic nettle yarn production [8].



(a) Cotton/Nettle (b) Cotton/Linen (c) Cotton

Figure 1. Yarn cross-sectional SEM images (a) Cotton/Nettle, (b) Cotton/Linen, (c) Cotton

According to the latest studies, Samanta et al. investigated the applications of nettle fiber in textile. It has been stated that there are limiting factors such as the suitability of harvesting technology for fiber production and the lack of large-scale fiber production, but the efforts made to produce yarn from 100% nettle fiber or blending various fibers have been successful [4].

In another study Samanta et al. investigated the physical, mechanical, chemical, thermal and morphological properties of fibers produced from the Himalayan nettle plant. At the same time, blended yarns were produced by blending viscose fiber in different proportions. The properties of woven fabrics produced by using the produced yarns in the weft were examined. The fineness of the obtained nettle fiber was determined to be 2.2–2.4 tex, its strength was 10–16 cN/tex and its elongation was 3%. Blended yarns were produced by blending the obtained nettle fiber and viscose fiber in the ratios of 100/0, 75/25, 50/50 and 25/75. Woven fabrics were produced using cotton yarn in the warp and nettle-containing yarns in the weft. As a result of the study, biodegradable fashionable clothing fabrics were produced. It can be said that the nettle plant is a potential yet untapped source for fiber extraction and application in clothing textiles [9].

Prasad et.al investigated the physical and mechanical properties of different natural fibers (such as hemp, nettle) reinforced polyester resin composite materials. Its physical characteristics were revealed by morphological analysis. Mechanical properties (hardness, tensile, bending and impact resistance) and scanning electron microscopy have been used to test composite surfaces. As a result of the study, it was seen that higher mechanical properties that can be used in many applications were obtained by using innovative natural fibers such as hemp and nettle instead of classical natural fibers [10].

Başaran and Bekiroğlu investigated that open-end and ring yarn were produced by blending nettle fiber obtained from the nettle plant and cotton fiber in different combination. Knitted fabric was produced with the ring yarn produced and it was stated that a softer and more elastic surface was obtained than the woven fabric. As a result of the study, it was seen that as the nettle ratio increased, the strength decreased compared to other plant fibers, and it was stated that it could be suitable for use in areas where high strength is not desired, such as bandages in the healthcare field [11].

Şansal investigated that surface modification was carried out on nettle threads with different concentrations of sodium hydroxide and acetic acid using conventional, ultrasonic and microwave methods. In general, it has been determined that ultrasonic and microwave surface treatments are more effective than conventional treatments [12].

Bodros and Baley investigated that the mechanical performance of nettle fibers as polymer reinforcement was compared with flax and other lignocellulosic-based fibers. Environmentally friendly nettle fiber has been found to be a harder composite material than glass fiber. It has been revealed that lightweight lignocellulosic-based fibers (nettle, flax, etc.) can be an alternative to glass fiber as high-performance reinforcing materials [13].

As a result of all the studies in the literature, it can be said that better results can be achieved by using nettle fiber in mixture with other natural-based fibers in terms of its mechanical properties (fineness, length and strength) [1].

In addition to the development of environmentally friendly, sustainable product/process designs in the textile industry, increasing costs as a result of repeated trials also emerge as an important factor. The Taguchi method, which is based on orthogonal arrays developed to optimize design processes in terms of performance, quality and cost, is used in textiles, chemical machinery, etc. The aim is to optimize the controllable factors (material, production method, etc.) by minimizing the effect of the uncontrollable ones (ambient temperature, humidity, machine wear, etc.) for the factors that cause variability in the product/process. Orthogonal arrays suggest simultaneous change of selected factor levels instead of changing them one by one, thus making it possible to reach results with fewer experiments. However, since this method does not produce a mathematical equation, it provides close to optimum results by finding the best combination of the determined levels. In this method, where all factors are included in the experimental plan at equal levels, the most commonly used 3-level indexes are L_9, L_{18} and L_{27}. The test outputs resulting from the application are evaluated by converting them into Signal/Noise (S/N) ratios such that the minimum value is the best, the nominal value is the best, and the maximum value is the best [14-17].

In this study, it was aimed to determine the optimum bleaching conditions for desized cotton, cotton/linen and cotton/nettle fabrics. Taguchi method was used to reveal the superiority of the samples in terms of whiteness degree, color yield, hydrophilicity and tear strength (weft and warp direction). The experiment was designed according to the L_9 standard orthogonal array for three parameters (sodium hydroxide concentration, hydrogen peroxide concentration and weft yarn type), each with three different levels. The optimum conditions obtained as a result of the analysis were tested and verified. Thus, while 27 (3^3) experiments were required to be carried out in the full factorial design for three factors and three levels, the results were achieved with 9 experiments using the Taguchi method, saving time and cost.

2. EXPERIMENTAL

In the study, 100% cotton, 79% cotton 21% linen and 81% cotton 19% nettle based woven fabrics were used. Fabric properties are given in Table 1.

Table 1. Fabric information

Number	**1**	**2**	**3**
Composition	100% Cotton	79% Cotton %21 Linen	81% Cotton 19% Nettle
Warp Yarn	Ne 50/1 Cotton Compact		
Weft Yarn	Ne 30/1 Cotton OE BCI	Ne 24/1 Cotton/Linen (70/30)	50 Nm Cotton/Nettle (70/30)
Warp Density	28 thread/cm		
Weft Density	30 pick/cm		
Weave Type	Twill 2/1		
Weight	105 g/m^2	125 g/m^2	105 g/m^2

All fabrics used in the study were desized before bleaching. In order to determine the bleaching process conditions that provide the best performance properties, the experimental set was created by using the Taguchi Method instead of trying all combinations of the selected parameters. Within the scope of the study, experiments were designed according to the L_9 standard orthogonal array for three parameters (sodium hydroxide, hydrogen peroxide and weft yarn type) each with three different levels. The factors and levels used in the design phase are given in Table 1.

Table 2. Factor levels

Parameter / Level	1.Level	2.Level	3.Level
A (Sodium Hydroxide g/L)	1	3	5
B (Hydrogen Peroxide g/L)	1	3	5
C (Weft Yarn Type)	Nettle	Cotton	Linen

The experimental plan designed for the L_9 orthogonal array based on the Taguchi method is presented in Table 3.

Table 3. Experiment plan

Experiment Number	A	B	C
1	1	1	Nettle
2	1	3	Cotton
3	1	5	Linen
4	3	1	Cotton
5	3	3	Linen
6	3	5	Nettle
7	5	1	Linen
8	5	3	Nettle
9	5	5	Cotton

For color yield (K/S) measurement, all fabrics dyed in khaki color with 0.72 % color strength (17-0618 TCX) with reactive dyestuffs with bifunctional groups. Whiteness index and color yield (K/S) measurements of bleached fabrics were made in SI mode on a Datacolour SF600 Plus-CT spectrophotometer with a 6.6 mm observation plate.

The tear strength of the fabrics in the weft and warp directions was tested according to TS EN ISO 13937-2, and the capillarity values were tested according to the DIN 53924 standard.

Optimum process conditions for the test results were determined according to the Taguchi method. The prediction performance of the model was measured with verification experiments carried out under these process conditions. Minitab 2023 trial version was used to implement the Taguchi method.

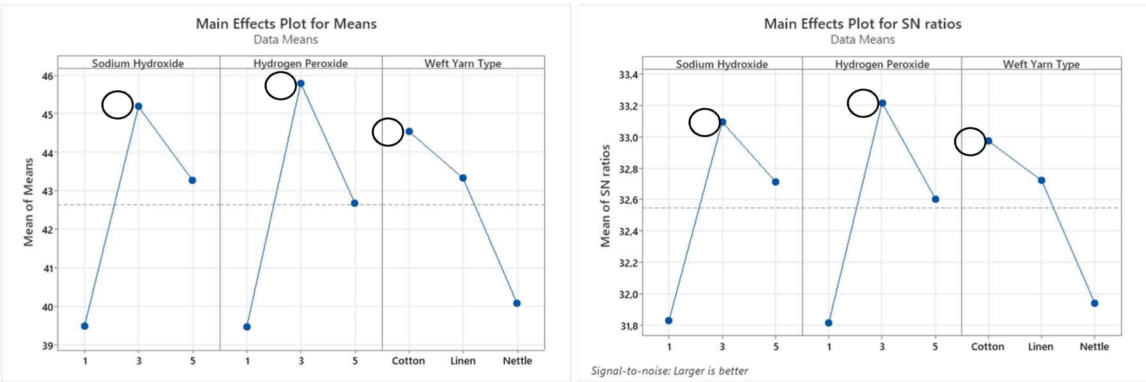
3. RESULTS AND DISCUSSION

The whiteness degree, color yield (K/S) and hydrophilicity test results of the bleached fabrics according to the experimental plan are given in Table 4.

Table 4. CIE whiteness, color yield and hydrophility test result

Experiment Number	CIE Whiteness (0-100)		Color Yield (K/S)		Capillarity (cm)	
	Experiment	Prediction	Experiment	Prediction	Experiment	Prediction
1	31.44	33.75	2.68	2.50	8.83	8.74
2	44.57	44.52	2.58	2.64	11.77	11.55
3	42.47	40.20	2.31	2.43	9.93	10.23
4	46.17	43.90	2.27	2.39	11.60	11.90
5	46.69	49.00	2.75	2.57	10.87	10.78
6	42.69	42.64	2.20	2.26	9.40	9.18
7	40.82	40.77	2.20	2.26	12.30	12.08
8	46.11	43.84	2.22	2.34	10.40	10.70
9	42.88	45.19	2.27	2.09	13.40	13.31

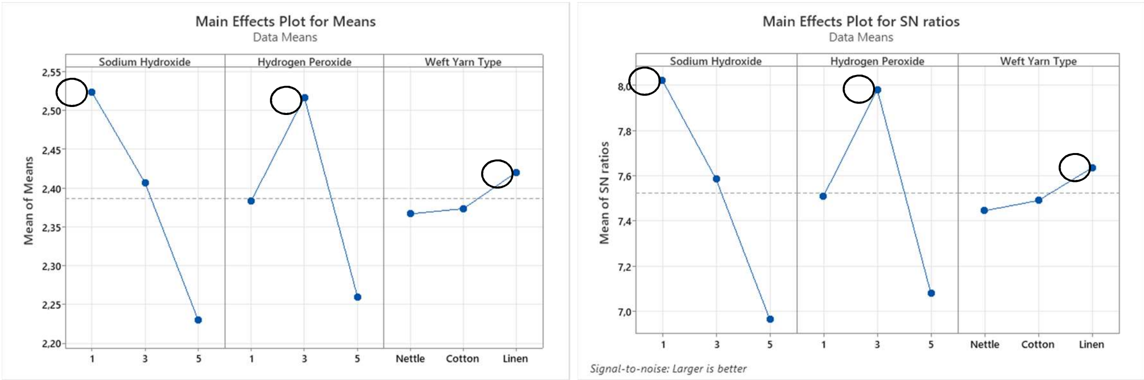
For all test results given in Table 4, when the experimentally obtained values were compared with the predicted ones, it was seen that the results confirmed each other.



(a) Main effects plot for means (b) Main effects plot for S/N ratios

Figure 1. Mean and S/N ratio results for CIE Whiteness values

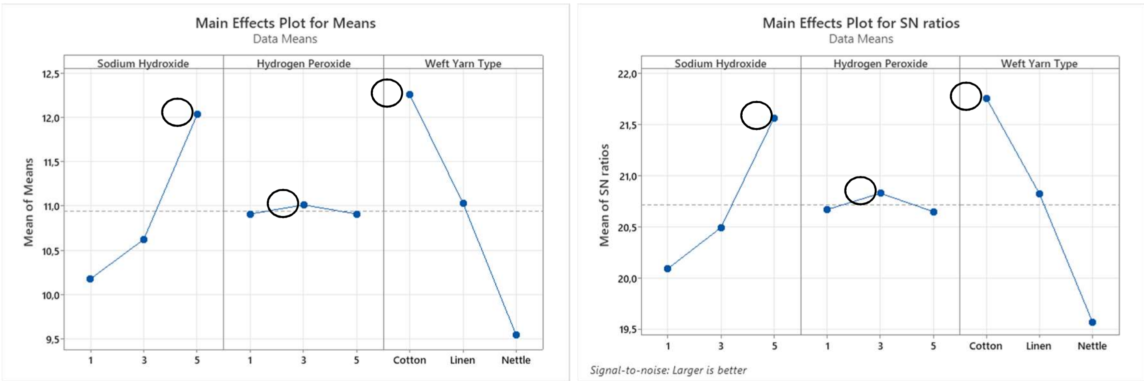
When the S/N ratio graph of the CIE Whiteness measurement results given in Figure 1 is evaluated, it is seen that the sample with the optimum whiteness degree can be obtained as a result of bleaching using in the weft yarn cotton, 3g/L sodium hydroxide and 3g/L hydrogen peroxide ($A_2B_2C_2$). The estimated whiteness degree for the $A_2B_2C_2$ optimum level was found to be 50.21. The whiteness degree obtained as a result of the verification test was measured as 50.



(a) Main effects plot for means (b) Main effects plot for S/N ratios

Figure 4. Mean and S/N ratio results for K/S values

It was given in Figure 4 that the S/N ratio graph of the color yield (K/S) of fabrics dyed in khaki color with 0.72 % color strength. When the graphs are examined, it is seen that the sample with the maximum color yield (2.69) was obtained by using in the weft linen and bleaching with 1g/L sodium hydroxide and 3 g/L hydrogen peroxide ($A_1B_2C_3$). In the verification experiment, the K/S ratio was determined to be 2.683.



(a) Main effects plot for means (b) Main effects plot for S/N ratios

Figure 5. Mean and S/N ratio results for capillarity values

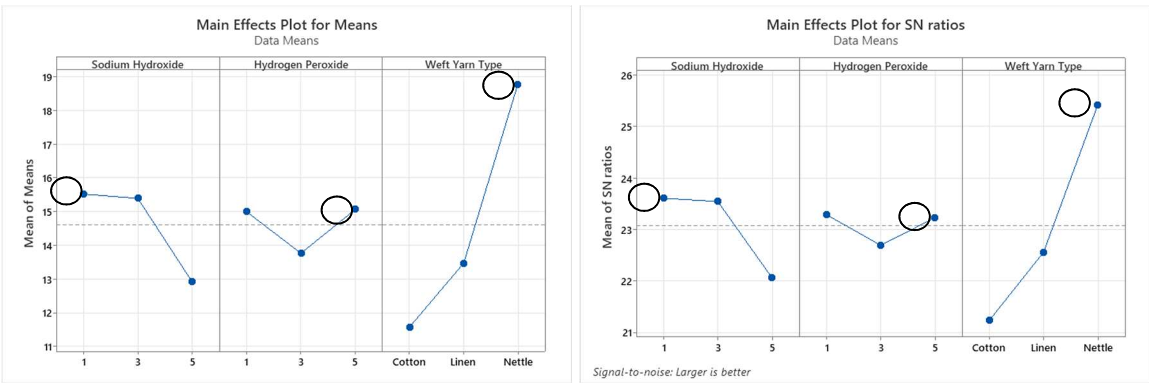
When the S/N ratio graph of the capillarity values given in Figure 5 was interpreted, it was determined that the experimental plan that gave the best result (13.41 cm) was $A_3B_2C_2$ (5g/L sodium hydroxide, 3 g/L hydrogen peroxide and weft yarn cotton). In the measurement made as a result of the verification experiment, the capillarity value was measured as 10.46 cm. As stated by Şansal, it has been observed that the hydrophilicity value increases with the increase in the amount of sodium hydroxide in bleaching nettle fibers [12].

The predicted and experimentally found warp and weft direction tear strength test results of the samples are given in Table 5.

Table 5. Warp and weft direction tear strength test result

Experiment Number	Tear Strength (N)			
	Warp Direction		Weft Direction	
	Experiment	Prediction	Experiment	Prediction
1	19.99	20.07	0.01	0,62
2	11.79	11.64	7.99	8.44
3	14.77	14.83	19.17	18.10
4	12.68	12.74	8.09	7.02
5	13.33	13.41	15.38	15.99
6	20.16	20.01	0.01	0.46
7	12.31	12.16	14.71	15.16
8	16.17	16.23	0.01	-1.05
9	10.26	10.34	6.83	7.44

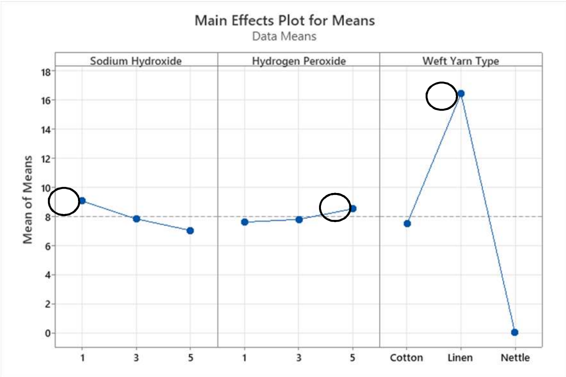
When the results in Table 5 are examined, the tear strength test results in warp and weft directions and the results predicted from the model support each other.



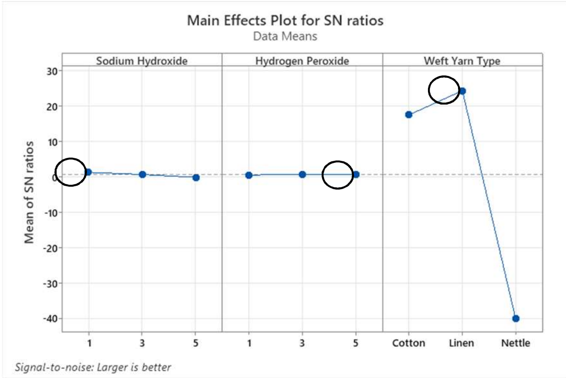
(a) Main effects plot for means (b) Main effects plot for S/N ratios

Figure 2. Mean and S/N ratio results for Tear Strength (Warp) values

When the graphs of the tear strength (tearing of the weft yarns) results in the warp direction are examined, the best results were obtained when nettle yarn, 1 g/L sodium hydroxide and 5g/L hydrogen peroxide ($A_1B_3C_1$) were used in the weft. The tear strength was calculated as 20.14 N under $A_1B_3C_1$ process conditions. The tear strength result in the warp direction of the experiment carried out under these conditions was determined as 25.95 N. The fact that the strength value obtained as a result of the experimental study is higher than the predicted result is thought to be due to the irregular structure of the nettle yarn and the irregularities on the woven fabric structure.



(a) Main effects plot for means



(b) Main effects plot for S/N ratios

Figure 3. Mean and S/N ratio results for Tear Strength (Weft) values

As seen in Figure 3, the highest value for tear strength in the weft direction (18.10 N) was obtained with 1 g/L sodium hydroxide, 5 g/L hydrogen peroxide and weft yarn linen ($A_1B_3C_3$). The strength value obtained as a result of the test carried out under $A_1B_3C_3$ conditions was measured as 15.18 N.

4. CONCLUSIONS

In this study, it was aimed to optimize the bleaching processes of cotton, cotton/nettle and cotton/linen blended woven fabrics. Sodium hydroxide concentration, hydrogen peroxide concentration and the type of yarn used in the weft were determined as parameters affecting the process. The determined parameters consist of three levels. Instead of trying all combinations, the experimental set was created using the Taguchi method based on orthogonal arrays. Nine experiments designed according to the L_9 orthogonal array consisting of three factors and three levels were carried out. According to the experimental plan, the degree of whiteness, hydrophilicity and tear strength (warp and weft direction) of the bleached fabrics were measured. Then, the fabrics were dyed in khaki color with bifunctional group dyes at 0.72% color strength. Color yield (K/S) values of the dyed fabrics were measured. S/N ratios giving the maximum value were calculated for all results.

It was concluded that the amount of hydrogen peroxide is the most important parameter affecting the degree of whiteness. When the S/N chart was examined, it was determined that the maximum whiteness degree (50.21) was obtained after the bleaching process performed at $A_2B_2C_2$ (3g/L sodium hydroxide, 3g/L hydrogen peroxide and weft yarn cotton) parameter levels. The result of the verification experiment (50) confirms the prediction performance of the model.

According to capillarity values of the fabrics, it was seen that the most important parameter was the weft yarn type. According to the S/N ratios of the selected parameters, it was found that the sample with the highest capillarity (13.41 cm) could be obtained with the combination of $A_3B_2C_2$ (5g/L sodium hydroxide, 3 g/L hydrogen peroxide and weft yarn cotton) levels. The value obtained after the experimental study is 10.46 cm.

According to warp and weft direction tear strength results, it was seen that the type of yarn used in the weft was the parameter that most affected the strength. Tear strength in the warp direction (tearing of weft yarns) gives the maximum value (20.14 N) at $A_1B_3C_1$ (1 g/L sodium hydroxide, 5 g/L hydrogen peroxide and weft thread nettle) levels. The tear strength of the test carried out under these conditions is 25.95 N. In the weft direction, it was observed that the parameter levels that gave the maximum tear strength (18.10 N) were $A_1B_3C_3$ (1 g/L sodium hydroxide, 5 g/L hydrogen peroxide and weft yarn linen). The value measured after the experimental study is 15.18 N.

It was determined that the maximum color yield was 2.69 at parameter levels $A_1B_2C_3$ (1 g/L sodium hydroxide, 5 g/L hydrogen peroxide and weft yarn linen). The color yield of the experiment carried out under these conditions was 2.683, which supports the result.

At the end of the study all the results were evaluated in general, it was seen that cotton fabric had a higher degree of whiteness and hydrophilicity than linen and nettle blended fabrics. According to tear strength results, it was concluded that nettle based fabric was more durable than linen and cotton based fabrics. It has been determined that the concentration of sodium hydroxide and hydrogen peroxide, respectively, is very effective on the color yield in dyeing in medium and dark colors. When examined in terms of blending ratios, it was revealed that fabrics using cotton/linen yarn in the weft had higher color yield than using cotton and cotton/nettle. Using the Taguchi method, 18 fewer trials were performed compared to the full factorial design, saving approximately 65% in time and cost.

5. REFERENCES

[1] AKPINARLI, F.H., BAŞARAN, F.N. ve BEKIROĞLU, E. Isırgan bitkisinden lif elde etme yöntemleri. 4th International Symposium on Multidisciplinary Studies (ISMS), Paris, Fransa, 27-28 Nisan 2018, s.225-245.
[2] KURBAN, M., YAVAŞ, A. ve AVINÇ, O.O. Isırgan otu lifi ve özellikleri. Tekstil Teknolojileri Elektronik Dergisi, 2011, Cilt: 5, No: 1, s.84-106.
[3] HUANG, G. Nettle (Urtica cannabina L) fibre, properties and spinning practice. Journal of the Textile Institute, 2005, vol. 96, no.1, pp 11-15.
[4] SAMANTA, K.K., ROY, A.N., BAİTE, H., DEBNATH, S., AMMAYAPPAN, L., NAYAK, L.K., SİNGHA, A. and KUNDU, T.K. Applications of nettle fibre in textile: A brief review. International Journal of Bioresource Science Citation: IJBS, 2021, 08(01), p.39-45.
[5] YAVAŞ, A., AVİNÇ, O. and GEDİK, G. Ultrasound and microwave aided natural dyeing of nettle biofibre (urtica dioica L.) with madder (rubia tinctorum L.). Fibres & Textiles in Eastern Europe, 2017, 25, 4(124), p.111-120.
[6] HARWOOD, J. and EDOM, G. Nettle Fibre: Its prospects, uses and problems in historical perspective. Textile History, 2012, 43:1, p.107-119.
[7] MOHAN, R. Nettle fiber: The eco-friendly resurgence in sustainable fashion. International Journal of Home Science, 2023, 9(2), p.268-273.
[8] VOGL, C.R. and HARTL, A. Production and processing of orginally grown fiber netle (Urtica dioica L.) and its potential use in the natural textile industry. A review, American Journal of Alternative Agriculture, 2003, vol.18, no.3, pp 119-128.
[9] SAMANTA, K.K., ROY, A.N., BAİTE, H., DEBNATH, S., AMMAYAPPAN, L., NAYAK, L.K., SİNGHA, A. and KUNDU, T.K. Properties of himalayan nettle fiber and development of nettle/ viscose blended apparel textiles. Journal of Natural Fibers, 2023, Vol. 20, No. 1, p.1-16.
[10] PRASADA, L., KUMAINB, A., PATELC, R.V., YADAV, A. And WINCZEK, J. Physical and mechanical behavior of hemp and nettle fiber-reinforced polyester resin-based hybrid composites. Journal of Natural Fibers, 2022, 19:7, pp.2632-2647.
[11] BAŞARAN, F.N. ve BEKİROĞLU, E. Isırgan bitkisinden elde edilen liflerle üretilen ring ve open-end ipliklerin mukavemet özellikleri. Ulakbilge Sosyal Bilimler Dergisi, 2020, 46, s.286-301.

[12] ŞANSAL, S. Ekolojik yüzey işlemlerinin ısırgan ipliğinin fiziksel ve morfolojik özelliklerine etkisinin araştırılması. Yüksek Lisans Tezi, Bartın Üniversitesi, Fen Bilimleri Enstitüsü, Tekstil Mühendisliği Anabilim Dalı, 2017, s.58-61.
[13] BODROS, E. & BALEY, C. Investigation of the use of stinging nettle fibres (urtica dioica) for polymer reinforcement: study of single fibre tensile properties, 2008.
[14] ALMETWALLY, A.A. Multi-objective optimization of woven fabric parameters using Taguchi–grey relational analysis. Journal of Natural Fibers, 2020, Vol. 17, No. 10, p.1468-1478.
[15] FRAJ, A.B. and JAOUACHI, B. Study of the effect of enzymatic washing parameters on the bagging properties of denim fabric with Taguchi method. Journal of Surfactants and detergent, 2022, Vol.25, No.4, p.505-519.
[16] KUMAR, S., PRASAD, L., PATEL, V.K., KUMAIN, A. And YADAV, A. Experimental and numerical study on physico-mechanical properties and Taguchi's designed abrasive wear behavior of hemp/nettle-polyester hybrid composite. Polymer Composites, 2021, Vol.42, No.12, p.6912-6927.
[17] MEZARCIOZ, S. and OGULATA, R.T. Optimization of bursting strength of single jersey fabrics with taguchi orthogonal design. Textile and Apparel, 2010, vol.20, no.4, pp 320-328.

ENVIRONMENTAL IMPACTS OF 100% VIRGIN COTTON AND RECYCLED COTTON/VIRGIN COTTON BLENDED FABRICS

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ABSTRACT

This study aims to evaluate environmental impacts of 100% virgin cotton and recycled cotton/virgin cotton blended fabrics. Environmental impacts were calculated with life cycle analysis in the raw material stage, yarn production and 3-thread knitted fabric production stages. Based on the results of this study, it was observed that the environmental impacts was reduced in the fabrics containing recycled cotton fibres compared to those containing 100% virgin cotton fibre in all impact categories. The highest reduction rates of approximately 10-11% were determined in terrestrial ecotoxicity, total water use and freshwater ecotoxicity categories with the use of recycled fibre.

Key Words: Life cycle analysis, virgin cotton, recycled cotton, environmental impact.

1. INTRODUCTION

The textile industry is one of the most important sectors that cause both natural resource consumption and significant environmental impacts [1,2]. Cotton, which is the most important natural fibre, is a renewable, biodegradable cellulosic fibre. Although the environmental perception of cotton is generally positive for consumers, significant environmental effects occur during its production stages. Main factors such as land use, chemical pesticides, synthetic fertilizer use, irrigation and mechanical harvesting in cotton production damage the environment [3,4]. In the yarn and fabric production stages, electric and heat energy are used in the machines for production and in air conditioners for air conditioning. Environmental impacts caused by fibre production are eliminated with the recycling of cotton. The environmental effects of textile production are calculated through life cycle analysis. Life cycle analysis is a scientific method used to measure and evaluate environmental impacts at all stages of a product, service or process from raw material to disposal [5]. There are different studies on life cycle assessment of textiles produced with virgin cotton and recycled cotton in the literature. Zhang et al. (2015), analyzed the life cycle of a cotton T-shirt and stated that most of the environmental impacts were caused by the use of water, fertilizers and pesticides in cotton cultivation and the energy consumption in the dyeing, finishing, apparel and usage processes [6]. Esteve-Turrillas and Guardia (2017), examined the life cycle analysis of T-shirts containing recycled cotton and virgin cotton. As a result of the study, it was found that the production of recycled cotton was the process creates the least environmental impact [7]. In the study conducted by Spathas (2017), life cycle analysis was made for 4 different recycling processes and the recycled yarns for each process caused less environmental impact in all environmental impact categories compared to virgin yarn samples [8]. Kazan et al. (2020), investigated life cycle analysis of cotton woven shirt production for 4 different scenarios in which virgin cotton and recovered cotton are used as raw materials. Their findings revealed that the use of virgin cotton caused the highest environmental impact and the use of recovered cotton led to significant decrease in different environmental impact categories [1]. The results of the study by Erayman Yüksel and Korkmaz (2023), showed that the usage of recycled cotton created less environmental impact than the usage of BCI cotton in many environmental impact categories [9]. The objective of this study to compare environmental impacts of 100% virgin cotton and recycled cotton/virgin cotton blended fabrics using life cycle analysis.

2. EXPERIMENTAL

In this study, life cycle analysis was carried out with the input and output data for raw material stage, the yarn production and 3-thread knitted fabric production stages. For this purpose, Ne 30/1 combed yarns from 100% virgin cotton fibres were used as face and binding yarns in the production of 3-thread knitted fabrics. As fleecy yarns, Ne 10/1 open-end yarns made of 100% virgin cotton and 50/50% virgin cotton/recycled cotton were used in conventional and recycled samples, respectively. Within the scope of the study, the yarns and fabrics produced for life cycle analysis are given in Table 1. All production parameters were kept constant in order to determine the effect of usage recycled fibre in the life cycle analysis.

Table 1. Yarns and fabrics produced for life cycle analysis

	Face yarn		Fleecy yarn		Binding yarn	
Fabrics	**Type**	**Fibre content**	**Type**	**Fibre content**	**Type**	**Fibre content**
Conventional fabric	Ne 30/1 combed yarn	%100 CO	Ne 10/1 open-end yarn	%100 CO	Ne 30/1 combed yarn	%100 CO
Recycled fabric	Ne 30/1 combed yarn	%100 CO	10/1 open-end yarn	%50/50 CO/ recycled CO	Ne 30/1 combed yarn	%100 CO

In the first step of the life cycle analysis, the process flows and functional units of the products were determined. In the inventory analysis step, the inputs (raw materials, water, energy, chemicals, etc.) and outputs in each process were numerically determined. The inventory data was transferred to the SimaPro® life cycle software and environmental impacts were calculated with the CML-IA baseline method using Ecoinvent database for 12 different environmental impact categories (abiotic depletion, abiotic depletion (fossil fuels), global warming, ozone layer depletion, human toxicity, freshwater/marine/terrestrial ecotoxicity, photochemical oxidation, acidification, eutrophication and total water use). Process flows for yarn and fabric production are given in Table 2.

Table 2. Process flows for yarn and fabric production

Process	**Combed yarn**	**Open-end yarn**	**Knitting machine**
Machines	Blowroom Carding Draw frame Combing Roving Ring spinning Winding	Blowroom Carding Draw frame Open-end spinning	Circular knitting machine

3. RESULTS AND DISCUSSION

Characterization results for life cycle analysis are given in Table 3. Comparing the fabrics, it was observed that conventional fabrics containing 100% cotton fibres exhibited more environmental impact than fabrics produced using recycled cotton fibres in all impact categories. Since all parameters were constant except for the fibre type in the fabrics, it is thought that the main reason for the difference between the characterization results is the fibre type in the yarn production stage. These results are due to the high environmental impacts of conventional cotton fibre production. The environmental impacts from conventional cotton fibre production stage were reduced with usage of recycled cotton. The production and use of chemicals such as fertilizers, pesticides and insecticides in cotton fibre production, intensive irrigation conditions and energy use are the main factors that create environmental impacts. In addition, environmental effects occurred due to the electricity consumption of the machines used in the yarn and knitted fabric production process for both fabrics.

Table 3. Life cycle analysis results of fabrics

Impact category	Unit	100% CO	50/50% CO/r-CO
Abiotic depletion	kg Sb eq	2,73E-05	2,46E-05
Abiotic depletion (fossil fuels)	MJ	98,971056	98,301692
Global warming	kg CO2 eq	8,7560663	8,5873993
Ozone layer depletion	kg CFC-11 eq	6,66E-07	6,11E-07
Human toxicity	kg 1,4-DB eq	3,6037374	3,4828989
Freshwater ecotoxicity	kg 1,4-DB eq	37,395932	33,516432
Marine ecotoxicity	kg 1,4-DB eq	10767,981	10681,171
Terrestrial ecotoxicity	kg 1,4-DB eq	2,6309395	2,3302293
Photochemical oxidation	kg C2H4 eq	0,002040353	0,00199325
Acidification	kg SO2 eq	0,061639266	0,05923159
Eutrophication	kg PO4--- eq	0,033680417	0,032304975
Total water use	m^3	2,1171939	1,8768997

The change (%) of the life cycle analysis values of the fabrics produced after the recycling process compared to the conventional fabric containing 100% cotton fibre are illustrated in Figure 1. According to these results, 3 impact categories that changed significantly with usage of recycled fibre were determined as terrestrial ecotoxicity, total water use and freshwater ecotoxicity. Approximately 10-11% reduction rates were observed in these categories for recycled fabric production stages compared to conventional fabric production stages. Fertilizers, pesticides and insecticides used in cotton fibre production cause emissions to soil and water, hence resulting decrease the biological diversity in the terrestrial and freshwater ecosystems. In addition, water use potential was found to be high due to intensive irrigation conditions in the cotton fibre production process. The usage of recycled fibres led to a reduction in all environmental impacts categories. The impact categories with the least difference (approximately 1%) were found to be abiotic consumption potential and marine ecotoxicity potential comparing recycled fabric production stages and conventional fabric production stages. These impact categories are associated with fossil fuel consumptions.

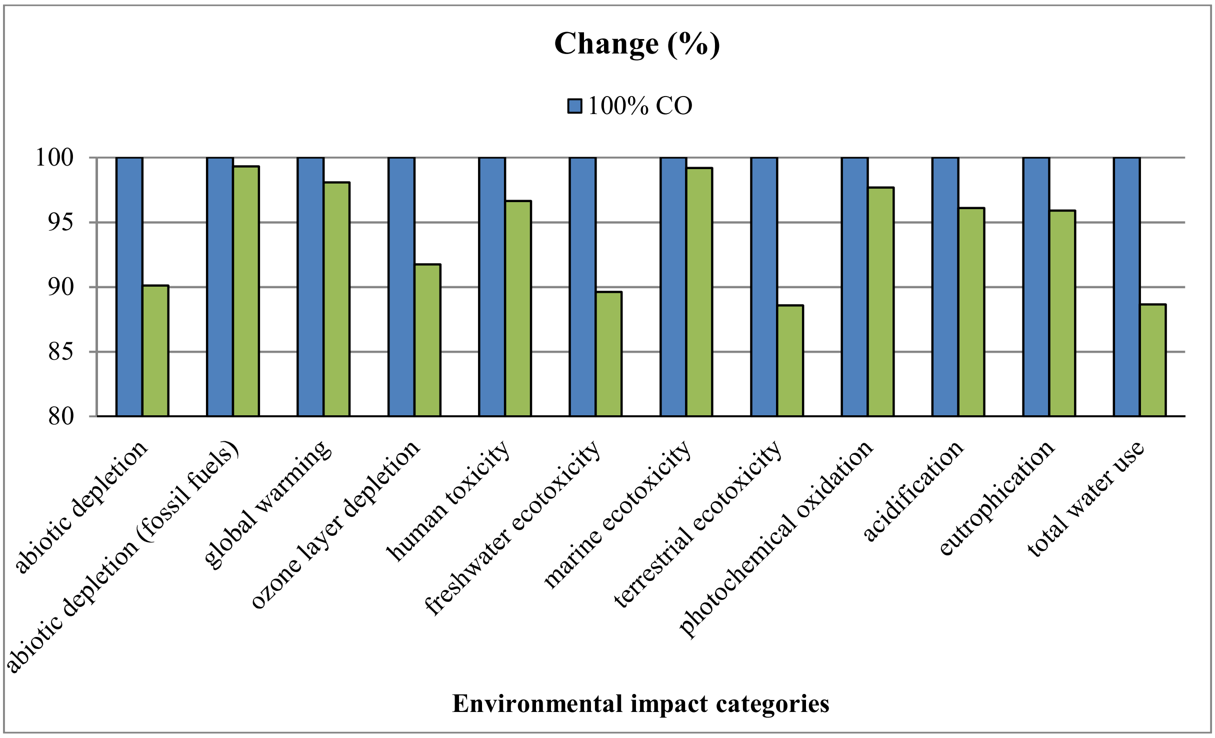

Figure 1. Change (%) of recycled sample compared to conventional sample

4. CONCLUSIONS

In this study, environmental impacts of two fabrics produced from virgin cotton and virgin cotton/recycled cotton compared with life cycle analysis. As a result, fabrics produced from 100% cotton fibre had more environmental impact than fabrics containing recycled cotton fibre in all impact categories due to due to the harmful effects of cotton production. As well as cotton production stage, the electrical energy consumed in yarn and knitted fabric production process in both fabrics has an important share in environmental impacts.

ACKNOWLEDGMENT

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5. REFERENCES

[1] KAZAN, H., AKGUL, D., and KERC, A. Life cycle assessment of cotton woven shirts and alternative manufacturing techniques. Clean Technologies and Environmental Policy, 2020, vol. 22, pp 849-864.
[2] ŞENER FIDAN, F., KIZILKAYA AYDOĞAN, E., and UZAL, N. The impact of organic cotton use and consumer habits in the sustainability of jean production using the LCA approach. Environmental Science and Pollution Research, 2023, vol. 30, no. 4, pp 8853-8867.
[3] BAFFES, J., BADIANE, O., NASH, J. Cotton: Market structure, policies and development issues. In WTO Africa Regional Workshop on Cotton, Cotonou, Benin, 2004, Vol. 2324.
[4] CLAY, J. World agriculture and the environment, a commodity-by-commodity guide to impacts and practices. Washington DC, USA: World Wildlife Fund, Island Press. 2004, p 570.

[5] MUTHU, S.S. Environmental sustainability in the textile industry. In Sustainability in the textile industry, Edited by: Muthu S.S. Singapore: Springer, 2017, pp 9-15.
[6] ZHANG, Y., LIU, X., XIAO, R. and YUAN, Z. Life cycle assessment of cotton T-shirts in China. The International Journal of Life Cycle Assessment, 2015, vol. 20, no. 7, pp 994-1004.
[7] ESTEVE-TURRILLAS, F. A., de la GUARDIA, M. Environmental impact of recover cotton in textile industry. Resources, Conservation and Recycling, 2017, vol. 116, pp 107-115.
[8] SPATHAS T. The environmental performance of high value recycling for the fashion industry, LCA for four case studies: Master's thesis. Chalmers University of Technology, Department of Energy and Environment. Gothenburg, Sweden, 2017, 67 p.
[9] ERAYMAN YÜKSEL, Y., KORKMAZ, Y. Çevre dostu denim kumaş tasarımı ve yaşam döngü analizi. Kahramanmaraş Sütçü İmam Üniversitesi Mühendislik Bilimleri Dergisi, 2023, vol. 26, no. 1, pp 117-125.

A STUDY ON REDUCING THE COLOR DIFFERENCE BETWEEN DYEING IN THE LABORATORY AND DYEHOUSE

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ABSTRACT

Within the scope of the study, it is aimed to examine the laboratory-dyehouse harmony, which is one of the biggest problems in the business, and to minimize the difference. In addition, it is aimed to make the necessary corrections in order to reduce the trials made during the application of the recipes prepared by the laboratory and to prevent the time, labor and dye/chemical consumption lost in this process. For this purpose, dyeing processes were applied to a selected woven fabric containing viscose / cotton / elastane with different recipes in the laboratory and in the dyehouse, and evaluations were made by comparing the color values. The color difference has been tried to be minimized with the applied experiments. In the results of working; it has been observed that darker colors can be obtained by completely removing the caustic from the dyeing recipe in the laboratory and lowering the pH value.

Keywords: Dyeing, laboratory dyeing, spectrophotometer, color difference, energy/labor/consumable saving.

1. INTRODUCTION

The part that has the greatest importance in terms of usage characteristics and added value of the products produced in the textile sector is the finishing department. Fabrics, which are one of the cornerstones of textile ready-to-wear products, consist of three stages, namely finishing processes in order to create a difference. Coloring from these stages is an important factor in the commercial success of textile products with high fashion content, especially apparel fabrics and home textile products.

Parameters such as color, touch, pattern and cut are effective in the purchasing process of a product. One of the process steps in which these parameters are provided is the coloring process. The main purpose of coloring is to increase the appeal of the finished product and to achieve the desired color. Coloring is applied with two different methods as dyeing and printing, and dyeing processes are more widely used.

In general, the following can be said about the dyeing process:

- Fashion is important in terms of taste and appeal of the product.
- Dyeing done with the desired standards and correct methods adds value to the product[1].

Cotton fiber is the fiber with the highest consumption rate in the global textile industry. Reactive, cube, direct, sulfur and azoic dyestuffs are widely used in dyeing cotton fiber. Due to their properties, reactive dyestuffs are the most common dyestuff class used for dyeing cotton products.

Unlike other dyestuffs, reactive dyestuffs have the property of covalent bonding to the fiber by reacting with fiber macromolecules. In addition, since reactive dyes can be dyed at low temperatures, this class of dyestuffs has developed rapidly in a very short time (İçoğlu, 2006).

Reactive dyestuffs are dyestuffs used in dyeing products made of cellulosic fibers, which have the most common usage area, give desired fastnesses, have a wide color palette and a wide color gamut. However, chlorine fastness is low, there is a risk of hydrolysis of the reactive group in basic media, and water, energy consumption and time spent in washing processes after dyeing are high [2].

The development of reactive dyestuffs, which have broad spectrum properties, brought about their transfer to textile materials in different ways. Reactive dyestuffs, which are preferred in the dyeing of cotton fabrics today, can be applied according to the impregnation and extraction method. While some reactive dyestuffs are only suitable for the impregnation method, some reactive dyes are suitable for the extraction method. Some reactive dyestuffs can be used in both impregnation and extraction methods. Considering that it is important to provide economy and desired fastness properties in dyeing, which method should be chosen for dyeing cotton fabrics with reactive dyestuffs is of great importance [3].

1.1. Reactive Dyes

Dyeing with reactive dyestuff, which is one of the most preferred methods for dyeing cellulose-based materials in the textile sector, is based on the formation of covalent bonds between –OH groups in cellulose macromolecules and reactive groups in dyestuff under appropriate conditions. Therefore, in the structure of reactive dyestuffs, there should be a reactive part that can react with the hydroxyl groups in cellulose, a chromophore part that gives the color, a bridge between the two parts, and groups that provide water solubility (Figure 1) due to the fact that the dyeing takes place in an aqueous medium [4].

Figure 1. Schematic Structure of Reactive Dyes [5]

In principle, the dyeing process consists of 3-4 steps, whether the dyeing process is done with dyes that can be dyed cold or hot according to the shrinkage method with reactive dyestuffs. These stages are; It can be listed as uptake of the dyestuff by the fibers (migration step), the reaction of the dyestuff with the fiber (fixing step), the removal of the dyestuff part that has been hydrolyzed and not fixed to the fiber from the product (washing step).

During dyeing with reactive dyestuffs, the reactive group of the dyestuff is hydrolyzed by reacting not only with the hydroxyl groups of cellulose macromolecules, but also with the hydroxyl groups of water. The hydrolyzed dyestuff loses its ability to react with the fiber, resulting in a decrease in dyeing efficiency. In addition, they cause a decrease in wet fastness due to their mechanical bonding to the fibers. It is not possible to completely prevent hydrolysis. However, measures can be taken to reduce it.

1.2.Dyeing by Impregnation Method

According to the impregnation method, dyeing begins with the product being passed through the dye liquor and squeezed through the squeezing rollers, and then the fixation process is applied with a suitable method. This method does not contain water, dyestuff, chemicals, auxiliaries, etc. It saves money and reduces waste water generation.

The basic machine used in the impregnation method is the padding. A typical horizontal foulard structure is shown schematically in Figure 1.2.

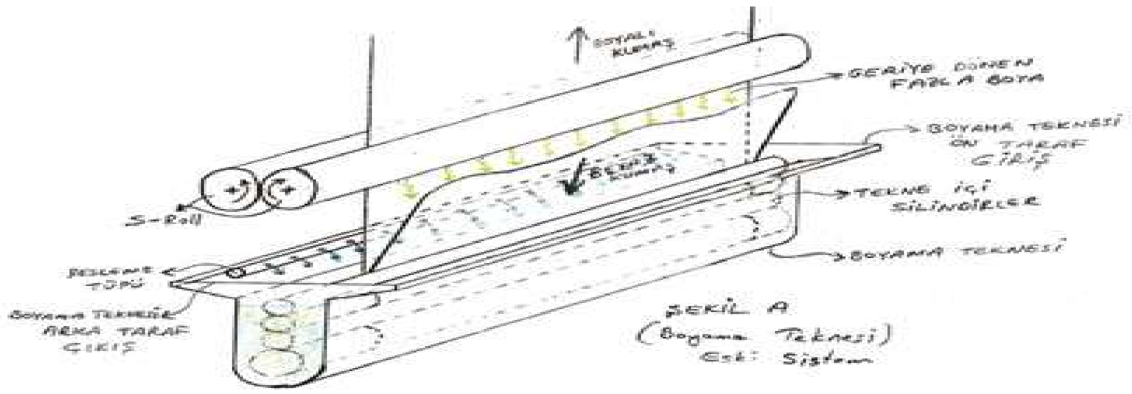

Figure 2. A Typical Horizontal Fulard Structure [6]

The impregnation method consists of three main steps:
1. Impregnation
2. Fixed
3. Washing and soaping processes

The impregnation process, according to the condition of the product; It can be applied from dry to wet or from age to age by using a foulard. This method has two basic features, and the opposite is true for the extrusion method.
1) Short liquor ratio (less than 1:1.5 liquor ratio)
2) Short treatment time

In application with impregnation, it is not necessary to keep the transit time of the product from the liquor too long. However, in very short passes, the application may not be sufficient. Sufficient time should be provided for the wetting of the textile product, the application of dyestuffs and chemicals.

In this process, dyestuff and alkali can be given together or applied separately. Giving them all together is called the one-bath method, while giving them separately is called the two-bath method. In the one-bath process, liquor stability is important. As the reactivity of the dyestuff increases, the loss of color intensity increases in long waiting times. For this reason, the dye solution is pumped to the scarf from separate vessels and the alkaline solution from separate vessels. In addition, the trough volume of the scarf is kept low. In this way, 5 minutes after the dyestuff and solution come together, it is completely displaced.

According to the impregnation method, dyeing can be applied continuously or semi-continuously. In this context, semi-continuous systems working according to the impregnation method are pad-batch, pad-jig and pad-roll, while continuous systems are pad-steam, pad-dry and pad-thermosol. Continuous dyeing is a process in which the dyeing process continues uninterrupted. Due to the high initial investment cost, it is more suitable for businesses that constantly paint in large batches. All continuous dyeing methods begin with impregnation, as with semi-continuous dyeing. Then, it continues with fixing and washing processes according to the method.

Advantages of the impregnation method:
1) Short liquor ratio, low water usage and waste water amount
2) Low consumption of dyestuff and chemical substance used
3) Low energy costs
4) Economical dyeing of long lots
5) Suitability for long-length painting
6) The filling, unloading and cleaning time of the machine is short compared to the puller method.
7) Process repeatability is higher than the extrusion method
8) To be suitable for fabrics with the danger of permanent fracture scars.

Disadvantages of the impregnation method:
1) High investment expense
2) Not suitable for short parties
3) The squeezing rollers are sensitive in construction and require maintenance
4) The risk of painting irregularities such as head-end difference, wing difference, migration
5) The need for more precise adjustment of flotte concentration calculations
6) Continuous systems are not produced in Turkey [3]

1.3. Importance and Purpose of the Study

It is an important issue that reactive dyeing processes can be done correctly in one go and that they can be repeated in the same color applications in dyehouse enterprises in the textile industry. Reactive dyeing works are first carried out in the laboratory environment in line with the wishes of the customers, and production is started in the operating environment after customer approval. However, when the color studies made in the laboratory are transferred to the enterprise, the problem of color difference is encountered. In this context, in order to solve/reduce the problem, it is necessary to examine the parameters that may cause color difference for each stage. This situation increases the number of applications and causes cost increase, time loss, excessive raw material consumption and labor loss in dyehouse enterprises.
In this study, it is aimed to minimize the laboratory-business color compatibility and reproducibility problem, which is the biggest problem of the dyeing adventure that starts in the laboratory in the textile sector and ends in the enterprise. For this purpose, fabrics and colors that were dyed within the program in the enterprise where the study was carried out and that had color difference problems were preferred. Within the scope of the studies, experiments were carried out by making differences on the variables of pH, time, temperature, dyeing and washing place in order to reduce the percentage difference by considering both the laboratory recipe and the existing business recipe. As a result of the applied trials, new prescriptions were created to dye the prescriptions received by the enterprise from the laboratory with a minimum of changes.

The main purpose of the study is to minimize both labor, time, energy and water losses in the competition in the global market, to reach the right result at the first time and to reduce the problems experienced in repeatability.

2. MATERIAL AND METHOD
2.1. Material
2.1.1. Sample Fabric Properties

Within the scope of the experimental study, a viscose/cotton/elastane blend woven fabric was used as a sample, and the sample weaving process and all dyeing trials were carried out by Kıvanç

Tekstil Tic. and San. Inc. carried out with support. The fabric with a mixture ratio of 55% viscose, 40% cotton and 5% elastane was chosen as the sample, since it is widely produced in the enterprise and contains two different cellulosic fibers. Selected construction parameters of the sample fabric are given in Table 2.1.

Table 1. Sample fabric properties

Weave Type	2/1 Twill Z
Weft Density	26 wire/cm
Warp Density	32 wire/cm
Weft Yarn Count	Ne 14/1 carded + 70 dtex elastane(corespun)
Warp Yarn Count	Ne 28/2 viscose + 70 dtex elastane(ring)
Width	142 centimeter + 335 gram/meter

2.1.2. Dyes and Chemicals

In the thesis study, 4 different colors were selected for the dyeing trials to be made on the sample fabric. Preferred colors; It was determined by choosing the colors belonging to the light, medium and dark categories, which were previously dyed in the enterprise and where laboratory-operation incompatibility was experienced.

2.2. Method

The steps of the method followed in the experiments applied in the laboratory and in the enterprise within the scope of the experimental study are given below, respectively.

- First of all, sample woven fabric was produced.
- Before the dyeing trials, a pre-treatment process in the form of Lot Preparation–Burning–Bleaching–Drying/Fixing was applied to the woven sample fabric.
- Color-based recipes were created and dyed according to the desired reference in the laboratory environment.
- Using the recipes prepared by the laboratory, 3 meters of fabric were dyed according to the extrusion method in the enterprise.
- Colors painted in the facility were compared visually and spectrophotometrically according to the reference color given by the laboratory.
- According to the results of the comparison of the color dyed in the enterprise with the reference fabric (the fabric dyed in the laboratory with the laboratory recipe), new recipes were determined in the enterprise.
- In the laboratory environment, dyeing was carried out under both pH=12.5 and pH=10 conditions with laboratory prescription. On the other hand, the business recipe was dyed only in pH=10 environment.
- In order to reduce the color difference between the laboratory application and the business application, experiments were made in different combinations by changing the washing and drying place, fixation time and temperatures.
- As a result of these processes, the optimum conditions were tried to be determined by making evaluations with visual and spectrophotometric measurements.
- It was determined that the lowest color difference occurred under pH=10 conditions and new recipes were created under these conditions.

While dyeing is carried out at pH=12.5 under normal conditions, the reason why dyeing experiments are carried out in an environment with pH=10 within the scope of the study is briefly explained below.

During the dyeing process, caustic and soda are used to ensure that the dyestuff can be attached to the fabric and fixed and to regulate the alkalinity of the environment. When these chemicals and dyestuff combine, they pass from the acidic environment to the alkaline environment. However, the caustic chemical, which enables the dyestuff to bind to the fabric, is also used for dye removal from the fabric. For this reason, within the scope of the study, the caustic chemical was removed in the laboratory environment and dyeing was carried out with only different amounts of soda, at different pH values, and the pH value of the darkest color was observed. According to the results of the experiment, it was observed that the saturation level of the color was at the highest level in dyeings at pH = 10, and within the scope of these results, experiments were made to create new recipes in which the color closest to the color of the enterprise was transferred to the enterprise with the least amount of change by dyeing at pH=10 conditions.

2.2.1. Machines Used in the Laboratory

- ATAÇ GK 40E brand fixation machine,
- MATHIS brand LABDRYER dryer,
- ATAÇ FY 350 brand horizontal foulard,
- Wise Stir brand mixer,
- SARTORIUS brand precision balance,
- SARTORIUS brand pH meter,
- Scaled containers are used for weighing dyes – chemicals

2.2.2. Machinery Used in the Business and Its Features

Within the scope of this study, Kıvanç Tekstil Tic. Work has been carried out on the machine, which is known as Pad Humidity Fix in the terminology and known as E Control in the enterprise. There are 2 of these machines in the enterprise, one for the light color group and the other for the medium and dark color group. In these machines, cellulosic parts in 100% viscose, 100% tencel, 100% cotton, cotton-polyester, cotton-viscose and polyester-viscose groups are dyed.

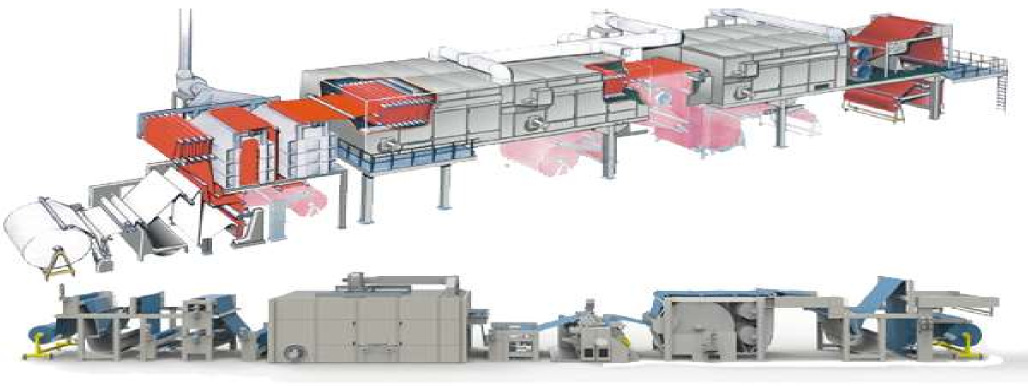

Figure 3. E Control Machine[7]

3. EXPERIMENTAL STUDY AND FINDINGS

Within the scope of the study, laboratory recipe and business recipe of 4 different colors dyed, different washing place (business and laboratory washing), different drying place (working and laboratory drying), different pH values (pH 10 and 12.5) and different fixation times were applied and The obtained colors were compared with the help of a spectrophotometer device. The results obtained were evaluated together and new recipe suggestions were made for each color, and the differences between the amount of dyestuffs between the enterprise and laboratory recipes could be reduced to a certain extent.

For these purposes, dyeing process was applied for 4 different colors on viscose/cotton/elastane blended fabric. A liquor was prepared according to the recipe and the fabric was passed through the scarf in a determined number of times, then different experiments were carried out by changing the washing place, drying place, fixation temperature and fixation times, and the effects of these variables on the color were observed. The dyeing experiments for each color and the evaluation of the results are given below.

In these studies, it is aimed to reduce the color difference between the laboratory and the enterprise and to make the transition without changing the amount of dyestuff in the recipe or with the least change.

4. CONCLUSIONS AND RECOMMENDATIONS

Within the scope of the study, it was aimed to examine the laboratory-business harmony, which is one of the biggest problems in the business, in the color formation adventure that starts in the laboratory and ends in the business, and to prevent the trials made during the application of the recipes prepared by the laboratory in the business part, and the time, labor and dye/chemical consumption lost in this process. It is aimed to minimize the difference by making the necessary corrections.

In other words, it is aimed to develop approaches to reduce the change in the amount of dyestuff in the recipe while the color transition is made from the laboratory to the enterprise in the impregnation dyeing method.

Within the scope of the study, laboratory recipe and business recipe of 4 different colors dyed, different washing place (business and laboratory washing), different drying place (working and laboratory drying), different pH values (pH 10 and 12.5) and different fixation times were applied and the obtained colors were compared with the help of a spectrophotometer device. The results obtained were evaluated together and new recipe suggestions were made for each color, and the differences between the amount of dyestuffs between the enterprise and laboratory recipes could be reduced to a certain extent.

Accordingly, the results obtained with the experimental studies applied within the scope of the study are summarized below.

• It has been observed that by removing caustic completely from the dyeing recipe in the laboratory environment, the pH value is lowered and deeper colors are obtained.

• Approximately 4 minutes of drying was carried out both in the laboratory and in the plant. However, it was observed that the color was dark due to the free drying in the fan drying and the collection from the weft-warp.

• Approximately 40% darker colors were obtained as a result of dyeing the recipe obtained from the laboratory without making any changes in the enterprise.

• When the color obtained by taking a piece from the fabric passing through the scarf in the plant dyeing machine after the printing cylinders and fixing it in the laboratory, the color obtained after passing through the chamber of the machine in the plant at the place where the part is taken, is darker.

• It has been observed that the effect of direct steam in the operating conditions on the color is different compared to the steam produced by the fixation machine in the laboratory.

5. REFERENCES

[1] AKPINARLI, HF. 2010. Tekstilde Kalite Kontrol Ders Notları, Gazi Üniversitesi Mesleki Eğitim Fakültesi, Ankara.

[2] KIROĞLU M., FETTAHOV R., KAPLAN M., 2017. Reaktif Boyama İşleminden Sonra İşletme ve Laboratuvar Yıkama Uygulamalarının Renk Değişimine Etkisinin İncelenmesi. Bartın Üniversitesi Mühendislik ve Teknoloji Bilimleri Dergisi,5(1).

[3] İÇOĞLU İ., 2006. Pamuklu Dokunmuş Kumaşların Reaktif Boyarmaddelerle Boyanması ve Uygulama Yöntemlerinin İncelenmesi. Yüksek Lisans Tezi, Çukurova Üniversitesi, Fen Bilimleri Enstitüsü, Tekstil Mühendisliği Anabilim Dalı, Adana.

[4] SARIDERELI A., 2010. Boyahanelerde Laboratuvar ile İşletme Arasındaki Renk Değişimlerinden Kaynaklanan Hataların Azaltılması. Yüksek Lisans Tezi, Dokuz Eylül Üniversitesi, Fen Bilimleri Enstitüsü, Tekstil Mühendisliği Anabilim Dalı, İzmir.

[5] ERCAN E., 2019. Reaktif Boyamada Laboratuvar ile İşletme Renk Farkının Azaltılması: Taguchi Yaklaşımına Dayalı Bir Uygulama. Yüksek Lisans Tezi, Pamukkale Üniversitesi, Sosyal Bilimler Enstitüsü, İşletme Anabilim Dalı, Denizli.

[6] https://www.tekstilteknik.com.tr/acik-en-duz-boya prosesinde-orta-kenar-renk-farkinin-en-aza-indirilmesi-icin-gelistirilen-patentli-boya-besleme sistemi/, Mart 2023

[7] www.tekstilteknik.com.tr, Erişim tarihi: Mart 2023

THE IMPORTANCE OF FIBER TYPE AND COLOR IN THE ENVIRONMENTAL EFFECTS OF GARMENTS

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ABSTRACT

Life Cycle Assessment (LCA) methodology is widely used to calculate environmental impacts of products. In this study, LCA approach was applied for garments produced from two fiber types and three colors to determine the environmental effects of them. As a result, the use of PET fiber increases the global warming potential (GWP) of the product. The GWP value of 50% PET addition relative to 100% cotton fiber increased by 29%, 49%, and 36% for white, tinte, and smaragd color, respectively. The darkening of the color also causes an increase in the GWP value.

Key Words: Textile, LCA, fiber, color

1. INTRODUCTION

The most important factor that determines the characteristics of the clothes is the type of fabric used [1]. Fashionably dressed people prefer clothes prepared according to the current color and fabric type. Fashion designers can choose different fiber types according to the usage areas of textile products. While producing and dressing fashionable clothing is important in modern societies, a more important issue today is choosing clothing with the least environmental impact. It is a known fact that the textile industry is one of the industries that harm the environment more. Since dressing is a compulsory need for people, producing environmentally friendly clothes and choosing such clothes is an important issue in terms of sustainability approach. It has to be a life philosophy for people to choose products that are less harmful to the environment throughout their life cycle, and accordingly, behaviours need to change [2]. So, in this context, which color fabrics produced with which fiber should be preferred? One of the methods that can be used to find the answer to this question is life cycle analysis (LCA).

LCA provides a holistic approach to the assessment of environmental impacts throughout the life cycle of a product or manufacturing process and also allows informed decision making [3,4]. The use of life cycle thinking approach will help to make the most informed decisions in order to make a sustainable production in the apparel industry.

With this study, it was aimed to reveal the current environmental effects of polo t-shirts, which are cut and sewn in TYH Tekstil company, and determine the effects of fiber type and color on the environmental impacts of garments by LCA analysis. Up-to-date data on all production processes of the polo t-shirt were collected from the field.

2.MATERIAL AND METHODS

This study was conducted in accordance with the Life Cycle Assessment (LCA) methodology according to ISO 14040-44 standards [5,6]. LCA consists of four basic stages: definition of goal and scope, inventory analysis, life cycle impact assessment and interpretation [7].

2.1. Goal and Scope

In LCA studies, the priority parameters to be defined are the functional unit and system boundaries [8]. The functional unit was selected as one polo t-shirt with different unit weights. The system boundary includes upstream and main production processes with a cradle-to-gate approach. Consumer-side distribution, use phase, and end-of-life phases were excluded due to lack of high-quality data. The system boundary of the LCA study conducted on polo t-shirts in Figure 1. This LCA study aims to calculate the estimated life cycle environmental impacts of polo t-shirts of different fiber types and colors. Technical information of selected textile products are shown in Table 1.

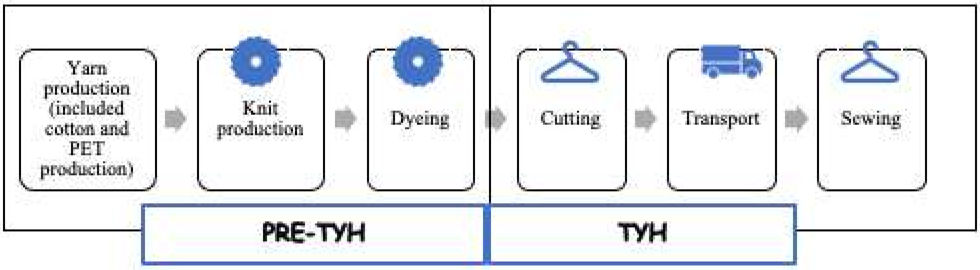

Figure 9. System boundary

Table 2. Information of the studied garments

Fabric type	Weight of the product	Color of the product
A short sleeve polo shirt made of 100% cotton	323 g	White
A short sleeve polo shirt made of 50% cotton and 50% polyester fiber	323 g	White
A short sleeve polo shirt made of 100% cotton	200 g	Tinte
A long sleeve polo shirt made of 50% cotton and 50% polyester fiber	300 g	Tinte
A short sleeve polo shirt made of 100% cotton	200 g	Smaragd
A long polo shirt made of 50% cotton and 50% polyester fiber	300 g	Smaragd

2.2 Inventory Analysis

The LCA model was created using the GaBi 10.7 software system developed by PE International [9]. LCI consists of primary and secondary data collected in the following categories: raw material production, yarn and fabric production, transportation, apparel production. Primary data is data collected directly from the field. If primary data is not available, secondary data were obtained from the existing database. The databases in GaBi software are used for energy generation, raw materials, process materials, transportation, wastewater treatment, etc. It provides secondary LCI data used for modeling [10]. Data sources of polo t-shirts are given in Table 2.

Table 2. LCI data sources

Life cycle stage	Data type	Source
Yarn production (raw material+spinning)	-The cradle-to-grave LCI for global average fiber covers raw material production from field through ginning. -Polyethylene terephthalate (PET) fibres; reaction of dimethyl terephthalate and ethylene glycol; production mix.	Extention database; On-field investigation
Knit production	The gate-to-gate LCI for knitting from fiber through fabric.	On-field investigation
Dyeing (pretreatment+dyeing+ finishing)	The gate-to-gate LCI for dyeing from fabric through dyed fabric.	On-field investigation; Textile database
Cutting	On-site energy and material use; loss rates of fabrics	On-field investigation
Sewing and Packaging	On-site energy and material use	On-field investigation
Transportation	Transportation distance of factories, by truck	Google map

3. RESULTS

In the LCA interpretation step the results are reviewed and identified the significant issues based on the result of LCIA phases [11]. The impact categories chosen to determine the environmental impacts of products are different in each study, depending on the purpose and LCA methodology chosen. The most widely used LCIA methods for cotton textiles have been EDIP, CML and ReCiPe, which are comprehensive methods that include many environmental impact categories [12]. Therefore, the impact category method was chosen as CML2001-Aug 2016. In this study, abiotic depletion-fossil (ADP), acidification (AP), eutrophication (EP), and global warming (GWP) potentials are taken into consideration and the results are given in Figure 2.

3.1. Abiotic Depletion-Fossil (ADP)

ADP-fossil refers to the amount of non-renewable raw materials globally over a period of at least 500 years. As seen from Figure 2, cotton (CO)-polyester (PET) polo t-shirts have the highest ADP. It was determined that the effects of PET raw material are higher than 100% CO polo t-shirts, since it is obtained from non-renewable energy source petroleum. The tinte CO-PET polo t-shirt has about 103% higher ADP from the white CO polo t-shirt.

3.2. Acidification Potential (AP)

The highest AP effect was found for the tinte 50% cotton-50% polyester polo t-shirt, followed by the smaragd polo t-shirt in the same fabric composition. The products with the lowest AP effect were the white polo t-shirts. The upstream electricity production process emits sulfur dioxide to air, causing AP impact [13]. In addition, NOx and SO_2 emissions caused by the intensive use of chemicals, the dyeing step increases the AP [14].

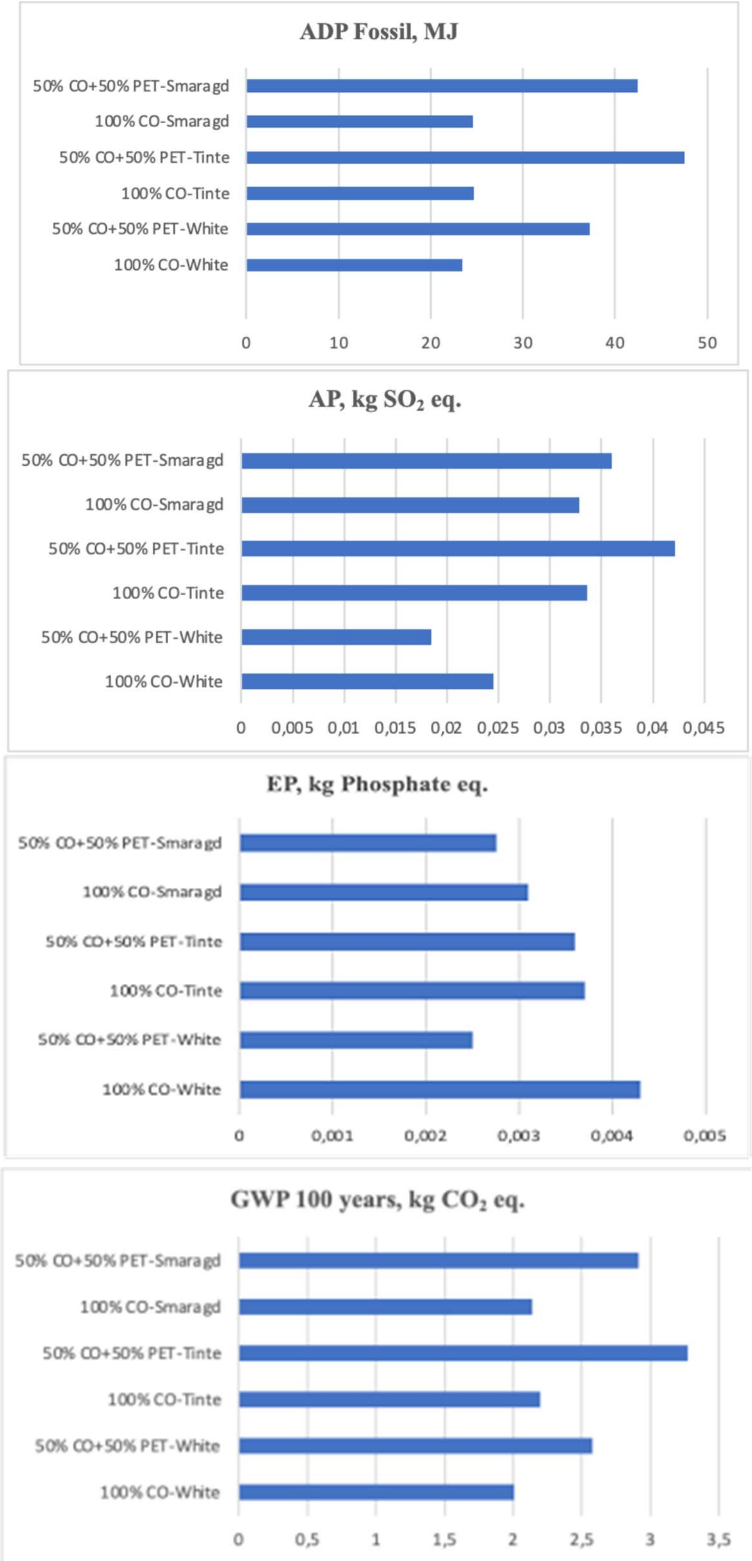

Figure 2. Environmental impact results of the analyzed polo t-shirt for different compositions

3.3. Eutrophication Potential (EP)

Figure 2 shows that the white cotton polo t-shirt has a higher effect than all the polo t-shirts. The total potential contribution to EP per 100% CO white polo t-shirt amounts to 0.0043 kg SO_2 eq. The second highest impact products are tinte polo t-shirts, and their impact values are close to each other. For cotton products, the process that contributes the most to EP is the agricultural phase. Especially during cotton production, phosphate and nitrate content flowing into surface waters from fertilized fields increases EP. In addition, HN_3, NO and N_2O emissions given to the air during cotton planting accumulate and reach the surface waters and increase the EP [14]. Chemicals, auxiliary chemicals and dyes in dyeing process also increase EP. More dyes, chemicals and water are needed to dye a textile product in dark color [15]. It should also be noted that white polo t-shirts contribute to greater environmental impact due to the weight-based allocation method.

3.4. Global Warming Potential (GWP)

As can be seen from Figure 2, the use of PET fiber increases the GWP of the product. The GWP of the 50% PET addition relative to 100% cotton fiber increased by 29%, 49% and 36% for white, tinte and smaragd color, respectively. Besides polyester production, it increases GWP due to the large amount of energy required to extract crude oil and refine it to make polyester. In addition, the dyeing of fiber is done separately for cotton dyeing and then for PET dyeing. Therefore, the energy use in the dyeing processes of the mixtures is higher [16].

4. DISCUSSION

The environmental effects of a polo t-shirt with different compositions (two different fibers and three different colors) were evaluated with the field data collected from pre-TYH and TYH company with LCA and these products were compared according to the selected impact categories. In the life cycle of the analyzed polo shirts, the highest GWP values are the tinte, smaragd, and white colored 50%-50% cotton-polyester polo t-shirt respectively. Similar results were also observed for ADP and AP. Significant energy consumption from crude oil, natural gas and electricity use for polyester fiber production has greatly affected the GWP, ADP and AP. However, when the EP potential effect of the products was examined, it was found that the highest effect was in 100% cotton products. The stage that contributes most to EP is the use of fertilizers and pesticides during cotton growing.

5. CONCLUSIONS

In this study, a LCA was conducted for different configurations of polo t-shirts and it was concluded that the use of PET fibers caused more environmental impact in other impact categories except EP while the cotton production caused the highest environmental impact in the EP impact category. The use of recycled polyester, recycled cotton, organic cotton and flax fiber for a more sustainable textile production will contribute to a significant reduction in environmental impacts in these impact categories [13]. Apart from raw material production, fabric dyeing, which is among the sub-stages of the garment manufacturing life cycle stage, has the other highest environmental impact. If the products with the same fibers are compared in terms of color, it can be seen that tinte colored products has a slightly higher environmental impacts than smaragd colored products.

ACKNOWLEDGMENT

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6. REFERENCES

[1] HOQUE, M. S., HOSSAIN, M. J., RAHMAN, M. M., & RASHID, M. M. Fiber types and fabric structures influence on weft knitted fabrics. Heliyon, 2022, 8(6).
[2] ORZAN, G., CRUCERU, A. F., BĂLĂCEANU, C. T., & CHIVU, R. G. Consumers' behavior concerning sustainable packaging: An exploratory study on Romanian consumers. Sustainability, 2018, 10(6), 1787.
[3] GUPTA, S., PATEL, P., and MONDAL, P. Life cycle analysis (LCA) and economic evaluation of catalytic fast pyrolysis: implication of co-product's end-usage, catalyst type, and process parameters. Sustainable Energy & Fuels. 2022, 6(12), 2970-2988.
[4] MUTHUKUMARANA, T. T., KARUNATHILAKE, H. P., PUNCHIHEWA, H. K. G., MANTHILAKE, M. M. I. D., and HEWAGE, K. N. Life cycle environmental impacts of the apparel industry in Sri Lanka: Analysis of the energy sources. Journal of Cleaner Production, 2018, 172, 1346-1357.
[5] ISO 14040:2006; Environmental management – Life cycle assessment – Principles and framework.
[6] ISO 14044:2006 Environmental management – Life cycle assessment – Requirements and guidelines.
[7] BARNES, E., REED, J., WALLACE, M., PETERSON, M., and O'LEARY, P. A life cycle assessment of the cotton textile chain. North Carolina, USA: Cotton Incorporated. 2010
[8] BUSI, E., MARANGHI, S., CORSI, L., and BASOSI, R. Environmental sustainability evaluation of innovative self-cleaning textiles. Journal of Cleaner Production, 2016, 133, 439-450.
[9] GaBi 10.7, 2023 [online], updated 29.08.2023. Available on: https://sphera.com/product-sustainability-software/
[10] BARNES, E., REED, J., WALLACE, M., PETERSON, M., & O'LEARY, P. A life cycle assessment of the cotton textile chain. North Carolina, USA: Cotton Incorporated, 2010.
[11] MOAZZEM, S., DAVER, F., CROSSIN, E., and WANG, L. Assessing environmental impact of textile supply chain using life cycle assessment methodology. The journal of the Textile Institute, 2018, 109(12), 1574-1585.
[12] CHEN, F., JI, X., CHU, J., XU, P., and WANG, L. A review: life cycle assessment of cotton textiles. Ind Textila, 2021, 72(01), 19-29.
[13] MOAZZEM, S., CROSSIN, E., DAVER, F., and WANG, L. Life cycle assessment of apparel consumption in Australia. Rigas Tehniskas Universitates Zinatniskie Raksti, 2021,25(1), 71-111.
[14] KAZAN, H., AKGUL, D., & KERC, A. Life cycle assessment of cotton woven shirts and alternative manufacturing techniques. Clean Technologies and Environmental Policy, 2020,22, 849-864.
[15] SEMIHA, E. R. E. N., KARADAG, N., YIGIT, I., and EREN, H. A. Süperkritik Ve Klasik Ortamda Poliester Boyamanın Yaşam Döngüsü Analizi İle Değerlendirilmesi. Uludağ Üniversitesi Mühendislik Fakültesi Dergisi, 2022, 27(3), 927-940.
[16] VAN DER VELDEN, N. M., PATEL, M. K., and VOGTLÄNDER, J. G. LCA benchmarking study on textiles made of cotton, polyester, nylon, acryl, or elastane. The International Journal of Life Cycle Assessment, 2014, 19, 331-356.

A STUDY ABOUT THE CORRELATION BETWEEN SEAM FATIGUE AND STATIC FRICTION TESTS FOR AUTOMOTIVE UPHOLSTERY CIRCULAR KNITTED FABRICS

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ABSTRACT

Automotive seat cover fabrics are typically produced by combining three layers by using flame lamination. The face fabric is produced by the technique of weaving or knitting, while the middle layer utilizes polyurethane foam and the back layer is a lightweight fabric defined as lining, scrim or backing fabric. Particularly in high-end cars and sports vehicles seats have more complex shapes according to mid-range vehicles. Knitted fabrics' trimming performances are better than the other fabric production techniques due to their flexibility and preferred because of better aesthetic concerns. While assembling seat cover with using circular knitted fabric is subjected to significant tensile forces and tensions. These tensions are increased the gap between the seams and/or sewing yarn may cause of the loop damage. Within the scope of this study, a double jersey circular knitted fabric was produced. Two different chemicals were applied to the fabric and the effect of these chemical applications were evaluated according to automotive testing standards.

Keywords: Seam fatigue, circular knitted fabric, seam breakage, static friction

1. INTRODUCTION

Woven and knitted are two main technologies method for automotive seat cover production. Both these two technologies can be divided according to own technology and technique [1]. As shown as Table 1, the percentages of fabric technologies used in automotive seat fabrics. that main fabric technologies used for automotive seat covers are woven velour, flat woven, warp knit tricot, warp knit pile sinker, warp knit double needle bar raschel, and circular knit [2].

Table 1. Relative volume of different seating fabrics [3]

Fabric Type	Europe	USA	Asia
Flat Woven	47%	14%	12%
Woven Velour	1%	30%	24%
Warp Knit Tricot (including Pol)	15%	11%	44%
DNBR	5%	23%	9%
Circular Knitted	21%	1%	7%
Leather	11%	21%	4%
Total	**100%**	**100%**	**100%**

Both warp and weft knitting technologies are used to generate numerous types of structures in automotive fabrics. For getting flat and pile fabrics, tricot machines, double needle bar warp knitting machines and in double jersey circular knitting machines can be used. For better trimmability, assembling and fabric flexibility can be combined. Within this combination, seat cover may meet with automotive testing standards. Knit are perceived by the automotive industry to deliver the desirable characteristics of low cost, low weight, and high performance [4]. According to The European automotive industry thinks that knitting fabric design flexibility, stretch characteristics, appearance and comforts are good opportunity to use for seat cover trimming. This design flexibility can provide the short-term type of color and pattern complexity with the minimum transition time required by European markets [5]. The advantage of knitted fabric is its elasticity and softness, making it more comfortable than woven fabrics. Materials used in the automotive industry require high elasticity [7]. The stretching feature of knitted fabrics provides ease of application, especially in shaped parts such as headrests and molded parts such as headlining and door panels [6].

Due to the flexibility characteristics of circular knitted fabrics, seam problems may arise during assembly processes and the creation of shaped parts. To test the seam durability, seam fatigue test and static friction tests are performed. As a result of the tests application, the seam durability of the produced circular knitted fabric, such as seat covering is determined.

2. EXPERIMENTAL STUDY

2.1. Materials

As the beginning of the study, fabric selections were made. A fabric that is currently produced for a Main Automotive Manufacturer and has encountered issues in the seam fatigue test was chosen. Fabric production was carried out by Mayer&Cie double jersey circular knit machine. These fabrics can be non-jacquard or jacquard. Subsequently, finishing processes were applied. Fabrics were washed at 70°C as open width. Fabrics are which is finishing were done, two different chemicals applied to the fabric as shown as Table 2. Chemicals are applied to the fabric with impregnation technique. Also, chemical-free application was done for the comparison.

Table 2. Chemical Application in Detail

	Chemical Application Step		
Samples	**Chemical**	**g/Lt**	**Temperature**
Sample A	Chemical-Free		
Sample B	Polyethylene-based	20 g/lt	140°C
Sample C	Polyacrylate-based	20 g/lt	

After the fabric production process were completed, the testing phase was initiated. Two different tests were performed in the testing phase: seam fatigue test and static friction test.

2.2 Methods

2.2.1. Seam Fatigue Test

The seam fatigue test is performed to determine the durability of the seam during trimming. Test pieces are cut from the length, width, and crosswise sections of the fabric. Two pieces from the same section are stitched together. Stitching needle number is 120 and Groz Beckert needles are used. In addition, 90 tex polyester stitching yarn is used. Afterwards, pieces are placed into the jaws and machine start to move in horizontal way. The testing is carried out with a load of 29.4 N

(3 kg) for 30 ±1 cycles. After completing the testing, measurements of the gap were taken, and it needs to be checked whether there is any seam breaking. The Figure 1 shows the seam fatigue device on below.

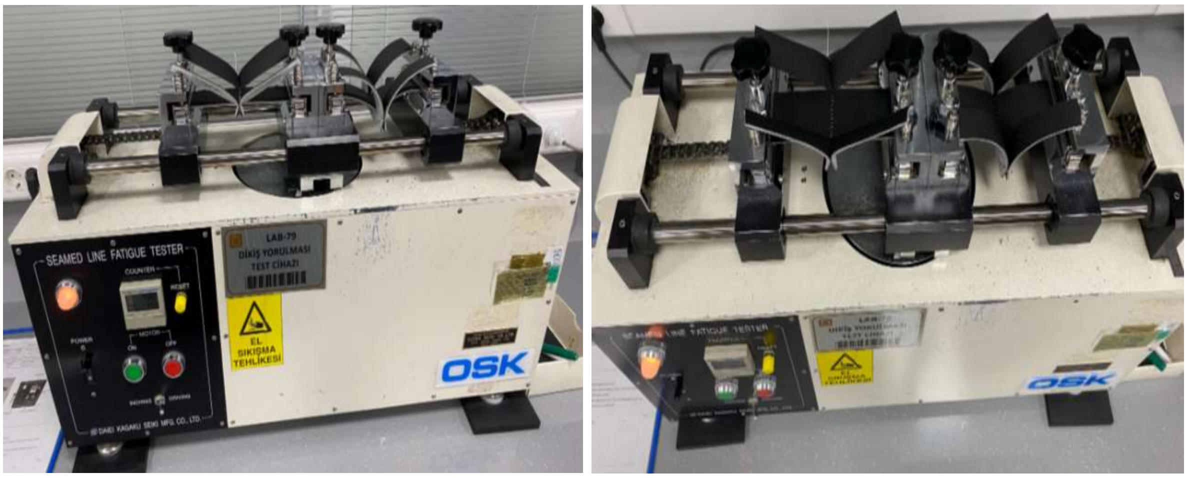

Figure 1. Seam Fatigue Testing Device

2.2.2. Static Friction Test

Static friction tests are performed for determined the slipperiness of the fabric. Test samples are cut from fabric as a length, width ways. Fabric placed on machine. Sled with abrasive fabric fitted placed on to fabric. Sled's dimensions are 65*105 mm, and the weight is 1500 g. The test speed is set to 2.7°/s and movable plate start to rise at an angle. Testing device shows the angle which is the sled slides from fabric at the end of the testing. The Figure 2 shows the seam fatigue device on below.

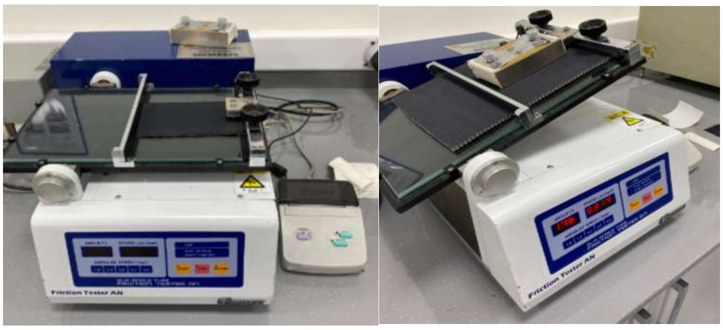

Figure 2. Static Friction Testing Device

3. RESULTS AND DISCUSSION

3.1. Seam Fatigue Test Results

Table 3. Seam Fatigue Test Results

	Sample A		**Sample B**		**Sample C**	
	L Direction	T Direction	L Direction	T Direction	L Direction	T Direction
100 cycles	1,5 mm	1,5 mm	1,5 mm	1,5 mm	2,0 mm	2,5 mm
1500 cycles	1,0 mm	1,5 mm	1,5 mm	1,5 mm	2,0 mm	2,0 mm
	Seam Break Status		**Seam Break Status**		**Seam Break Status**	
	L Direction	T Direction	L Direction	T Direction	L Direction	T Direction
100 cycles	Breakage	No Break	No Break	No Break	Breakage	Breakage
1500 cycles	Breakage	No Break	No Break	No Break	Breakage	Breakage

According to the seam fatigue test results are given in Table 3, Sample A's seam gap measurement results are 1 mm and 1,5 mm, so its in the acceptable range but on the L direction seam breakage is observed. Test results are not acceptable because of this seam breakages even if the seam gap measurements are in the acceptable area.

On Sample B there is no seam breakage is observed and the seam gap is 1,5 mm for both L and T direction. According to these results, the fabric meets the required test standards.

According to the test results of Sample C, seam breakage is observed on both L and T directions and seam gap is 2 mm and 2,5 mm and which is not acceptable according to the specifications.

3.2. Static Friction Test Results

Table 4. Static Friction Test Results

	Sample A	**Sample B**	**Sample C**
L Direction	23,8°	17,6°	25,8°
T Direction	23,5°	22,9°	36,1°

According to the static friction test results are given in Table 4, static friction angle of the Sample B is 17,6° for L direction and 22,9° for T direction. Static friction force of Sampe B's surface is less then Sample A and Sample C's surfaces.

Sample A's static friction angle is 23,8° for L direction and 25,8° for T direction. While on T direction of Sample A and Sample B a major difference was not seen in terms of static friction values, on L direction a significant difference was seen.

Sample C’s static friction angle is 25,8° for L direction and 36,1° for T direction. Static friction force of Sample C’s surface is the higher than Sample A and Sample B.

4. CONCLUSION

Within the scope of this study, polyethylene-based and polyacrylate-based chemicals were applied to the same circular knitted base in different batches using impregnation techniques. Subsequently, seam fatigue and static friction tests are performed on to fabric. Accordingly, the test results were evaluated. According to evaluation, Polyethylene-Based chemical significantly improved the results of the seam fatigue test. On the other hand, polyacrylate-based chemicals have a negative effect on seam fatigue test results. There is a correlation between seam fatigue and static friction tests. When the seam fatigue test results do not meet the OEM's specifications, the static friction test result is higher. This correlation can be explained by the fact that fabric surface behavior needs to have less surface friction force to obtain acceptable seam fatigue test results. When the fabric exhibits more surface friction force, it is considered more rigid. This rigidity leads to seam breakages and directly causing that results do not meet OEM'S specifications.

5. REFERENCES

[1] ANAND, S., Developments in Technical Fabrics-Part 1, Knit. Intern., July, 32–35.
[2] HARDCASTLE, M., In the driving seat I, Knit. Intern., July, 51–53 (2001).
[3] ANAND, S. AND SHAH, T., Recent Advances in Technical Textiles, in “International” Conference on Textile and Clothing”,
[4] FUNG, W., HARDCASTLE, M. (2001). Textiles in Automotive Engineering. Woodhead Publishing Limited, Cambridge, England
[5] ANON.2004b. Weft Knits Drive Forward, Knitting International, July, Vol. 111, Issue 1316, pp. 28-29
[6] RODGERS, S. AND POWELL, N., 2006 ‘Automotive Textile Durability 2D Testing im a 3D Application’, Autex Conference Proceedings, June 13, 2006, College of Textiles, Raleigh, N.C.
[7] KOVAČEVIĆ, S., & UJEVIĆ, D. (2013). Seams in car seat coverings: properties and performance. Joining Textiles, 478–506.

MACHINE MODIFICATION TO SOLVE COLOR CONTAMINATION PROBLEM IN YARN PRINTING MACHINES

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ABSTRACT

Dyeing of the yarn by the roller print method involve staining problem. This problem result from contact of the yarns during winding of the yarn on the hank by the conventional winding technology.
A new winding system was developed to overcome this problem. The new winding system established on conventional winding machine by modification of the machine and developing a new software. On the contrary of the conventional technic, the new technic give possibility winding of the yarn separately on the hank. Because of that, the different colors yarns on the hank are not contact with each other and the staining problem can not be occurred.

Key Words: Printing machines, yarn printing, yarn dyeing, hand knitting yarns, staining of the yarns.

1. INTRODUCTION

Hand Knitting yarns are generally soft twisted, bulky and thick yarns that are produced from acrylic fiber [1]. These products are manufactured by running a sequential series of processes which are stretch tow breaking, carding, process in the draw frame machine, yarn cleaning, folding and twisting, yarn printing, fixation and balling. Dyeing processes of this yarns can be done in different methods, one of this method is yarn printing dyeing. In this method, yarn can be dyed 6 different colors by using changeable pattern length by using dyeing machine as seen from Figure 1.

Figure 1: Yarn print dyeing

Figure 2: Knitting fabric sample which produced from print dyeing yarn

Hand knitting yarns are produced from acrylic fibers so that basic dyestuff are used as a dyestuff. During dyeing process, dye path are transferred to the yarns by roller printing method and then drying-fixing processes is applied. After these operations, the colored yarn is transferred to the hank parts. In machines with 6 printing cylinders, 6 different colors can be applied onto the yarn so the yarn can be dyed in 6 different colors within yarn length.

After dyeing process, some dyestuff not reacted with fiber molecular structure or hydrolyzed in the dye bath. As a result of this situation, the result of color fastness can be low, the migration of dyestuff can be high [2,3]. After dyeing with basic dyestuff, some unfixed dyestuff can stay on the fiber. So that reason it causes color contamination on the other yarn [4].

In case of this type of dyeing procedure there is no color contamination problem if color difference in short patterns. But it has been observed that there is color contamination in the yarns in case of color difference in long patterns. This problem can be seen especially sequence in dark&light color tones.

The mentioned problem appears as a major mistake on the fabric after knitting operation. (Figure 4) This problem causes customer dissatisfaction and losing market share. For the solution of this problem, different alternatives has been considered in the company like that production speed has been reduced to increased the fixation time, but the solution increased the production cost and the problem could not be solved permanently.

Figure 3: Print dyed yarn on the hank winder

Figure 4: Contamination of the white yarn by red dyestuff

2. MATERIAL AND METHOD

This staining problem continues to happen at different times even if lots of precaution has been taken. For solving this problem permanently, the modification of the print dye machine winding system has been decided according to literature review. Modification has been made in two ways, one of them is developing new software and the other of them is modification of the winding system of the machine. Winding system modification was based on the changing traverse driving and mechanic units. The conventional machine winding system was drive by the gear system through main motor. Because of that the stroke of the traverse was short and not to be controlled. The new drive system includes servo motor which provide longer stroke and control of the travers.

3. RESULT AND CONCLUSION

As seen in the figure 5 the new developed software involves control of the traverse driving units. By using this program, the travers unit of the winding system can be controlled result in winding different color yarn separately on the hank. The travers mechanism which transferred the yarn to the hank mechanism on the machine, converted to computer controlled system which cause automatically color changing detection. By using this type of winding mechanism each color has been transferred in different length and different area on the hank wheel. (Figure 5) The detection can be made from machine setup and drive the motor which drive the yarn winding carriage.

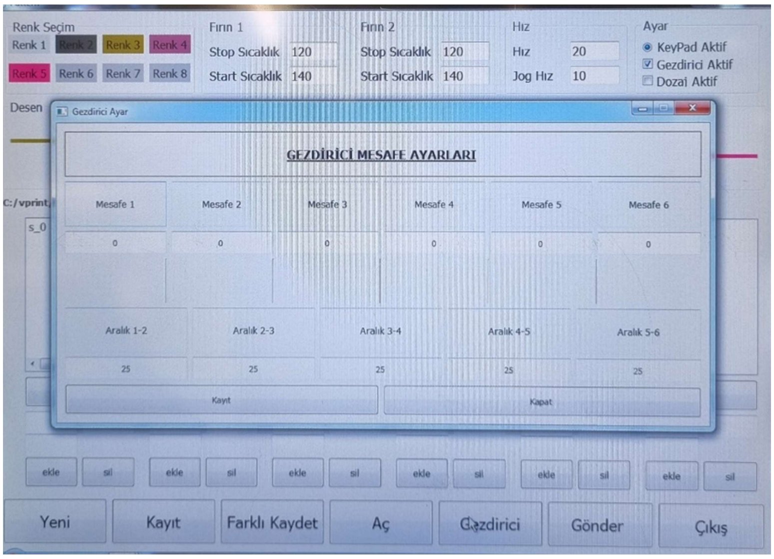

Figure 5: The software program that controls traverse driving unit

By this way, staining of the yarns under temperature and pressure is prevented, because of not wrapping of different colors yarns on each other. (Figure 6)

Figure 6. Skein on the hank as divided based on the color by modified machine

Figure 7. Knitting fabric from print dyeing yarn produced by modified machine setup

4. REFERENCES:

[1] Ormo Yün İplik San. Ve Tic. Aş. Kalite Yönetim Sistemi-Süreçler/ Tarama, Üretim, Boyahane.
[2] LIN L., RAMHAN Z., WEN S., NAVIK R., ZHANG P., CAI Y., (2016) Improvement of Colour Fastness for Deep Blue Shade of Cotton Fabric, 4th International Conference on Machinery, Materials and Computing Technology, China.
[3] Tekstil Teknolojisi Selülozu Boyama 1. EriGim: 01 Ocak 2019
http://www.megep.meb.gov.tr/mte_program_modul/moduller_pdf/Sel%C3%BClozu%20Boyama%201.pdf
[4] UDDIN, M. G. & ISLAM, M. (2015). Effects of Different Soaping and Fixing Agents on Washing Fastness of Reactive Dyed Cotton Fabric, Journal of Multidisciplinary Engineering Science and Technology, 2 (1), 57-61.

THE OPTIMIZATION STUDY ON TREATMENT OF DENIM FABRICS WITH SOL-GEL METHOD

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ABSTRACT

This study introduces the results of an optimization study applied on sol-gel application conditions onto denim fabrics. The result pointed out that it is possible to approach the optimum process conditions applicable at industrial scale working conditions to obtain good water repellency performance

Keywords: Sol-gel, denim fabric, super hydrophobic

1. INTRODUCTION

Denim fabric is mainly characterized by certain physical properties like high abrasion, high weight, tensile and tear resistance compared to frequently used cotton fabrics such as gabardine or poplin produced from cotton yarn. It is also popular choice in clothing industry through breathable structure with good level of thermal comfort due to their hydrophilic nature and has been produced for work wear and sportswear for many years. In recent years, various processes (coating / lamination, ozone fading, laser finishing, sandblasting, resin finishing, etc.) are applied to the denim product in order to give a new look and / or functionalities. There is an important market demand in denim industry towards functional properties especially for liquid repellence and flame retardancy. Combining those functionalities and to produce so-called multifunctional textiles find large market share. With sol-gel method, many functional properties that cannot be obtained by conventional methods can be added to textile materials and multifunctional fabrics can be produced easily. There are various studies in sol-gel applications over textile surfaces and all these pointed the high contribution of sol-gel process parameters like drying, condensation temperature, pH of the bath and the precursor type [1-19]. This study aimed to optimize the process parameters of sol-gel method to be applied to improve the water repellency of denim fabrics. It helped to find out the best applicable parameters of drying and condensation to utilize for usage at industrial scale from the water repellency point of view.

2. MATERIALS AND METHODS

2.1. Materials

The denim fabric properties used in this study are given in Table 1. The fabrics were supplied after caustic soda scouring by Çalık Denim A.Ş.. / Malatya. For the experimental plan, which is determined by the Design Expert, the input values were selected as drying / condensation (temperatures and duration) and commercially available water repellent chemical as additive; other parameters like pH, pre-cursor type and pre-cursor : solvent molar ratio were removed not to result with any negative effect on hydrophobic performance. The up-and-down limits of the inputs were selected as pointed in Table 2, The sol-gel application recipe given in Table 2 was applied onto denim fabric sample by foulard with the input variations given. The fabric samples were then tested for the contact angle and the water repellency tests (output data) according to ISO 4920.

Table 1. Denim sample properties

Fiber composition	Woven type	Warp x weft density (ends and picks/cm)	Warp Yarn Number (Ne)	Weft Yarn Number (Ne)	Weight (g/m^2)
97% : 3%, cotton : elastane	3/1 Z	21x18	14/1	18/1	275

Table 2. Recipe to be used for process optimization of water-repellent sol-gel bath

Ethanol	50 ml
TEOS	8 ml
Water	35 ml
HCl (0,01 N)	15 ml
HDMS	4 ml
GPTMS	11 ml
Urea	2 ml
Tween 20	2 ml
Commercial water repellant	A ml

Variation conditions for drying:
90 ^{0}C 15 min - 100 ^{0}C 10 min - 110 ^{0}C 5 min
Variation conditions for condensation:
170 ^{0}C 75 sec – 150 ^{0}C 5 min - 130 ^{0}C 20 min
Variation requirements for commercial water repellent chemical product:
0 ml – 3 ml – 5 ml

TEOS: Tetraethylorthosilicate (precursor**),** **HDMS:** Hexadecyltrimethoxysilane (co-precursor),
GPTMS: Glycidoxypropyltrimethoxysilane (co-precursor)

The minimum number of experiments and conditions to be applied in order to use the variation conditions determined according to the Design Expert supported mathematical modeling in the optimization study was as obtained in Table 3. Then, some of the model supported input data was rounded up; also since trials run by foulard with 1 mL commercially available water repellent chemical gave low water repellency, that value was also revised. So, the final application plan was as given in Table 4.

Table 5 gives the testing results (output data). It was found that commercially available water repellent chemical would increase contact angle value as expected but it was possible good level of water repellency with low amount of that chemical thanks to so-called ideal drying and condensation conditions. Later, the Design Expert were run again between up-and-down limits of outputs and 10 new optimized application conditions with expected output (contact angle value) were obtained as given in Table 6. The results revealed that it is possible to obtain contact angle over 135^0 with using low amount of water repellent chemical (16,22 mL). Therefore a new application set was prepared where the A value in Table 2 was 15 mL and drying and condensation conditions were as used in trial 5,8 and 10 which applied low, medium and high amount of water repellent chemical (Table 7). The final applications were completed by foulard and water angle measurements were run again. The results in Table 8 showed that sol-gel application with optimized process conditions resulted with very good water repellency performance (contact angle value of around 140^0).

Table. 3. Primary Experimental Conditions

Trial number	Drying Temperature (⁰C)	Drying time (min)	Condensation Temperature. (⁰C)	Condensation Time (min)	Commercial WR Chemical (mL)
1	94,05	15,00	138,11	10	3,99
2	90,00	15,00	150,00	5	2,50
3	94,05	15,00	161,89	2,5	3,99
4	105,95	7,00	138,11	10	1,01
5	100,00	10,00	130,00	20	2,50
6	105,95	7,00	161,89	2,5	3,99
7	100,00	10,00	150,00	5	2,50
8	105,95	7,00	138,11	10	3,99
9	100,00	10,00	150,00	5	0,00
10	94,05	15,00	138,11	10	1,01
11	110,00	5,00	150,00	5	2,50
12	100,00	10,00	150,00	5	2,50
13	100,00	5,00	150,00	5	2,50
14	105,95	7,00	161,89	2,5	1,01
15	100,00	10,00	150,00	5	5,00
16	100,00	10,00	170,00	1,25	2,50
17	100,00	10,00	150,00	5	2,50
18	100,00	10,00	150,00	5	2,50
19	100,00	10,00	150,00	5	2,50
20	94,05	15,00	161,89	2,5	1,01

Table. 4. Final Experimental Conditions

Trial number	Drying Temperature (⁰C)	Drying time (min)	Condensation Temperature. (⁰C)	Condensation Time (min)	Commercial WR Chemical (mL)
1	95,00	15,00	140,00	10	4,00
2	90,00	15,00	150,00	5	2,50
3	95,00	15,00	160,00	2,5	4,00
4	105,00	7,00	140,00	10	37,50
5	100,00	10,00	130,00	20	2,50
6	105,00	7,00	160,00	2,5	25,00
7	100,00	10,00	150,00	5	2,50
8	105,00	7,00	140,00	10	25,00
9	100,00	10,00	150,00	5	0,00
10	95,00	15,00	140,00	10	37,50
11	110,00	5,00	150,00	5	2,50
12	100,00	5,00	150,00	5	2,50
13	105,00	7,00	160,00	2,5	37,50
14	100,00	10,00	150,00	5	50,00
15	100,00	10,00	170,00	1.25	2,50
16	95,00	15,00	160,00	2,5	37,50

Table 5. Contact angle measurement results (average of ten measurements) as output data

Trial number	**Contact angle (^{0})**	**Water repellency score**
0 (Non treated)	119,16	0
1	138,37	50
2	138,96	50
3	121,83	50
4	131,72	50
5	140,65	50
6	**143,64**	**90**
7	134,05	50
8	**140,99**	**90**
9	123,90	50
10	**143,23**	**90**
11	143,17	50
12	143,39	50
13	136,88	80
14	**143,84**	**90**
15	130,25	50
16	**140,12**	**90**

Table 6. Optimized input and output data set by the Design Expert

Drying Temperature (^{0}C)	**Drying time (min)**	**Condensation Temperature. (^{0}C)**	**Condensation Time (min)**	**Commercial WR Chemical (mL)**	**Expected contact angle (^{0})**
99.97	7.44	148.34	4.99	37.17	146.347
105.05	7.02	139.62	9.78	41.66	140.03
101.03	9.41	139.24	15.19	21.35	141.311
98.88	11.16	162.41	4.41	38.84	148.846
98.18	11.59	152.15	15.82	19.59	119.289
100.89	9.68	154.44	7.19	16.22	135.697
100.22	9.97	156.69	11.56	36.52	148.288
102.29	8.55	149.28	11.66	17.80	119.716
98.18	11.88	156.12	5.11	34.98	147.601
99.92	10.58	136.94	11.02	41.72	131.113

Table 7. The final application conditions

Trial number	**Drying Temperature (^{0}C)**	**Drying time (min)**	**Condensation Temperature. (^{0}C)**	**Condensation Time (min)**
5	100	10	130	20
8	105	7	140	10
10	95	15	140	10

Table 8. The final application test result (average of ten measurements)

Trial number	**Contact angle (^{0})**
5	138,61
8	141,17
10	142,03

3. RESULTS AND DISCUSSSION

It has been shown that in the sol-gel trials applied to denim fabrics a contact angle of around 140 ^{0} can be obtained when the drying temperature is between 100 – 105 ^{0}C , the drying time is between 7 – 12 minutes and the addition of a low amount of commercial water repellent.

4. REFERENCES

[1] BENTIS, A., BOUKHRISS, A., & GMOUH, S. (2020). Flame-retardant and water-repellent coating on cotton fabric by titania–boron sol–gel method. Journal of Sol-Gel Science and Technology, 94(3), 719–730.
[2] CHAILLOT D., J. MIEHE-BRENDLE, S. BENNICI (2019), Insights on the influence of the precursors on the sol-gel synthesis of hybrid organiceinorganic saponite-like materials, Comptes Rendus Chimie, 22, 258-268
[3] FAN, D. D., YOU, F., ZHANG, Y., & HUANG, Z. (2018). Flame Retardant Effects of Fabrics Finished by Hybrid Nano-Micro Silica-based Sols. Procedia Engineering, 211, 160–168.
[4] HEIMAN-BURSTIEN, D., A. DOTAN, H. DODIUK, S. KENIG. (2021). Hybrid Sol–Gel Superhydrophobic Coatings Based on Alkyl Silane-Modified Nanosilica, Polymers 13, 539.
[5] JINDASUWAN, S., SUKMANEE, N., SUPANPONG, C., SUWAN, M., NIMITTRAKOOLCHAI, O., & SUPOTHINA, S. (2013). Influence of hydrophobic substance on enhancing washing durability of water soluble flame-retardant coating. Applied Surface Science, 275, 239–243.
[6] KUNDU, C. K., WANG, X., HOU, Y., & HU, Y. (2018). Construction of flame retardant coating on polyamide 6.6 via UV grafting of phosphorylated chitosan and sol–gel process of organo-silane. Carbohydrate Polymers, 181(November), 833–840.
[7] KUNDU, C. K., WANG, X., LIU, L., SONG, L., & HU, Y. (2019). Few layer deposition and sol-gel finishing of organic-inorganic compounds for improved flame retardant and hydrophilic properties of polyamide 66 textiles: A hybrid approach. Progress in Organic Coatings, 129(August 2018), 318–326.
[8] LI, S., LIN, X., LI, Z., & REN, X. (2019). Hybrid organic-inorganic hydrophobic and intumescent flame-retardant coating for cotton fabrics. Composites Communications, 14, 15–20.
[9] LIN, D., ZENG, X., LI, H., LAI, X., & WU, T. (2019). One-pot fabrication of superhydrophobic and flame-retardant coatings on cotton fabrics via sol-gel reaction. Journal of Colloid and Interface Science, 533, 198–206.
[10] LIU, J., DONG, C., ZHANG, Z., SUN, H., KONG, D., & LU, Z. (2020). Durable flame retardant cotton fabrics modified with a novel silicon–phosphorus–nitrogen synergistic flame retardant. Cellulose, 27(15), 9027–9043.
[11] QIN, R., SONG, Y., NIU, M., XUE, B., & LIU, L. (2020). Construction of flame retardant coating on polyester fabric with ammonium polyphosphate and carbon microspheres. Polymer Degradation and Stability, 171, 109028.

[12] ŠEHIĆ, A., TOMŠIČ, B., JERMAN, I., VASILJEVIĆ, J., MEDVED, J., & SIMONČIČ, B. (2016). Synergistic inhibitory action of P- and Si-containing precursors in sol-gel coatings on the thermal degradation of polyamide 6. Polymer Degradation and Stability, 128, 245–252.
[13] SPONTONI M., D. ESTENOZ, G. LLIGADAS, J.C. RONDA, M.GALIA, V. CADIZ (2012), Synthesis and characterization of a hybrid material based on a trimethoxysilane functionalized benzoxazine, Journal of Applied Polymer Science, 126, 4, p. 1369-1376
[14] WANG, S., XU, D., LIU, Y., JIANG, Z., & ZHU, P. (2021). Preparation and mechanism of phosphoramidate-based sol-gel coating for flame-retardant viscose fabric. Polymer Degradation and Stability, 190, 109620.
[15] WANG, X., LU, Y., ZHANG, Q., WANG, K., CARMALT, C. J., PARKIN, I. P., ZHANG, Z., & ZHANG, X. (2021). Durable fire retardant, superhydrophobic, abrasive resistant and air/UV stable coatings. Journal of Colloid and Interface Science, 582, 301–311.
[16] XU, D., GAO, Z., XU, B., REN, H., ZHAO, X., ZHANG, Y., WANG, S., JIANG, Z., & ZHU, P. (2020). A facile and effective flame-retardant coating for cotton fabric with α-aminodiphosphonate siloxane. Polymer Degradation and Stability, 180, 109312.
[17] ZHANG, A.-N., ZHAO, H.-B., CHENG, J.-B., LI, M.-E., LI, S.-L., CAO, M., & WANG, Y.-Z. (2021). Construction of durable eco-friendly biomass-based flame-retardant coating for cotton fabrics. Chemical Engineering Journal, 410, 128361.
[18] ZHANG, D., WILLIAMS, B. L., SHRESTHA, S. B., NASIR, Z., BECHER, E. M., LOFINK, B. J., SANTOS, V. H., PATEL, H., PENG, X., & SUN, L. (2017). Flame retardant and hydrophobic coatings on cotton fabrics via sol-gel and self-assembly techniques. Journal of Colloid and Interface Science, 505, 892–899.
[19] ZHU, Y. S., YOU, F., ZHOU, H. T., HUANGFU, W. H., & WANG, Z. H. (2018). Pyrolysis Properties and Flame Retardant Effects of Fabrics Finished by Hybrid Silica-based Sols. Procedia Engineering, 211, 1091–1101.

A STUDY ON THE EFFECT OF ABRASIVE TYPE ON THE PILLING PERFORMANCE OF PLAIN and BLENDED FABRICS

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ABSTRACT

Pilling is a fabric surface defect that results from regular wear-cleaning cycles, giving an unsightly appearance. Pills are formed by the entanglement of loose fibers protruding from the fabric surface during wear, washing and rubbing. It can be affected by different factors such as fiber, yarn and fabric structural properties as well as applied finishing processes. In this study, it is aimed to compare two distinct abrasives type (standard wool fabric and the test fabric) on the pilling performance of three blended fabrics (one of woven fabric and the other two knitted fabrics) with different constructions and compositions.

Keywords: Pilling, martindale, abrasive, cotton and blended fabric

1. MATERIALS AND METHODS

Pilling is a condition that arises in wear due to the formation of little ‘pills’ of entangled fiber clinging to the fabric surface giving it an unsightly appearance. Pills are formed by a rubbing action on loose fibers which are present on the fabric surface [1].

Pill formation consists of three stages due to mechanical impact to the surface of rasped products, primarily, the tips of several fibers of fiber are pulled out creating a fuzzy surface. Later on, broken fibres grip to felt tips and form separate, gradually growing pills [2].

Fabric manufacturers have studied the pilling problem on the fabric surface for a long time. While pilling was a problem that existed on the fabric surface, it was not a major problem with wool and cotton fibers. However, with the introduction of synthetic fibers, manufacturers and consumers began to consider this problem [3].

New garments made from cotton and cotton-blend fabrics have a hand that is rather hard and stiff. The garment surface is not smooth, since small fuzzy micro fibrils protrude from it. Additionally, after a relatively short period of wear, pilling will appear on the garment surface, thereby giving it an unappealing and worn look [4].

Fabric structure is also important in the fabric's tendency to pill. A very tight and compact construction such as denim usually causes very little pilling. However, a loosely knit or loosely woven fabric will introduce more pilling from both wear and cleaning [5].

In order to determine the impacts of rubbing to tested fabric and rubbing to standard abrading on the pilling performances, three different fabrics were selected. The fabrics were knitted Cotton fabric (320 g/m2), knitted Cotton/Elastane fabric (192 g/m2), and woven Polyester (PES)/Cotton fabric (114 g/m2). Pilling tests were conducted according to EN ISO 12945-2 Martindale method.

EN ISO 12945-2 standard, Martindale method is one of the best methods that shows the performance of pilling and surface fuzzing caused by friction on the outer surface of the fabric.

Before starting the test, all test samples and abrasive fabrics were conditioned for 24 hours according to ISO 139.

Test specimens were prepared from evenly spaced areas across the fabric width and unwrinkled/unwrapped parts according to the standard [6].

Three different fabrics were tested using two different abrasives, one being a standard wool abrasive fabric and the other being tested fabric.

For the first group of tests, four test specimens in the form of disks with a diameter of 140+5 cm were prepared from all fabrics. These test specimens were used as one group for the test specimen holder and one group for the pilling table.

For the second group of tests, woolen abrasive fabrics were used on the pilling table and the tested fabrics were prepared for the test specimen holders with the same diameters.

In order to make comparative evaluation with the tested sample, another sample was cut from each test sample.

Test specimens were mounted in the test specimen holders and abrasives were mounted on the pilling table, before testing began. A mass of (155 ± 1) g for knitted fabrics and a mass of (415 ± 2) g for woven fabrics was used in the test specimen holder.

Martindale Abrasion& Pilling tester was used as the testing machine in the tests. A photo of the testing machine is given in Figure 1.

Figure 1. Martindale Abrasion & Pilling test device

At the end of the test, the test samples, which were rubbed at 6000 rubs on the Martindale device in the Universal pilling evaluation cabin, were evaluated according to EN ISO 12945-4.

Visual evaluations (degrees of pilling, fuzzing and matting) after the tests were made according to the new standard EN ISO 12945-4 [7].

Each specimen views were evaluated at a distance of 30 cm to 50 cm between eye and specimen as placed on assessment unit ensuring glare from the light source is not visible.

In the evaluations Universal Pilling Cabinet was used, it is given in Figure 2.

Each observer (three people) assessed each test specimen with respect to pilling, fuzzing and matting degrees according to EN ISO 12945-4 to use three separate grades.

The test specimens (left) and a reference specimen (right) were placed centrally on the assessment unit as seen in Figure 2.

Figure 2. Universal pilling assessment cabinet

All test specimens were evaluated according to the grading schemes that were given below Table 1 (pilling), Table 2 (fuzzing) and Table 3 (matting) [7] and also considering to the standard photographs.

Table 1. Pilling grading scheme [5]

Grade	Description
5	No change
4	Partially formed pills
3	Moderate pilling — pills of varying size and density partially covering the specimen surface
2	Distinct pilling — pills of varying size and density covering a large proportion of the specimen surface
1	Severe pilling — pills of varying size and density covering the whole of the specimen surface

Table 2. Fuzzing grading scheme [5]

Grade	Description
5	No change
4	Slight surface fuzzing
3	Moderate surface fuzzing
2	Distinct surface fuzzing
1	Dense surface fuzzing

Table 3. Matting grading scheme [5]

Grade	Description
5	No change
4	Slight surface matting
3	Moderate surface matting
2	Distinct surface matting
1	Dense surface matting

2. RESULTS AND DISCUSSSION

In this study, pilling performances were evaluated according to last edition Martindale and Pilling Assessment standards [6,7].

Pilling test was applied 6000 rubs to selected fabrics of three different constructions using two different abrasives. Each surface appearance was recorded. The surface appearances were determined in three evaluation stages: pilling, fuzzing and matting by three people.

Images of tested and evaluated fabrics are given in Figure 3.

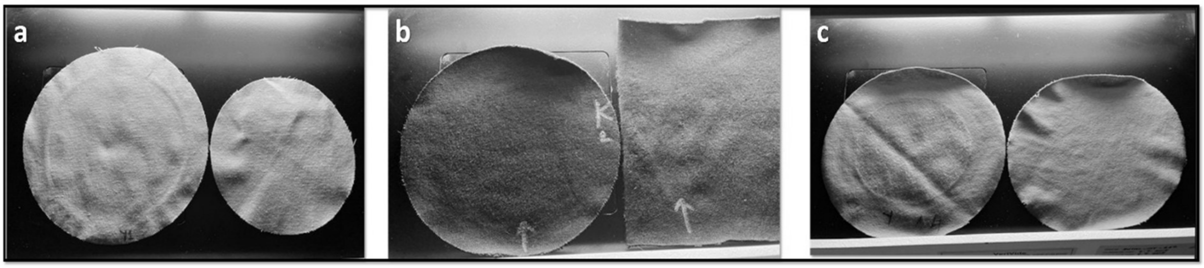

Figure 3. Images of tested and evaluated fabrics
(a) PES/Cotton woven fabric, (b) Cotton knitted fabric, (c) Cotton/Elastane knitted fabric)

The grades of each test specimen on all three fabrics are summarized in Table 4.

Table 4. Determination of fabrics propensity to surface pilling, fuzzing, matting according to abrasive type

	Number of Pilling Rubs	Pilling	Fuzzing	Matting	Abrasive Type
PES/COTTON Blue Fabric (Woven) 114 g/m²	6000 rev.	3-4	3	4	Standard wool fabric
	6000 rev.	3-4	3	4	Standard wool fabric
	6000 rev.	2-3	3	4-5	Test sample
	6000 rev.	2	2-3	4	Test sample
COTTON Black Fabric (Knitted) 320 g/m²	6000 rev.	4-5	3-4	4-5	Standard wool fabric
	6000 rev.	4-5	3-4	4-5	Standard wool fabric

	6000 rev.	4	4	4-5	Test sample
	6000 rev.	4	4	4-5	Test sample
COTTON/ELASTANE Brown Fabric (Knitted) 192 g/m²	6000 rev.	3-4	3-4	4-5	Standard wool fabric
	6000 rev.	3-4	3-4	4-5	Standard wool fabric
	6000 rev.	3	3	4	Test sample
	6000 rev.	3	3	4	Test sample

The evaluation results are as follows:

When test fabric was used as the abrasive type, the worst results were obtained for all fabrics compared to standard wool fabric.

In the evaluation of the test specimens, the fuzzing assessment grades for PES/Cotton woven fabric and cotton knitted fabric were found to be lower than the pilling assessment grades.

When cotton was chosen as the fiber type, it was evaluated that the fiber lengths tended to show fuzzing rather than pilling, and there were no fiber mismatches that would increase static electricity.

The matting degrees were found to be almost the same for all fabrics.

As with Polyester/Cotton blended fabric, it has been observed that when two different fiber blends were used, the pilling level increases and fuzzing level is moderate.

It has been observed that in cotton knitted fabrics using elastane yarns, elastane yarn increases friction, causing a rise in fuzzing and pilling.

In another study, it was concluded that pilling tendency increased as the polyester ratio increased in polyester cotton blended fabrics [8].

With future studies, it can be determined how the pilling level changes by using fabrics consisting of different types of fiber blends.

3. CONCLUSION

In this study, pilling performance was evaluated for three fabrics using two different abrasive fabrics. In the pilling test; rubbing against tested fabric gave worse results in pilling performance compared to rubbing against standard abrasive wool fabric.

In addition, it has been determined that the pilling and fuzzing tendency of fabrics produced with polyester blended yarns is higher than that of fabrics produced with single type of fiber.

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4. REFERENCES

[1] JAHAN, I. (2017). Effect of Fabric Structure on the Mechanical Properties of Woven Fabrics. Adv Res Text Eng. 2(2): 1018.
[2] BUSILIENE,G., LEKECKAS, K., URBELIS, V. (2011). Pilling Resistance of Knitted Fabrics. Materials Science, Vol.17, No.3, 297-301.
[3] DR. HEBA ASSEM EL-DESSOUKI (2010), A Study on Abrasion Characteristics and Pilling Performance of Socks, International Design journal Volume 4 Issue 2 Pages 229-233
[4] Ukponmwan,J.O.., Mukhopadhyay A. & , Chatterjee, K.N., (1998). Pilling, Textile Progress, 28:3, 1-57.
[5] AMIN MD. RUHUL 1 , RANA MD. RAFIQUL ISLAM. (2015), Analysis of Pilling Performance of Different Fabric Structures with Respect to Yarn Count and Pick Density, Art. Nr.72-9-14
[6] EN ISO 12945-2, (2020), "Textiles – Determination of fabric propensity to surface pilling, fuzzing or matting - Part 2: Modified Martindale method".
[7] EN ISO 12945-4, (2020), "Textiles – Determination of fabric propensity to surface pilling, fuzzing or matting - Part 4: Assesment of pilling, fuzzing or matting by visual analysis".
[8] DR. HAITHAM ABDEL DAIM MAHMOUD AHMED (2021), Effect of yarn structure variables on pilling performance for blended woven fabrics, MJAF_Volume 7_Issue 36_Pages 586-594

FASHION DIET – CHALLENGES AND POTENTIALS OF OPEN EDUCATIONAL RESOURCES (OER) FOR EDUCATION FOR SUSTAINABLE DEVELOPMENT (ESD) IN TEXTILE EDUCATION

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ABSTRACT

A strong demand for sustainable products and processes in the textile and fashion industry and its global markets imposes a continuous implementation of the guiding principle Education for Sustainable Development (ESD) in textile and fashion education. To achieve this goal, the European Fashion DIET project developed Open Educational Resources (OER) within a partnership of a university of education and universities with textile departments. As the main output, the project elaborated a further education module on ESD in the context of fashion and textiles, based on a survey of over 120 university lecturers in the partner countries Bulgaria, Germany, and Romania.

Key Words: Curricula, fashion design, esd, oer, textile and clothing technology

1. INTRODUCTION

Within the framework of a sustainable transformation, a reorientation of established production techniques and products, consumption patterns and lifestyles is demanded by the United Nations [1]. Companies are called upon to recognize sector-specific challenges to sustainability and to develop socially responsible solution strategies. Nevertheless, a green transformation cannot be successful without informed and sustainability-oriented consumers. To support students and pupils in classifying the relevance of their actions for the environment and society, targeted educational offers in the sense of Education for Sustainable Development (ESD) are needed. ESD represents an educational approach to enable learners to make responsible judgements and act sustainably in everyday culture and their professional lives [2].

To achieve this goal, the European project Fashion DIET (Sustainable Fashion Curriculum at Textile Universities in Europe – Development, Implementation and Evaluation of a Teaching Module for Educators) developed teaching and learning materials as Open Educational Resources (OER) for an e-learning platform. A further education module on ESD for higher education in the context of fashion and textiles was elaborated with a three-part module comprising 42 lectures on didactic-methodical concepts, sustainable fashion design and production technologies as well as a sustainable orientation of the fashion market. Another outcome is teaching and learning materials for general and vocational schools, based on selected lectures of the ESD module [3]. A second platform is the Fashion and Textile Database (F+TD), a comprehensive database to collect up-to-date information on fashion and textile related topics. Fashion DIET thus strengthens the quality and relevance of sustainability-oriented fashion design, textile and clothing engineering as well as management education.

Overall, 40 percent of young people in Germany are thinking about how they can behave in a more climate-friendly way. 37 percent are more concerned about the future, 34 percent are trying to get friends and family to act in a more climate-friendly way and 28 percent want to get (even) more involved in environmental and climate protection in the future [4]. It is therefore important to present students with sustainable, feasible options for action or motivating solutions. This finding is supported by Ojala's study [5] that teachers should take students' emotions seriously and communicate in a forward-looking, positive, and solution-oriented way. In Germany, the curricular implementation of ESD is demanded for universities and higher education institutions [6]. The promotion of the necessary skills of knowledge acquisition, critical thinking, autonomous decision-making, and action is a task and third mission of universities for a societal transformation.

2. CRITERIA-LED DEVELOPMENT OF OER IN THE PROJECT FASHION DIET

A qualitative-quantitative questionnaire was conducted with Google Forms (Google Inc.) to identify the attitudes and the needs for contents and methods of university lecturers. The survey in the three partner countries Bulgaria, Germany, and Romania was conducted in the official languages of the respective countries. In a first step the online questionnaire was piloted, based on a five-part Likert scale to determine the attitudes and the need for content and methods of the target group. A total of 122 respondents took part in the roll-out, of which 15% were men and 85% were women. 92% of the responding participants were lecturers, 8% PhD students and researchers or participants who performed other types of activities in the textile and fashion sector.

The questions addressed several aspects such as perceived usefulness, experiences, and opinions on ESD. By means of a one-factor analysis of variance (ANOVA), it was possible to narrow down the expectations and requirements of the lecturers regarding the design of the ESD module. The data were processed by chi-square ($\chi 2$) analysis method using the software product Statistica 12 (Stat Soft Inc.). Data were processed by one-way analysis of variance (ANOVA) using the three criteria: p-level, Fisher's criterion, and Wilk's lambda. The distribution of the data was checked by three methods: Shapiro-Wilks Test, Kolmogorov-Smirnov Test and the Lilliefors Test. The answers to the open-ended questions were grouped and standardized to compare the obtained results. All data were processed at a level of significance p-value=0,05. The most important questions of the questionnaire are listed in the following table.

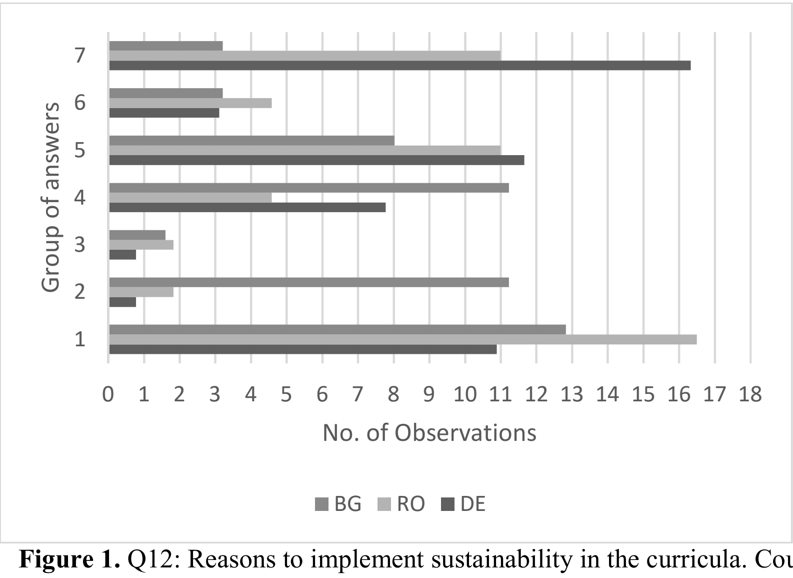
Table 1. Selected questions of qualitative-quantitative online questionnaire according to pilot test (Q = question number of questionnaire). Weight coefficients above 0.6 were selected.

No. in Survey	**Selected Questions**
Q1.2	How many years of experience do you have in professional higher education?
Q2.1	What does sustainability mean to you in the context of fashion and textile?
Q2.2	Importance of and Commitment to ESD (Education for Sustainable Development)
Q3	What are the most important reasons to implement sustainability aspects to your curricula?
Q5	How many years of experience do you have in implementing sustainability aspects to your curricula?
Q6	If you already implement sustainability aspects in your lectures, what is your primary target?
Q7.1	What are major obstacles that prevent you from implementing ESD in your curricula?
Q12	In general, what are your suggestions we should take care of when developing an ESD Module for implementing sustainability aspects in your curricula?

The questionnaire allowed analyzing what the lecturers in all countries have in common regarding sustainable fashion and textiles. Most of the respondents had 6-10 years of teaching experience (Q1.2). Overall, they attached great importance to the environment and durability of textiles as key aspects. Furthermore, they found it very significant to integrate sustainability aspects in the curricula in higher education. The difference that appeared in the answers of the respondents from

Germany is the fact that they add social aspects as equally significant, they also indicated further aspects that are not given in the questionnaire (Q 2.1-Q2.2). The answers to Q3 revealed that especially in Bulgaria a sustainable fashion and design education is focused, whereas Romanian lecturers are mainly experienced in teaching aspects of sustainability related to textile and clothing technology. German lecturers tend to weight sustainability aspects more equally in design and technology. Thus, the development of a sustainable product strongly has to take into account the design phase and textile and clothing technology. Concerning question Q5, the respondents from Bulgaria and Romania do not have more than a year of experience in applying sustainability aspects in their curricula. Respondents from Germany have had this experience for over 5-10 years.

Dissenting opinions of the three countries were observed when asking lecturers on their primary targets if they already implement sustainability aspects in their lectures (Q6). In Germany emphasis is mainly put on critical thinking. Romanian lecturers address aspects of textile technology education and up-cycling/recycling concepts, whereas their colleagues in Bulgaria foster sustainability in the education of designing and patterning of clothing. Regarding the obstacle that prevent lectures form implementing ESS in their curricula, the most prominent response to question Q7.1 from lecturers in Bulgaria and Romania was unanimously the lack of ESD in their curricula. Concerning the question what information they need to implement ESD successfully in their respective curricula (Q8) there was no significant statistical difference between the answers of the respondents from Germany and Romania. Such a difference appeared with the respondents from Bulgaria who wished to implement new sustainable methods. Considering the Bulgarian focus on fashion design, new methods for implementing ESD in the education of design and pattern making needed to be elaborated.



Categorised answers to open-ended questions:

1. Reducing the impact on the environment
2. Preservation of textile heritage
3. Legal aspects of sustainability
4. Implementation of new technologies
5. Improvement of student skills
6. Impact on the national economy
7. Formation of a critical thinking

Figure 1. Q12: Reasons to implement sustainability in the curricula. Country-specific answers (left side) to open-ended questions (right side). Results given as percentage relative to average country value.

When participants were asked for critical suggestions to develop an ESD module with sustainability aspects (Q12), a strong demand for practical relevance was observed regarding the teaching and learning methods as well as a need for sustainability information and data access. The respondents saw the environmental impact as the main problem. However, there were no significant statements on social impacts. A deeper analysis of the questionnaire revealed country-specific views of the project partners. This was obvious when asking e.g., open-ended questions on specific reasons to implement sustainability in the curricula. All countries agreed on reducing the impact on the environment and improving student skills as good reasons. Germany and Romania identified the formation of critical thinking as an important reason, whereas educators in Bulgaria mainly focused on a preservation of textile heritage (Figure 1).

All in all, the answers revealed that there are different cultural value orientations and views regarding ESD that need to be aligned. This is in line with other cross-cultural comparative studies of sustainability consciousness [7]. In this respect the Fashion DIET project takes a holistic view on sustainability to integrate the different perspectives of cultural specificity. The feedback questionnaire allowed the selection of criteria for the elaboration of an action- and research-oriented further education module for ESD in textile education. The module is divided into three parts; each course is designed in the scope of one semester comprising 14 lectures with a workload of at least two credit points. The topics follow the project's holistic approach, covering both a sustainable design, textile and clothing production as well as a sustainability-oriented consumption and entrepreneurship (Figure 2).

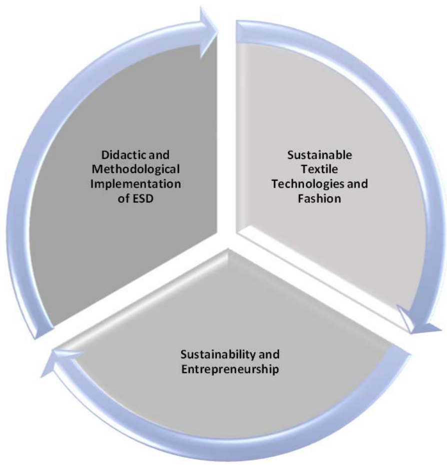


Figure 2. Structure of the ESD Module

Open Educational Resources (OER) remark enormous use in the field of education comprising all levels starting from primary to higher education. These materials exist in the public province or are released under an open license that permits no-cost access, adaptation, use, and reorganization by others with no or limited restrictions [8]. All teaching and learning arrangements of the Fashion DIET project are therefore provided as OER on the open access e-learning platform Glocal Campus (https://glocal-campus.org). This includes access to further teaching and learning materials such as manuals, podcasts, and the supply of interactive and physical material. A major project website (https://fashiondiet.eu) was developed as the access-point to the information and e- learning platform and inform on a continuous basis in accordance with the project objectives.
Three Learning, Teaching and Training (LTTs) activities were run, each over a period of three days, to inform about and evaluate the content and developmental status of the ESD module and the teaching and learning materials for schools as well as the usability of the e-learning platform. Furthermore, the database F+TD (https://opus.bsz-bw.de/ftrc/home) was developed as an ongoing co-creation project to collect current information on fashion and textile topics. Everybody who is working in the textile environment may propose sources to be included. In September 2023, the database comprised about 750 sources from 41 countries.

There were feedback rounds and an online survey conducted at the end of each LTT activity. The three LTTs had about 195 participants. The online survey involved 43 respondents in the first LTT in Romania, 55 in the second in Bulgaria and 40 in the third one in Germany. The results flew directly into the development of the IOs. The main reason for the respondents' participation was the interest in a training on ESD, followed by the interest in an international exchange. An in-depth comparative analysis of the results shows that the respondents highly appreciated the content of the LTTs. The majority strongly agreed and agreed that their point of view regarding fashion, textiles and sustainability was developed and that their point of view regarding ESD in the context of fashion and textiles changed. The participants became aware of this educational approach, how they can implement ESD in their courses and study programs and thus pave the way for a transfer into practice.

3. RESULTS

Overall, the EU project strengthened the quality and relevance of textile and fashion education in terms of a more sustainable textile and fashion sector. The project´s main outputs comprise: (1) a further education module with 42 lectures and a manual in English, translated into the three national languages in the project, as OER, (2) the development of an information & e-learning portal, including the open access database F+TD, and (3) the provision of research-based teaching and learning materials for schools as OER under the guiding principle of ESD. The project comprises the holistic ESD view of both production and consumption of textiles and clothing and explores the use of OER by educating the educators and enabling them as multipliers for a more sustainable textile and fashion industry and market.

All ESD courses deliver learning and teaching materials with either specific content or an overview that can be adapted by the target group. The project's objective is not to change the study programs, but rather to implement ESD as a guiding principle in the existing curricula and enable university lecturers and schoolteachers as well as educators in the textile and fashion industry to decide for themselves whether to use the content for their learning groups and/or as self-learning materials. According to this, all materials can be seen as suggestions or proposals of content on the respective topic, which can be directly used in the classroom, but each educator is also invited to adapt the content to the needs of the respective learning group.

4. CONCLUSION

Through educational processes, challenges of a sustainable development in the textile and fashion industry and its market can be reflected upon. Hence, in a competitive education world, more and more institutions and individuals share digital learning resources over the internet. The Fashion DIET project follows this trend as the project's holistic approach faces a quite diverse target group encompassing lecturers, teachers, and vocational trainers with their heterogenous learning groups. Universities and higher education institutions can make important contributions to sustainable development by implementing ESD as a guiding principle in their teaching, research, and operational tasks as a whole institution approach. They can contribute to an understanding of the complex, multi-layered interrelationships between ecological, economic, social, cultural and political conditions for sustainable development and a change of values, attitudes and action. This can initiate or deepen a change in consciousness to get people involved and enable them to responsibly shape the present and the future.

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5. REFERENCES

[1] UNITED NATIONS GENERAL ASSEMBLY (2015). Resolution Adopted by the General Assembly on 25 September 2015. 70/1. Transforming Our World: The 2030 Agenda for Sustainable Development [online], updated 21.10.2015 [cited 04.09.2023]. Available on https://sdgs.un.org/2030agenda

[2] RIEß, W., MARTIN, M., MISCHO, C., KOTTHOF, H.-G. and WALTNER, E.-M. How Can Education for Sustainable Development (ESD) Be Effectively Implemented in Teaching and Learning? An Analysis of Educational Science Recommendations of Methods and Procedures to Promote ESD Goals. Sustainability, 2022, vol. 14, 3708.

[3] BLAGA, M., AVADANEI, M., CURTEZA, A., BERTEA, A., GRUNDMEIER, A.-M., STRÄHLE, J., WAGNER, M. and KAZLACHEVA, Z. Education on Sustainable Textile Technologies and Fashion in the European Market. In 18th Romanian Textiles and Leather Conference: Proceedings. Edited by Faculty of Industrial Design and Business Management. Iaşi: "Gheorghe Asachi" Technical University, September, 2023, pp 447-454.

[4] WILLIAMS, H., REICH, H. and GELLRICH, A. Zukunft? Jugend fragen! – 2021. Umwelt, Klima, Wandel – was junge Menschen erwarten und wie sie sich engagieren [online], updated 01.02.2022 [cited 04.09.2023]. Available on https://www.bmuv.de/fileadmin/Daten_BMU/Pools/Broschueren/zukunft_jugend_fragen_2021_bf.pdf

[5] OJALA, M. Hope in the Face of Climate Change: Associations With Environmental Engagement and Student Perceptions of Teachers' Emotion Communication Style and Future Orientation. The Journal of Environmental Education, 2015, vol. 46, no. 3, pp 133–148.

[6] NÖLTING, B., MOLITOR, H., REIMAN, J., SKROBLIN, J.-H. and DEMBSKI, N. Transfer for Sustainable Development at Higher Education Institutions – Untapped Potential for Education for Sustainable Development and for Societal Transformation, Sustainability, 2020, vol. 12, 2925.

[7] BERGLUND, T., GERICKE, N., BOEVE-DE PAUW, J., OLSSON, D. and Chang, T.-C. A cross-cultural comparative study of sustainability consciousness between students in Taiwan and Sweden, Environment, Development and Sustainability, 2019, vol. 22, pp 6287–6313.

[8] UNESCO. Recommendation on Open Educational Resources (OER) [online], updated 25.11.2019 [cited 04.09.2023]. Available on https://www.unesco.org/en/legal-affairs/recommendation-open-educational-resources-oer.

SPORTSWEAR COLLECTION DEVELOPED FROM PULP BASED BIODEGRADABLE REGENERATED CELLULOSE FIBERS

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ABSTRACT

This study presents an analysis of the performance properties of three-thread fabrics manufactured with pulp-based biodegradable regenerated cellulose fibers. In the study, Ecocell® raw material, which is an import substitute of lyocell fiber was used. Physical tests (basis weight, pilling, fastness, air permeability, burst strength, thickness, dimensional stability, abrasion tests) and characterizations were performed on fabric samples. When the test results were evaluated, it was determined that the increase in the Ecocell® percentage had a negative effect on wet rubbing fastness and burst strength of the fabrics, and other physical properties were within the range of customer criteria.

Key Words: Lyocell, Ecocell®, knitted fabric, biodegradable, sportswear

1. INTRODUCTION

As people's welfare and cultural levels increase, their desire for better quality and various clothing increases rapidly due to their desire to live better and more comfortably, and the amount of fiber consumed per capita in the world increases rapidly. Since the production of natural fibers could not increase due to the increase in the world population, the resulting gap will be filled with man-made fibers [1]. Today, many chemical fibers are produced as an alternative to cotton fiber, which is a natural fiber. One of the most important of these fibers, called regenerated cellulosic fibers, is viscose. Although viscose is the most produced and consumed regenerated cellulose fiber today, its low wet strength property has led to the development of modal fiber. Then, lyocell fiber produced with solvent N-Methylmorpholine N-oxide (NMMO) that does not harm the nature with different production methods started to be produced [2].

Within the scope of this study, three-thread fabrics, herein after referred to as "fleece", were produced from pulp-based biodegradable regenerated cellulose fibers dissolved with NMMO. In these blends, Ecocell®, hemp, cotton and recycle polyester were used as raw materials. The aim of the study is to examine and increase the properties of the products obtained from single plate fleece fabrics developed in different mixtures. Pulp-based biodegradable fibers were chosen as raw material for the project because natural fibers could not meet the increasing fiber demand, the demand for regenerated cellulose fibers increased, regenerated cellulosic fibers are more comfortable and healthy fibers compared to synthetics and the innovation potential of these fibers is high.

Lyocell fiber is produced by Tencel® in the world with its large share in the market. Fiber is used by importing in Turkey. In this study, Ecocell® raw material, which is an import substitute of lyocell fiber, is being developed by local supplier. The mission of this raw material is to protect our nature and promote sustainability without taking pulp from ancient and endangered forests. Rana et al. (2014), discussed the production, properties, applications and sustainability issues of various regenerated cellulosic fibers in their study. They stated that among various regenerated cellulosic fibers, lyocell fiber offers significant environmental benefits. They emphasized that the lyocell fiber is produced from renewable resources and using a solvent that is almost completely recyclable, as well as being completely biodegradable. They stated that the lifecycle assessment (LCA) studies on these fibers show that Lyocell fiber production (especially based on the use of municipal solid waste incineration (MSWI) as a process energy source) has advantages over other regenerated cellulosic fibers due to its lower energy, water and soil requirements as well as lower effects on global warming potential, abiotic depletion, ozone depletion, human toxicity, freshwater ecotoxicity and terrestrial ecotoxicity, acidification, photochemical oxidant formation and eutrophication [3]. Zhang et al. (2018), in their study, compared the production process, environmental effects and product quality of NMMO-based lyocell fibers with conventional viscose fibers. They stated that, unlike commercial viscose fiber, the NMMO-based lyocell production process is much more environmentally friendly. They also stated that lyocell fibers have unique fiber structure and properties such as fibril orientation and crystallinity and have very high strength compared to viscose fibers [4].

The aim of the study is to evaluate the performance characteristics of Ecocell® fiber produced in Turkey, which is an import substitute of lyocell raw material. Additionally, it is of great importance that this raw material is produced using an environmentally sustainable production process. Although studies on Ecocell® fiber are limited in the literature, there is no comparative study with different fabric compositions of this fiber in the literature. For this reason, the focus was on this subject in the paper.

2. EXPERIMENTAL

2.1 Materials

In this study, Ecocell® fiber is used as a raw material. Ecocell® fiber was supplied by Karafiber Tekstil A.Ş. The knitting process of the fabrics was also provided by the supplier. The fleece fabric qualities to be made were determined as 30/30/10 and 30/70/20 and productions were carried out. Ecocell®/cotton 33/67, 50/50, 67/33 in upper yarn, in the back yarn, 100% cotton, Ecocell®/cotton 50/50 and Ecocell®/cotton 33/67, 67/33 were preferred. In addition, 30/1 ring 90% Ecocell® 10% hemp product was added to the project in order to compare the fabric performance with Ecocell®/cotton products. In the scope of the project, knitted fabric samples in different mixtures were developed and fabric compositions are given in Table 1.

Table 1. Developed fleece fabrics

Sample code	Sample definition	Yarn compositions	Basis weight (g/m2)	Feeding type
01	33% Ecocell® 67% Cotton	30/30/10 Ring	328	Full-fed
S01	33% Ecocell® 67% Cotton	30/30/10 Ring	260	Semi-fed
02	67% Ecocell® 33% Cotton	30/30/10 Ring	310	Full-fed
S02	67% Ecocell® 33% Cotton	30/30/10 Ring	255	Semi-fed
03	58% Ecocell® 7% Hemp 35% Cotton	30/30/10 Ring	309	Full-fed
S03	58% Ecocell® 7% Hemp 35% Cotton	30/30/10 Ring	248	Semi-fed
101	25% Ecocell® 60% Cotton 15% r-Pes	30/70/20 Ring	266	Full-fed
102	42% Ecocell® 43% Cotton 15% r-Pes	30/70/20 Ring	269	Full-fed
103	30% Ecocell® 50% Cotton 20% r-Pes	30/70/20 Ring	220	Semi-fed
104	40% Ecocell® 40% Cotton 20% r-Pes	30/70/20 Ring	225	Semi-fed

2.2 Methods

To begin with, raw sample fabrics were produced in Pailung brand (32 pus, 20 fine, 22-23 cycles) circular knitting machine. Sample fabrics were produced to be semi-fed and full-fed, with two grades in each roll. The color was determined as archroma dark blue and was performed by reactive dyeing. At the end of the work, design studies carried out by developed fabrics. Product development design work was carried out by taking into account the fabric characteristics, current trends and fashion. Along with CAD drawings, three-dimensional designs were also studied. For 3D designs Clo3D design software was used. The physical performance characteristics and the relevant test standards analyzed in this study are given in Table 2.

Table 2. Used test equipment and related standards

Test	Test Standard
Standard Environments for Conditioning and Experimentation	TS EN ISO 139
Air Permeability Test (Prowhite)	TS 391 EN ISO 9237- 100 Pa/200Pa
Pilling Test (Martindale)	BS EN ISO 12945-1
Abrasion Test	BS EN ISO 12945-2/12945-3/12945-4
Thickness Measurement (Check-Line Europe®)	TS 7128 EN ISO 5084
Washing Fastness	TS EN ISO 105 C06
Rubbing Fastness	TS EN ISO 105 X12
Water Fastness	TS 423-3 EN 20105-A03
Dimensional Stability Test	EN ISO 5077
Basis Weight	TS 251

3. RESULTS

Firstly, fleece fabric knitting structure was developed in different combinations. Customer demands were influential in the selection of the knitting structure as fleece. Developed fleece fabrics physical test results are given in Table 3.

Table 3. Test results of developed fabrics

		Burst strength				Color fastness to rubbing	
Sample No	**Air Permeability (@200Pa)**	**Pressure (kPa)**	**Swelling (mm)**	**Time (sec)**	**Pilling**	**Dry**	**Wet**
01	508,34	141,9	32,2	19,7	4/5	4/5	3
S01	693,19	170,8	32,7	21,3	4	4/5	3
02	931,05	140,7	30,6	19,8	4/5	4/5	3
S02	1418,82	153,8	30,4	20,5	4	4/5	3
03	847,40	154,0	30,9	19,6	4/5	4/5	3
S03	1506,93	161,2	31,4	20,4	3/4	4/5	3
101	588,88	203,8	35,6	18,9	3/4	4/5	3/4
102	568,05	194,7	35,4	19,8	3/4	3/4	3/4
103	702,32	199,8	35,1	19,5	3	3/4	3
104	722,37	197,2	36,0	20,1	3	3/4	3/4

As expected, an increase in the air permeability value was observed in the fabrics produced with the semi-fed type. Increasing the Ecocell® percentage in two-blend fabrics positively affected air permeability. However, as the amount of Ecocell® increased in three-blend fabrics, a slight decrease or increase in air permeability was observed. Therefore, there is no clear correlation was found in this experimental group. It is thought that this situation is due to the presence of polyester fiber and the fabric construction.

When the burst strength of the fabrics was examined, it was observed that the strength increased slightly as the cotton percentage increased. This is thought to be due to the fiber property. Also, it was determined that the burst strength value was higher in fabrics with semi-fed type. In addition, it is clearly observed that the bursting strength is higher in polyester containing fabrics. For burst strength, the accepted customer criterion for single plate fabrics is 145 kPa. The results showed that these values were within the acceptance criteria.

When the pilling test results were examined, it was seen that the test results of the semi-fed knitted fabrics were decreased by half a point. When the pilling test results were re-examined both in the fabric manufacturer and in the TYH's laboratories, it was seen that the results of the polyester-containing fabrics were one or half points lower than the others. This situation is thought to be due to the polyester fiber property. In other words, it was determined that the pilling tendency was higher in polyester-containing fabrics.

The washing fastness, rubbing fastness, perspiration fastness and fastness to water performance of the fabrics were evaluated. Color fastness to water test results in terms of color change and degree of color staining were almost 4 and 4/5 in all cases. The color fastness to perspiration rating of fabrics in acid and alkaline conditions were 3/4 to 4/5. Washing fastness varied between 3 and 4/5. Color fastness to rubbing was found to be in the range of 4 to 4/5 in dry conditions, while wet rubbing fastness was generally found to be in the range of 3 and 3/4. The tests were carried out at the fabric manufacturer and then repeated in the TYH's laboratory. When the results of both tests are compared, the wet rubbing fastnesses are generally between 2 and 2/3 in the test results carried out in TYH laboratories. Therefore, the test results were accepted as fail. In addition, the fading values of all fabrics after five washings were examined and it was seen that the results were within the acceptance criteria.

According to the dimensional stability test results, less dimensional changes were observed in fabric width and length in the fabric samples containing PES. It is known in the literature that lyocell fibers show good dimensional stability [5,6]. However, higher shrinkage values were obtained in fabrics without polyester. Therefore, the results are not compatible with the literature.

In hemp-containing fabrics, the fiber-induced hand feeling has a crunchy structure. There were differences in the surface appearance. It is thought that there are differences in appearance because the percentages of dye pick-up are different (Figure 1). The figure 1 shown in order to emphasize the surface appearance, that's why color should be disregarded.

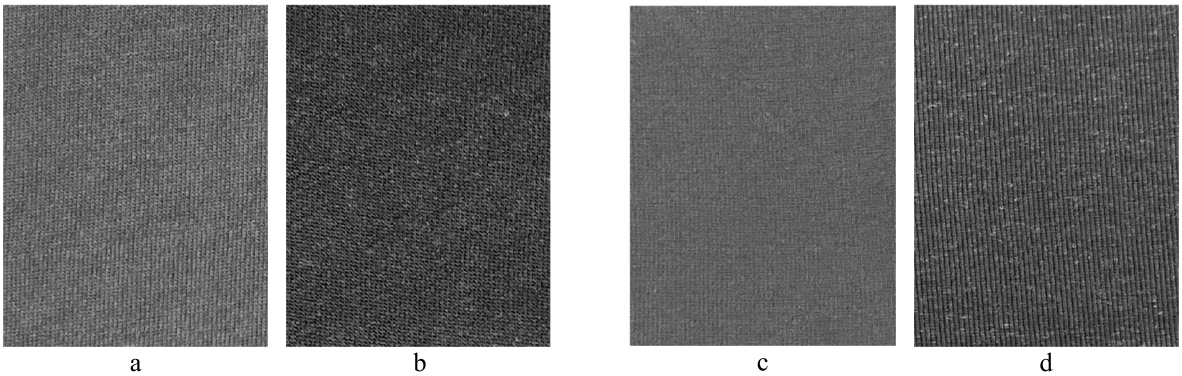

Figure 1. Comparison of surface appearances of hemp-free and hemp-containing fabrics (a- hemp-free fleece fabric, b-hemp-containing fleece fabric, c-hemp-free rib fabric, d- hemp-containing rib fabric)

Among the developed fabrics, 103, 104 and 02 coded fabrics were selected based on the air permeability and burst strength results, and design studies were carried out (Figure 2).

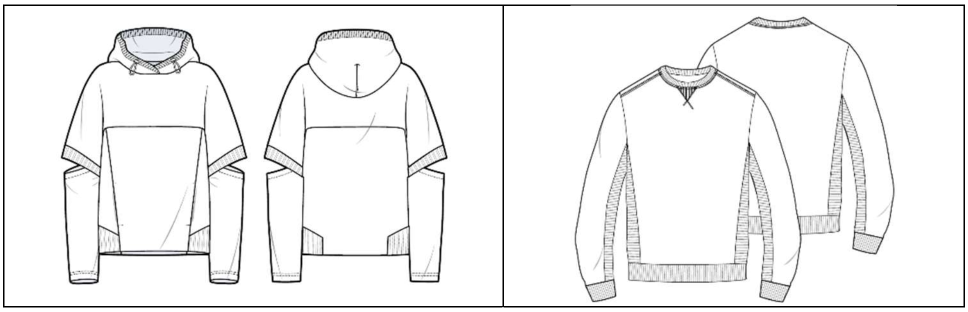

Figure 2. Design studies of developed fabrics

Sample products are produced from these fabrics and the comfort properties of the final product were examined. The hand-feeling properties were evaluated subjectively and it was decided that the hand feeling properties of the fabrics were suitable.

4. DISCUSSION

The experimental set was processed in two different groups. It is thought that this situation affects the results. The same process is recommended for further studies. The developed fabrics can be compared among themselves, but in further studies, the need for comparison has emerged by adding conventional fabric qualities. Although it is thought that the use of vortex yarn instead of ring will have a positive effect on pilling values, also it will negatively affect the hand-feeling properties. Back yarns of some qualities were used as open-end in fleece fabrics. In line with customer criteria, this choice does not meet our quality expectations. Therefore, this use is not recommended for high performance expectations.

When the test results were evaluated, it was seen that the feeding type of the knitting structure was effective on the results in general rather than the Ecocell® percentage. Although the semi-fed type increased the pilling value slightly, it had a positive effect on both air permeability and burst strength. Also, since the developed fabrics are produced as sample (minimum) quantities, it is thought that the test results are misleading in hand feeling and appearance.

5. CONCLUSIONS

In the present study, fleece fabric knitting structure was developed in different combinations and performance characteristics were analyzed. This study contributed to the literature on the comparative analysis of lyocell fiber with its Turkish substitute, Ecocell®. According to the results, it has been observed that usage of Ecocell® fiber with two fiber blend has a certain effect on air permeability performance. However, it has been determined that cotton fiber has a positive effect on the strength value of fabric. In general, it is possible to say that Ecocell® is a commercial fiber suitable for production. In conclusion, it was seen that all results were generally within the acceptance criteria.

6. REFERENCES

[1] ARDIÇ, Y. Selülozik Liflerin Farkli Şartlarda Fibrilleşme ve Yorulma Davranişlarinin İncelenmesi. Yüksek Lisans Tezi, Fen Bilimleri Enstitüsü. Bursa, 2007, 164s.
[2] ÖZBAĞCI, Ö. Pamuk ve Bazı Rejenere Selüloz Esaslı Süprem Örgü Kumaşların Fiziksel ve Boyutsal Özellikleri. Yüksek Lisans Tezi, Fen Bilimleri Enstitüsü. İzmir, 2008, 166s.
[3] RANA, S., PICHANDI, S., PARVEEN, S., FANGUEIRO, R. Regenerated Cellulosic Fibers and Their Implications on Sustainability. Roadmap to Sustainable Textiles and Clothing, 2014, 239–276.
[4] ZHANG, S., CHEN, C., DUAN, C., HU, H., LI, H., LI, J., LIU, Y., MA, X., STAVIK, J., NI, Y., Regenerated Cellulose by the Lyocell Process, a Brief Review of the Process and Properties. BioResources, 2018, 13(2), 4577-4592.
[5] DÜNDAR, E., Çeşitli Selülozik İpliklerden Üretilen Örme Kumaşlarin Performanslarinin Karşilaştirilmasi, Master Thesis, March 2008, İstanbul.
[6] GÖKÇEN, Ö., BAHADIR Ü, Z., Viskon Kumaş Üretiminde Konfeksiyon İşletmesinde Yaşanan Sorunlar ve Çözüm Önerileri, TJFDM, 2021, 3 (2): 57-68.

EFFECT OF RING YARN MACHINE SPINNING ELEMENTS ON RECYCLE YARN PRODUCTION

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ABSTRACT

In this study, it was aimed to observe the effects of cot and clip, which are spinning machine spinning elements, on yarn quality and running performance in pre-consumer recycle cotton and regenerated cellulose blended ring yarn production. Within the scope of the study, the fibers brought into fiber form by opening the pre-consumer textile wastes were mixed with regenerated cellulose fiber to obtain a blend and finally ring yarn was produced. During ring yarn production, cots of different hardness and clips of different sizes were used. It was seen that up to a certain hardness value, the cot hardness directly proportional affects the working performance of the yarn, but it affects the yarn quality inversely proportional. When the effect of the clip is examined, it has been observed that the clip height (mm) affects the working performance directly but effects the yarn quality in the opposite way.

Keywords: Recycle, yarn, clip, cot, cotton

1.INTRODUCTION

As a result of the rapidly increasing population, economy and industry, the increase in the ratio of all kinds of materials used causes an increase in the amount of waste generated. The elimination of wastes without harming the environment and bringing them into the economy has made recycling inevitable. The metals, plastics, papers, textile wastes and other materials used can stay in nature for many years and reduce the fertility of the soil. The recycling rate of textile waste in Turkey is increasing day by day with the efforts of companies and scientific organizations and has reached the level of 70% [1].

The textile industry is one of the most important industries in the world and in Turkey, and it has become one of the most energy-intensive areas with the intensification of environmental processes and the wastes it produces. Cotton, one of the basic raw materials of textile production, is a natural fiber with a significant environmental impact throughout its entire life cycle. One of the most effective methods of minimizing these environmental effects is recycling [2].

The most important difficulties in cotton recovery in Turkey are the production of thick and low quality yarn with low added value and the low product structure. Waste/waste recycling has gained a new dimension in the world in recent years and obtaining high value-added products from waste has gained importance. According to the Council for Textile Recycling, textile recycling materials are classified in two groups as pre-consumer and post-consumer waste.

Pre-consumer textile waste; are textile wastes generated during the production of fiber, yarn, textile, technical textile, nonwoven surface, ready-made clothing and shoes [3]. The study was carried out with this material.

Post-consumer textile waste; all kinds of clothing and home textile products that the consumer no longer needs and decide to throw away fall into this group [3].

Yarn quality plays an important role in the economic success of spinning mills and in maintaining this success. Therefore, in order to achieve better yarn quality results, it is of great importance to investigate the factors effecting yarn quality parameters [4]. Raw material, process control techniques and spinning parameters are the main factors effecting the final yarn properties. The working principles of the ring spinning system include drafting, twisting and winding steps, and the drafting step, which is among these processes, plays an important role on the quality values of the yarn. The drafting process components, especially the cot, have a significant impact on yarn quality and production costs in ring spinning. Since the cot is in direct contact with the fibers, its effect on the final yarn quality is significant [4].

There is a clip in the upper apron cage of the ring spinning machine. The clip colors change according to the fineness of the working yarn. The clip allows the pressure to be adjusted between the middle pressure roller and the draft roller. If there are no clips, the pressure between the aprons will deteriorate and there will be continuous breaks in the yarn. At the same time, poor quality yarn is produced [5].

Considering all these, the aim of this study is to examine the effects of cots and clips, which are spinning elements in ring spinning machines, on yarn quality.

2. EXPERIMENTAL

14/1 Ne and 18/1 Ne yarns were produced on the ring spinning machine from the roving obtained from recycle cotton and regenerated cellulose fiber mixture. Yarn production has been done on Zinser Yarn machine. In the experiment, different hardness of exit cots were used. At the same time, clips of different height sizes were attached and then yarn tests were carried out. The IPI quality tests of the yarns rolled into bobbins were made on Uster Tester 6 and Uster Tensojet devices.

U% is one of the important factors determining the quality of the product produced on the machine. The lower U% value means the better the quality. The opposite is also true. Another parameter that determines the quality of the produced product is the mass change coefficient (CVm). In order to obtain a product with the desired properties and quality, the coefficient of variation in the semi-finished product must be in the acceptable range. Higher CVm in yarn means lower product quality.

Uster % (U%), CVm (unevenness) and IPI (imperfection index) test measurements of Ne 14/1 and Ne 18/1 carded ring yarn samples used in this study were measured in Uster Tester 6 at 20±2ºC temperature and 65%±2 relative humidity values (standard atmospheric conditions) in a laboratory environment.

For each trial, 5 measurements were made and the average of these measurements was taken.

3.RESULTS AND DISCUSSION

During the production of recycle cotton and regenerated cellulose fiber blended yarn, the effects of spinning elements such as cots and clips on the yarn quality and working performance in the spinning machine were investigated.

When the effect of the cots is observed as a result of the trials; It has been observed that up to a certain cot hardness, as the cot hardness increases, the IPI values of the yarns increase, that is, worsen, and as the cot hardness decreases, the yarn IPI values improve.

The variability of U% and CVm values of carded ring yarns produced in Ne 18/1 number according to the cot hardness is presented in Table 1.

Table 1. The Effect of Cot Hardness on Yarn IPI Values

Yarn Ne: 18/1 Ring			
Cot Colors	**Cot Hardness (Shore)***	**Yarn U%**	**Yarn CVm**
Grey Cot	83	17.64	23.48
Brown Cot	75	16.11	21.18
Green Cot	70	15.66	20.79
Red Cot	65	15.99	21.25

*As the numerical value increases, the cot hardness increases

As seen in the table, the values improved as the cot hardness decreased until the red cot with a shore hardness of 65. However, values at 65 shore hardness began to be negatively affected.

The decrease and increase in U% and CVm values of carded ring yarns produced in Ne 18/1 number according to the cot hardness are presented in Figure 1.

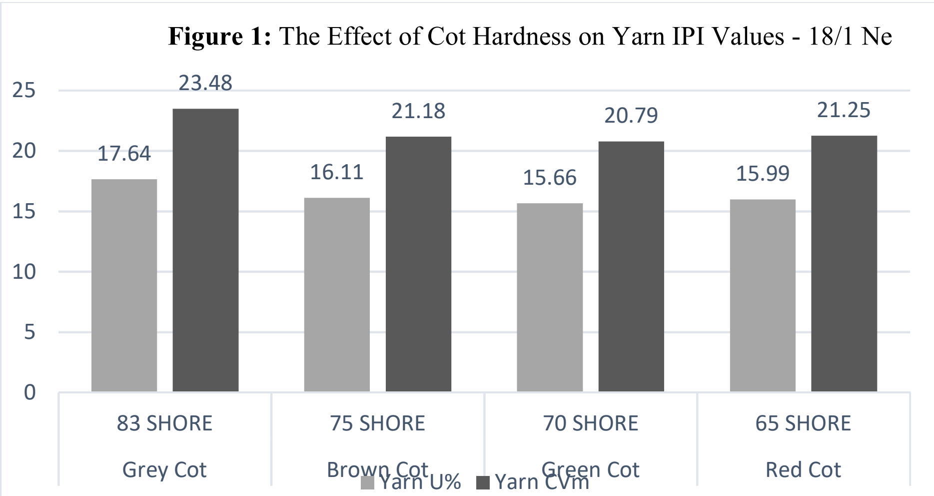

Figure 1. The Effect of Cot Hardness on Yarn IPI Values

The variability of U% and CVm values of carded ring yarns produced in Ne 14/1 number according to the cot hardness is presented in Table 2.

Table 2. The Effect of Cot Hardness on Yarn IPI Values

Yarn Ne: 14/1 Ring			
Cot Colors	**Cot Hardness (Shore)**	**Yarn U%**	**Yarn CVm**
Grey Cot	83	17.72	24.05
Green Cot	70	15.8	20.9
Red Cot	65	16.14	21.97

The same situation mentioned for 18/1 Ne yarn is also observed for 14/1 Ne yarn. When the values in the table are examined, the values improved as the cot hardness decreased until the red cot with 65 shore hardness. However, the values started to be negatively affected in the red cot with 65 shore hardness.

The decrease and increase of U% and CVm values of carded ring yarns produced in Ne 14/1 number according to the cot hardness are presented in Figure 2.

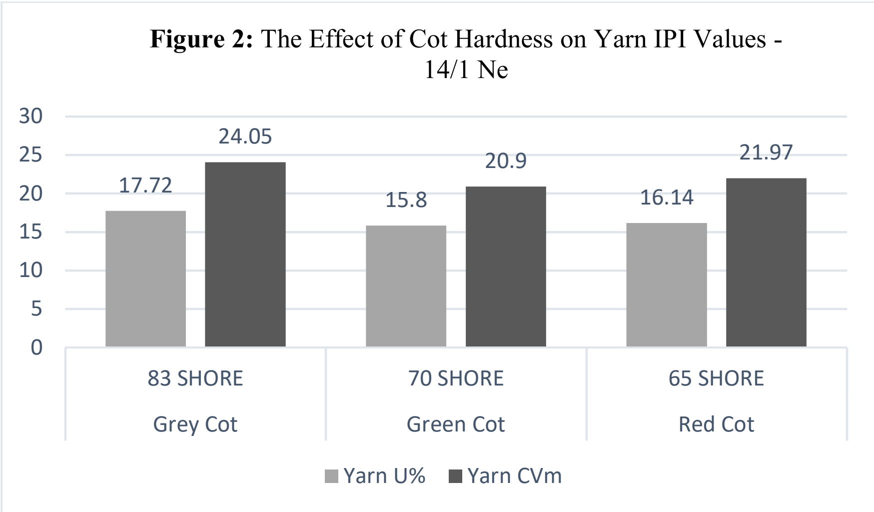

Figure 2. The Effect of Cot Hardness on Yarn IPI Values

In this study, technical information is given briefly to examine the effect of the clip. In the ring spinning machine, the drafting process is done between the roller pairs. The drafting region is the part where the draft is given to the roving sliver fed to the machine according to the desired yarn number. In this part, there are three draft rollers and three pressure rollers (cot). The draft rollers are metal and grooved. The pressure rollers (cots) are covered with rubber and take their movement from the drafting cylinders by friction.

The cots, provide better opening and drawing of the fibers. Aprons have been placed on the middle pressure and draft rollers in order to ensure smooth drafting and avoid clutter in fiber delivery. Thanks to the aprons, the untwisted fiber bundle, which has reduced its strength and thinned is transported to a distance close to the exit cylinder in controlled and smooth manner.

In the pre-drawing zone between the inlet rollers and the apron pair, the entanglement of the fibers is disturbed. The apron pair allows control of the fiber bundle over a larger area during drafting operations [5].
In order to continue experimenting with a single variable, the green cot was chosen, which was considered to be optimum in terms of both working performance and IPI values for both yarn counts. After then, clip tests were carried out on 14/1 Ne and 18/1 Ne yarns, on a fixed green cot. Observations of these experiments are shared.

As the height of the clip increases, the pressure between the middle pressure roller and the drafting roller also increases. This increased pressure results in a decreased contact surface between the upper and lower aprons in the area leading up to the output roller. Due to this reduction in contact surface, the fibres pass through the machine less uniformly and with less control. On one hand, the pressure between the middle pressure roller and draft roller rises, whilst on the other hand, the contact surface between the pair of aprons diminishes. As a result of this situation, there is an increase in the IPI values of the yarn being produced. Furthermore, there is an improvement in working performance.

Conversely, as the clip height decreases, the pressure between the middle pressure roller and the draft roller decreases and the contact surface between the apron pairs increases. The increase in the contact surface provides a more uniform and more controlled passage of the fibers passing through this region. It is seen that the IPI values of the yarn are positively affected by this situation.

Trials on 18/1 yarn were made with Black and Orange clips, which are thought to be suitable for this yarn number, and IPI values were examined.

The variability of U% and CVm values of carded ring yarns produced in Ne number 18/1 green cot according to the clip used is presented in Table 3.

Table 3. Effect of Clip Height on Yarn IPI Values

Yarn Ne: 18/1 Ring				
Cot Color	**Clip Colors**	**Clip Height (mm)**	**Yarn U%**	**Yarn CVm**
Green Cot	Black	3.8	15.22	20.21
	Orange	4.4	15.66	20.79

As indicated in Table 3, it is seen that the U% and CVm values of the black clip with a clip height of 3.8 mm are better than the U% and CVm values of the orange clip with a clip height of 4.4 mm. It can be said that the working performance of the yarn is negatively affected by this situation, while the values improve as the clip height decreases.

The variability of U% and CVm values of carded ring yarns produced in Ne 18/1 green cot according to the clip used is visually presented in Figure 3.

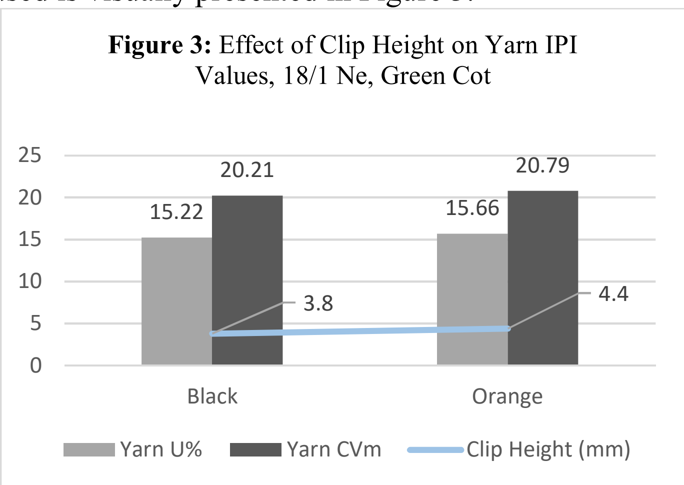

Figure 3. Effect of Clip Height on Yarn IPI Values

Trials on 14/1 Ne yarn were made with Beige, Green and Violet-Pink clips, which are thought to be suitable and close to this yarn count, and IPI values were examined. The variability of U% and

CVm values of carded ring yarns produced in Ne 14/1 green cot according to clip color and thus clip height is presented in Table 4.

Table 4. Effect of Clip Height on Yarn IPI Values

Yarn Ne: 14/1 Ring				
Cot Color	**Clip Colors**	**Clip Height (mm)**	**Yarn U%**	**Yarn CVm**
Green Cot	Beige	4.8	17.37	23.36
	Green	5.5	18.6	24.96
	Violet-Pink	6.3	19.3	25.94

When the data in Table 4 is examined, it is seen that the IPI values improve as the clip height decreases. On the other hand, when the working performance of the yarn is examined, it has been observed that the working performance of the yarn decreases as this height decreases.
The variation of U% and CVm values of carded ring yarns produced in Ne 14/1 green cot according to clip color and thus mm distance is presented in Figure 4.

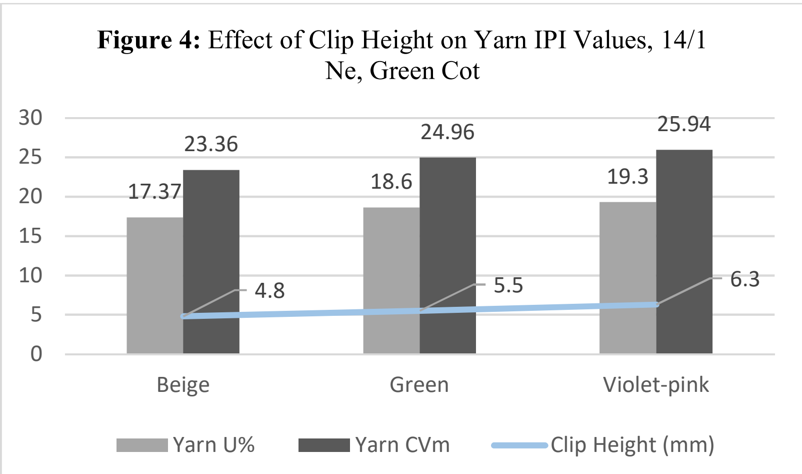

Figure 4. Effect of Clip Height on Yarn IPI Values

In the light of all this information, considering the effect of the clip, which is another spinning element, as the clip height (mm) increases; it is seen that the working performance has improved, but the IPI values of the yarn are negatively affected by this situation. Likewise, as the clip height decreases; It has been observed that the IPI values of the yarn have improved, but the working performance has been negatively affected by this situation.

4.CONCLUSION

In this study, it is aimed to produce ring yarn from the blend obtained as a result of the mixture of recycle fiber and regenerated cellulose fiber, which is brought into fiber form from pre-consumer textile wastes. In this context, various attempts were made to improve the yarn quality and working performance by looking at the effects of spinning elements such as cots and clips, which have different properties.

As a result of the study; up to a certain cot hardness value, it has been observed that the decrease in cot hardness, negatively affects the working performance of the yarn, while it positively affects the yarn quality values.

When the effect of the clip was examined, it was observed that the increase in the clip height (mm) positively affected the working performance, but negatively affected the yarn quality values.

Therefore, it is important to choose the cot and clip to be used depending on the properties of the yarn to be produced, in a way that will keep the yarn quality and working performance optimum.

The hardness of the cot should be chosen according to the blend used and the final yarn to be obtained.

In the same way, it is important to use clips in accordance with the fineness of the yarn produced and the blend used.

5. REFERENCES

[1] ERSOY, Y., & ZIRAPLI, M. (2014). Geri Dönüşüm İplikçiliğin Önemi ve İplik Üretim Yöntemleri. *Düzce Üniversitesi Bilim ve Teknoloji Dergisi*, *2*(2), 425-432.
[2] YURTASLAN, Ö. (2018). *Bir tekstil işletmesinde üretilen tekstil teleflerinin çevreci bir yaklaşımla geri kazanımı* (Master's thesis, Bursa Teknik Üniversitesi).
[3] BURÇIN, E. S. E. R., ÇELIK, P., AHMET, Ç. A. Y., & AKGÜMÜŞ, D. (2016). Tekstil Ve Konfeksiyon Sektöründe Sürdürülebilirlik Ve Geri Dönüşüm Olanaklari. *Tekstil ve Mühendis*, *23*(101), 43-60.
[4] ZEYBEK, A. (2020). Ön ve Arka Manşon Çapı Farklılıklarının Karde Ring İplik Kalite Parametreleri Üzerine Etkisi, Uluslararası Doğu Anadolu Fen Mühendislik ve Tasarım Dergisi, 2(2), 380-400.
[5] T.C. Milli Eğitim Bakanlığı, Tekstil Teknolojisi, Ring İplik Makinesi, Ankara, 2011.
http://www.megep.meb.gov.tr/mte_program_modul/moduller_pdf/Ring%20%C4%B0plik%20Makinesi.pdf

PROPERTIES OF NANOFIBROUS POLY(VINYL ALCOHOL) / NAFION POLYMER ELECTROLYTE MEMBRANES

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ABSTRACT

In this study, poly(vinyl alcohol)/Nafion nanofibrous composite membranes were produced by electrospinning followed by physical stabilization, polymer coating and sulfonation. Morphology, methanol permeability and proton conductivity of the resultant membranes were tested. It was investigated that poly(vinyl alcohol) coated nanofibrous membranes had the highest proton conductivity and lowest methanol permeability and had a potential to be used as polymer electrolyte membrane for fuel cell applications.

Key Words: Fuel cell, polymer electrolyte membrane, nanofiber, Nafion, poly(vinyl alcohol)

1. INTRODUCTION

The use of clean energy sources is now utmost important for a sustainable world in the fight against climate change and other environmental problems. With the developing technology, it is possible to produce environmentally friendly, reliable and efficient devices. One of them are fuel cells, defined as electrochemical cells in which the chemical energy of the fuel is directly converted into electricity in one-step for power generation [1, 2]. Among several types of fuel cells, polymer electrolyte membrane fuel cells (PEMFC) has found favor because of the advantages such as low operating temperature, high power density, flexibility of fuel type, etc. One of the most important components in PEMFC is the polymer-based membrane, known as the polymer electrolyte membrane (PEM), which acts as an electrolyte for protons and provides proton transfer. Another task of PEM is to prevent the permeation of fuel from the anode to the cathode [1, 3].

As of today's state of PEMFC technique, Nafion membranes are commercially available and the most widely used membrane material. However due to the several disadvantages of Nafion film membranes such as poor water management, high fuel permeability, etc., studies have been focused on the development of alternative new membranes [4, 5]. Among these studies, especially the development of nanofibrous composite membranes has become the focus of attention in recent years. In this study, poly(vinyl alcohol)/Nafion (PVA/Nafion) based nanofibrous composite membranes were produced by electrospinning method and their selected properties related to fuel cells were investigated.

2. EXPERIMENTAL

10% PVA (Mowiol ®20-98, 125000 g/mol) was dissolved in pure by stirring at 80°C for at least 3 hours. Then, PVA solution were mixed with 5% Nafion 117 solution at a ratio of 50:50 by volume. Nanofibers were produced by electrospinning (Nanospinner, NS Plus) with the parameters of 18 kV voltage, 15 cm tip-to-collector distance and 0.7 ml/h flow rate. The resultant electrospun nanofibers were thermally stabilized at 180°C for 1 hour, coated with PVA (using %5 PVA solution) or Nafion (using %5 Nafion 117 solution), and sulfonated by using 4-formyl-1,3-benzenedisulfonic acid disodium salt, respectively, to produce composite nanofibrous membranes. SEM, proton conductivity (at 100 RH (%)) and methanol permeability tests were applied in order to investigate their usability in fuel cells.

3. RESULTS AND DISCUSSION

Figure 1 shows SEM images of PVA/Nafion nanofibrous membranes coated with different fillers. It was observed that the membranes coated with PVA had a smoother surface. On the other hand, Nafion penetrated into the membrane but PVA filler mostly stays on the surface. This is thought to be because of the higher viscosity of the PVA solution compared to Nafion solution due to the higher molecular weight of PVA.

PVA/Nafion nanofibers	PVA coated PVA/Nafion nanofibers	Nafion coated PVA/Nafion nanofibers

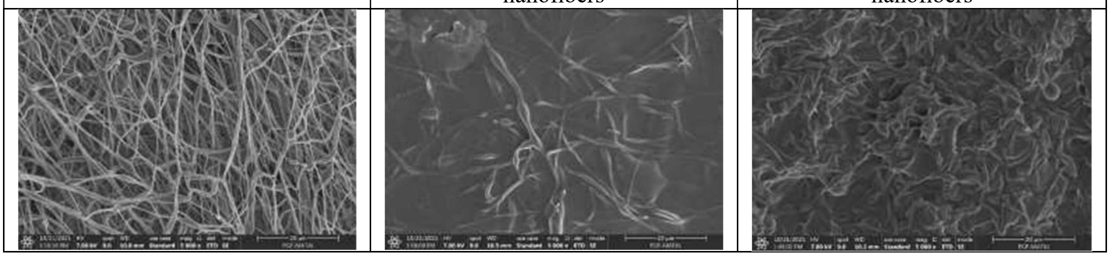

Figure 1. SEM images of PVA/Nafion nanofibers coated with PVA and Nafion

Methanol permeability and proton conductivity of the nanofibrous membranes were given in Table 2. It was shown that the methanol permeability of PVA coated PVA/Nafion nanofibers was the lowest, which was similar to the commercial Nafion membrane ($1.4x10^{-6}$). During PVA coating, as shown in SEM images, the membrane surface was covered with a film layer, which possibly act as a barrier layer. In addition, the higher affinity of PVA for water than methanol [4] might assist to have a lower methanol permeability.

Table 1. Methanol permeability and proton conductivity of PVA/Nafion nanofibrous membranes

Sample	Methanol permeability (cm^2s^{-1})	Proton conductivity (mS/cm)
PVA/Nafion	$3.8x10^{-5}$	-
PVA coated PVA/Nafion	$1.5x10^{-6}$	12.4
Nafion coated PVA/Nafion	$1.3x10^{-5}$	9.1

Uncoated PVA/Nafion nanofibers could not provide proton conductivity. On the other hand, coated membranes had proton conductivity property and PVA coated membrane had higher proton conductivity than the Nafion coated one.

4. CONCLUSION

In this study selected properties of PVA/Nafion nanofibrous membranes coated with PVA or Nafion were investigated to investigate their possible application as a polymer electrolyte membrane. The results showed that the easily produced and relatively inexpensive nanofibrous PVA/Nafion composite membranes have the potential for direct use in fuel cell applications.

ACKNOWLEDGMENT

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5. REFERENCES

[1] ALTAF, F., GILL, R., BATOOL, R., DREXLER, M., ALAMGIR, F., ABBAS, G, JACOB, K. Proton conductivity and methanol permeability study of polymer electrolyte membranes with range of functionalized clay content for fuel cell application. European Polymer Journal, 2019, 110, pp 155-1671.
[2] SHARAF, O.Z., ORHAN, M.F. An overview of fuel cell technology: Fundamentals and applications. Renewable and Sustainable Energy Reviews, 2014, 32, pp 810-853.
[3] DELUCA, N.W., ELABD, Y.A. Nafion®/poly(vinyl alcohol) blends: Effect of composition and annealing temperature on transport properties. Journal of Membrane Science, 2006, 282(1-2), 217-224.
[4] DELUCA, N.W., ELABD, Y.A. Polymer electrolyte membranes for the direct methanol fuel cell: A review. Journal of Polymer Science, Part B: Polymer Physics, 2006, 44, pp 2201-2225.
[5] WU, L., ZHANG, Z., RAN, J., ZHOU, D., LI, C., XU, T. Advances in proton-exchange membranes for fuel cells: an overview on proton conductive channels (PCCs). Physical Chemistry Chemical Physics, 2013, 15, pp 4870-4887.

EVALUATION OF THE TECHNICAL PERFORMANCE OF AUTOMOTIVE SEAT FABRICS PRODUCED USING POCKET STRUCTURES AND FILLER YARN

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ABSTRACT

Automotive seat covers are traditionally produced using jacquard and dobby weaving techniques. In the production of these fabrics, high density weave structures are commonly used to achieve successful results in abrasion and strength tests in accordance with automotive specifications. The necessity of meeting the test requirements in automotive seat cover fabrics is one of the factors that limit the design variability. Despite these limitations, customers always demand new design options. When it is predicted that autonomous vehicles will break into the market rapidly, it is believed that the amount of time driver and occupant spend inside vehicles will increase. Automotive fabric manufacturers are also expected to contribute to creating a home or office comfort experience within the vehicle through fabric designs. In order to enhance this experience, the quilted fabric structures commonly found in home upholstery have been investigated. Pocket structures supported by filler yarns are frequently observed in matelassé fabrics. In the scope of this study, fabrics supported with filler yarns in three different pocket sizes were produced. Produced fabrics were evaluated for surface abrasion, horizontal combustion, and seam fatigue tests according to the specifications of a major automotive manufacturer. Based on the test results, the effect of the sizes of these structures on automotive fabric quality was investigated.

Keywords: Automotive seat fabric, autonomous vehicles, matelassé fabric, weaving, pocket structures on weaving

1. INTRODUCTION

Automotive upholstery fabrics are composite structures consisting of surface fabrics, polyurethane lamination foam, and scrim layers, where flame lamination is used to combine these layers. The face fabric structures are produced to provide essential technical and aesthetic characteristics. In the production of these surfaces, PET-based air or friction-texturized yarns that meet automotive standards such as high abrasion resistance, flame resistance, and high lightfastness are commonly used [1]. Weaving machines with dobby or jacquard weaving techniques are generally used in fabric production, with pattern repeats such as double rips, panama, and twill. Although initially most of the automotive fabrics are jacquard woven structures producing using plain, dobby, or small-scale designs, trends and demands tend to move beyond traditional automotive patterns. Automotive companies or OEMs employ qualified textile designers to create designs and colors [2].

In the upcoming years, it is predicted that autonomous vehicle technology will increasingly dominate the automotive industry. Autonomous vehicles, equipped with automatic control systems, are capable of navigating, perceiving the road, traffic flow, and surroundings without the need for a driver's intervention [3]. As a result, it is anticipated that users of autonomous vehicles will be able to utilize their time during traffic by reading books or coordinating their work in the car. Consequently, the time spent by driver or occupent inside vehicles is expected to increase. Considering that 1/4 of the human body comes into contact with the seat, there is a need for designs in autonomous vehicles that create a home or office atmosphere. It is inevitable to improve the aesthetic and comfort properties of seat fabrics to achieve this atmosphere [3,4]

To create a home atmosphere in the vehicle, fabric structures used in home upholstery and bedding surfaces have been investigated for utilization of automotive seat cover fabrics. When examining these fabrics, it is observed that the structural characteristics or application processes mimic the irregular properties of natural textures. These fabrics, referred to three-dimensional, relief, or voluminous fabrics, achieve effects such as puffed, porous, or indented through the combination of structure and material. Matelassé fabrics, where the pocket or quilt effect is given to highlight the patterns, are among the most prominent representatives of relief fabrics. [5]. Matelassé fabrics are among the prominent representatives of relief fabrics. These fabrics can be produced using knitting or weaving techniques. When the matelassé fabric structures produced with the weaving technique are examined, it is observed that they are double-layered voluminous structures formed with at least two warps and two wefts. In these fabrics, the use of filling yarn between the fabric layers in the weft direction; in the warp, it has been observed that the warp yarns of different thicknesses forming the upper and lower series create a relief effect on the fabric due to the tension differences during weaving [6].

In this study, inspired by matelassé fabric structures, double-layer fabrics supported with filler yarns in three different pocket sizes were produced. The produced fabrics were evaluated for surface abrasion, horizontal combustion, and seam fatigue tests according to the specifications of a major automotive manufacturer. The impact of pocket sizes on the test results was investigated.

2. EXPERIMENTAL STUDY

2.1. Materials

In this study, double-layered automotive seat fabrics produced by filler yarn supported pocket structures, which contribute to the creation of home or office comfort with automotive seat fabrics, were used. The fabrics were produced on a double-beam, 66 warp density. 100% PES 150 Denier, 450 Denier, and 1200 Denier filler yarns were used in the weaving process. 30 dens 4.1 mm PU-based lamination foam and 40 gr/m2 PA-based scrim layer, produced by Martur Automotive Seating Systems, were laminated on the back of the fabric. Each fabric was treated in 70 degree open width washing and stentering processes under the same conditions.

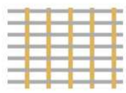
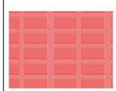
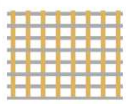
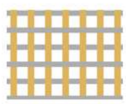
Design	Warp Densty	Weft Densty	Warp Yarn	Weft Yarn	Number of Warp ends per cm	The Length of the Pocket Structure (cm)	Pattern Simulation	Pattern Report
Design 1	66	48	LIGHT BLUE 150 Denier %100 PES	Grey 150 Denier %100 PES	94	1,4		
				BLACK 450 Denier %100 PES				
			DARK BLUE 450 Denier %100 PES	BLACK 1200 Denier %100 PES (Filler Yarn)				
Design 2	66	48	LIGHT BLUE 150 Denier %100 PES	Grey 150 Denier %100 PES	56	0,84		
				BLACK 450 Denier %100 PES				
			DARK BLUE 450 Denier %100 PES	BLACK 1200 Denier %100 PES (Filler Yarn)				
Design 3	66	48	LIGHT BLUE 150 Denier %100 PES	Grey 150 Denier %100 PES	41	0,62		
				BLACK 450 Denier %100 PES				
			DARK BLUE 450 Denier %100 PES	BLACK 1200 Denier %100 PES (Filler Yarn)				

Figure 1. Weaving parameters of produced woven fabrics

2.2. Method

2.2.1. Surface Abrasion Test

Surface abrasion is the deformation that occurs as a result of the rubbing of one surface against another. During the time spent in a vehicle, upholstery fabrics are subjected to the friction caused by different materials worn by utilizers, making surface abrasion tests crucial for automotive upholstery. The test is performed by rubbing the abrasion fabric on the fabric surface for 10.000 cycles under 1kg weight.

Figure 2. Surface abrasion test machine

2.2.2. Flammability Test

The self-ignition rate of the test fabric is calculated in mm/min after it is ignited at predetermined intervals inside a special chamber. This is one of the tests that every automotive manufacturer emphasizes on. It is desired to have the shortest possible time for the flame initiated on the sample to reach a specified point inside the combustion chamber. Flammability tester is indicated in Figure 3.

Figure 3. Combustion chamber

2.2.3. Seam Fatigue Test

Seam strength is the resistance of the stitch to tearing when a force is applied perpendicular to the direction of the stitch on sewn fabrics. It is essential for the stitch to be made using the actual needle and thread. Seam strength is measured by applying it to samples cut in the lengthwise, crosswise, bias, and reverse bias directions. Seam fatigue test was performed according to 400 cycles.

Figure 4. Seam fatigue test machine

3. RESULTS AND DISCUSSION

3.1. Surface Abrasion Test Results

The surface abrasion resistance tests is performed separately on the produced fabrics. It is observed that the surface abrasion resistances of each fabrics produced using different pocket dimensions are similar. A major difference was not seen from the comparison of pocket structures. It has been observed that the 1st fabric, which has the largest pocket structure, has a little more fluff compared to the 2nd and 3rd fabric. However according to the surface abrasion test results, it has been observed that the pocket structure in all three fabrics meets the automotive standards. Evaluation was made according to the gray scale.

Table 1. Surface abrasion test results

	Surface Abrasion 1kg, 10.000 cycles (TSL 2105G (4.7.3))
Design 1	4
Design 2	4
Design 3	4

3.2. Flammability Test Results

In the flammability test each fabric were performed in the width direction. Each fabrics results were 70-71 mm/min in the flammability test. It is observed that pocket structures content fabrics show similar flammability behaviour.

Table 2. Flammability test results

	Flammability (TSM 0500G) (mm/min)
Design 1	70
Design 2	71
Design 3	70

3.3. Seam Fatigue Test Results

It was observed that the increase in pocket structures did not adversely affect the sewing fatigue test result.

Table 3. Seam fatigue test results

	FATIGUE OF SEAMS 400 CYCLES (D45 2024) (mm)
Design 1	1,0
Design 2	1,5
Design 3	1,0

4. CONCLUSION

In this study, inspired by matelassé fabric structures, three different pocket size of double-layered woven fabric supported with filler yarns were produced. In order to evaluate the adaptability of these structures to automotive, their performance in automotive standards was examined. Although it is thought that the increase in pocket length will negatively affect the combustion speed by creating an air gap, it has been observed that the difference of 0,78 cm does not affect the test result. It was also observed that there was no effect on seam fatigue and surface wear tests. When the test results were evaluated, it was observed that the pocket size would be between 0.62 cm - 1.4 cm, it would be suitable for use in automotive standard and it could be an alternative to traditional automotive fabrics.

5. REFERENCES

[1]AKKUŞ, İ. (2019). Otomotiv döşemelik kumaş tasarımı ve tasarımı belirleyen faktörlerin incelenmesi (Yüksek lisans tezi). Eskişehir Teknik Üniversitesi, Endüstriyel Sanatlar Anabilim Dalı, Eskişehir.

[2]HARDCASTLE, J.M.,9 - Woven textiles for automotive interiors and other transportation applications,In The Textile Institute Book Series,Woven Textiles (Second Edition),Woodhead Publishing,2020,Pages 395-422,ISBN 9780081024973, https://doi.org/10.1016/B978-0-08-102497-3.00009-X.

[3]ÖZCAN BERBER, R., KURT, R., TUNA, T., TURAN, S.,KORKMAZ, V.,BEKTAŞ, E. Otonom araçlarda müşteri beklentileri ve konsept koltuk tasarımı. 9th International Automotive Technologies Congress OTEKON, 7-8 May 2018, BURSA

[4]ÇEKEN, F., & PAMUK, G., (2006). Properties of automotive seat fabrics. Technische Textilien , vol.49, no.1.

[5]Berber, G. Ş. & Başaran, F. N. (2018). RÖLYEF ETKİ AÇISINDAN DOKUMA KUMAŞLARDA İPLİK . Hars Akademi Uluslararası Hakemli Kültür Sanat Mimarlık Dergisi , 1 (1) , 57-68 .

[6]BAŞARAN, F. N., & ÖZCAN, N., (2020). “Matelasse” Kumaşlar ve Özellikleri. RESEARCHER SOCIAL SCIENCE STUDIES, vol.8, no.2, 81-98.

REVOLUTIONIZING SEWING MACHINES: ANALYZING THE INTEGRATION OF BOBBIN THREAD DETECTION DEVICES

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ABSTRACT

Considering that the production of ready-to-wear is a labor-intensive sector, efficiency is crucial. In mass production, similar operations are done repeatedly, and it is not desirable to waste time with divisive works. One of the reasons that interrupt the sewing machine operator's work and cause wasted time is running out of thread on the bobbin. Since the bobbin is in the bobbin case located under the sewing machine table, it cannot be seen, and the remaining thread amount cannot be checked. This research is expected as a technological advance for an automated, unmanned sewing process that measures the amount of thread still in the bobbin.
In this study, a system that measures the remaining thread amount is provided by an electrical signal with the help of a pin that enters the bobbin when the sewing process for detecting the remaining thread on the lower bobbin is completed and the thread wiper breaks the thread and warns the operator when it reaches the predetermined amount has been integrated into the sewing machines. Therefore, it is aimed to increase productivity by reducing time loss and to increase the quality of sewing, since no joints will be made in the seams. The lower bobbin measuring system integrated into the lockstitch sewing machine and compared with the conventional method, it is seen that the system that measures the lower bobbin thread amount reaches the breakeven point in nine months.

Key Words: Sewing, bobbin thread, denim, automation

1. INTRODUCTION

The future of the global textile and clothing (T&C) industry is a key topic of discussion. This fourth industrial revolution is a paradigm shift that has the potential to create the "smart factory" of the future by fusing the real and digital worlds [1].
The sewing process is one of the most time-consuming process in the manufacturing process of textile products. Due to the recent rise in labor costs, sewing costs are gradually rising. Along with the 4th industrial revolution, automation of the sewing process and smart factories are expected. Applying intelligent sensor technology to the sewing machine is essential to make the garment factory intelligent [2].

Due to the wide range of styles and fabric options available for the products, apparel manufacturing has always been labor demanding. To conduct consistent operations over a wide range of styles, most sewing machine manufacturers and several larger apparel firms have created semi-automated sewing stations. Since it affects the price of producing and distributing textile products, predicting sewing thread consumption demands an accurate computation approach. Researchers in the past have called attention to issues with the formulas used to calculate the amount of thread needed for sewing activities, including their restrictions. Due to a lack of knowledge about crucial factors that affect thread consumption, the current methods of consumption calculations display high error rates [3].

One of the important considerations in the purchase of thread is the prediction of sewing thread consumption.

For their logistics and purchasing operations for thread, both garment makers and thread suppliers in the apparel sector forecast the amount of thread that will be used per unit length of the stitch.

For both clothing manufacturers and sewing thread makers, erroneous thread consumption projections result in inaccurate costs and lower warehouse utilization [4].

Time losses related to the bobbin in mass production can be classified as follows.

1. Personnel notice the thread end of the lower bobbin during operation and when sewing is not performed.
    a. Since re-joining the sewing place is unsuitable in terms of quality, dismantling is done.
    b. and the operation starts from the beginning.
2. The operator continues to sew without noticing that the lower bobbin has run out of thread, and more than one job (piece) is progressing without sewing.
    a. When this is noticed, how many pieces are detected and moved in the opposite direction of the belt flow.
    b. Since no additional stitching can be done, the dismantling process takes place.
    c. The same operations are repeated.
    d. There may be a meta confusion.
3. When the lower bobbin runs out, if there is no threaded bobbin in reserve, time is wasted in winding the bobbin.

In this study, a system includes, a lower thread detection device for detecting a lower thread wound around a bobbin each time a sewing machine stops driving, comprising: a detection pin extending from the outer periphery toward the center in the radial direction of the bobbin; A moving means for moving the bobbin toward a center of the bobbin, a contact switch for detecting movement of the detecting pin, and a position adjusting knob for adjusting the position by screw feeding the contact switch in the moving direction of the detecting pin lower thread detecting device that measures the remaining thread amount with an electrical signal and warns the operator when it reaches the predetermined amount [5], with the help of a pin inserted into the bobbin, is integrated into the sewing machines while the sewing process for the detection of the remaining thread on the lower bobbin is completed and the thread wiper breaks the thread [6]. Thus, it is aimed to increase productivity by reducing time loss and to increase the quality of sewing, since no joints will be made in the seams.

2. EXPERIMENTAL

There are numerous distinct types of seaming have been devised for various sewing applications [7]. Due to the intense use of denim and non-denim sewing operations, the DDL-8700 model lockstitch sewing machine was selected for the integration of the bobbin thread detection device from Juki, Japan. Bobbin thread detection device was supplied by Shiro International Co., Japan. 60 tex polyester for the lower bobbin and 105 tex polyester for stitching threads were supplied from Coats, UK. Indigo-dyed denim fabric was purchased from Matesa Denim AŞ., Turkey. The weight of the fabric is 12 oz/yd^2. It has a 3/1 Z twill weave structure, and 98/2% - CO/EL fabric composition.

In order for the measuring pin to measure the remaining thread amount, a hole is drilled into the bobbin case so that the pin can enter (Figure 1).

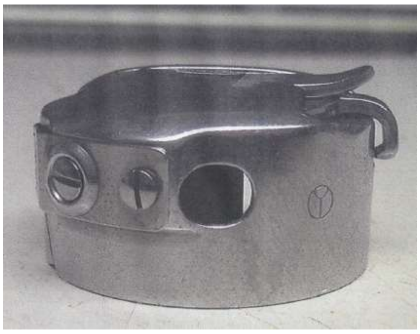

Figure 1. A hole was drilled in the bobbin case

The bobbin checker functions by an electric circuit and an air electromagnetic valve. The measurement pin was powered by DC24V from the sewing machine. The pressure of the air valve was set to 0.3 MPa. Electrical wires from the bobbin checker were connected to the control box of the sewing machine. The measuring pin was inserted into the inside of the hook/bobbin case and physically detects the remaining amount of bobbin thread. The determined amount of remaining bobbin thread on the bobbin is adjustable to specific requirements by adjusting the position of the limit switch. Figure 2 shows the image of the bobbin thread detection system assembled on the sewing machine.

Figure 2. Bobbin thread detection system

Denim fabrics were cut according to the determined design. Then, the assembly processes of the fabrics were carried out on the lockstitch sewing machine according to 301 stitch types. The processing times of the fabrics repeatedly sewn on the sewing machine with the lower bobbin thread warning system and the standard lockstitch sewing machine were compared. Table 1 includes the experiment plan.

Table 1. Experimental plan

Code	Operation	Stitch type	Number of needles	Number of stitched fabrics	Bobbin Changing Type	Thread Size (tex)
M1	Bottom hem sewing	301	2	483	Conventional	60
M2	Bottom hem sewing	301	1	404	Conventional	60
M3	Bottom hem sewing	301	1	347	Bobbin checker	60
M4	Inseam	301	1	269	Bobbin checker	50
M5	Inseam	301	1	256	Conventional	50

3. RESULTS AND DISCUSSION

Table 2 shows the time study results of repeated sewing operations with the selected models.

Table 2. Process time difference study results

Code	Operation	Bobbin Change Times (sec)	Total seam removal time (sec)	Number of stitched fabrics
M1	Bottom hem sewing (2-needle)	740,76	4108,06	483
M2	Bottom hem sewing	332	753,5	404
M3	Bottom hem sewing	289,2	25,8	347
M4	Inseam	879	49,7	269
M5	Inseam	1064	891	256

The average dismantling time for each product of the samples sewn on the sewing machines without the lower bobbin warning system was calculated according to formula 1.

$$ad = \frac{a/b}{60} ad = \frac{(a\text{-}b)}{60} \qquad (1)$$

Where,

a is the total seam removal time,

b is the number of stitched fabrics and,

ad is the average dismantling time.

The daily labor loss of a company that produces an average of 2000 products per day is calculated according to formula 2.

$$l = \frac{(ad*2000)}{540} \quad (2)$$

Where,

l is labor loss

When calculations are made according to formulas 1 and 2 for the trials with code numbers M1, M2, and M3, the results in Table 3 are obtained.

Table 3. Lost labor results for samples

Code	Average dismantling time per sample (min)	Labor loss (daily)
M1	0,14	0,52
M2	0,031	0,11
M3	0,001	0,005
M4	0,003	0,011
M5	0,058	0,214

Upon reviewing the results, it has come to attention that the M1 coded trial experienced the most labor loss. It was concluded that the reason for this is due to the use of double needle stitching in addition to the conventional method. It took a longer time to remove the unfinished double needle stitch when the lower bobbin was finished, as compared to single needle stitching.

When the M2 and M3 trials are compared, it is seen that the loss of labor due to wrong sewing has decreased by 95%. Similar results obtained for the M4 and M5 trials comparison. Labor loss was reduced by 94%. Regarding the effect of sewing thread count on the bobbin change time and labor loss, it was found that decreasing the thread count resulted in longer bobbin change times, but also caused an increase in labor loss due to the inseam stitch being longer than the bottom hem sewing stitch.

4. CONCLUSION

The fourth industrial revolution is anticipated to bring about the automation of the sewing process and the smart factory. Applying smart sensing technology to the sewing machines is crucial for making the sewing factories intelligent.

In this study, the conventional lockstitch sewing machine has been modified and a system integration has been made that warns the personnel about the thread remaining on the lower bobbin is close to running out. The advantage of the modified machine over the conventional method was determined by the labor force and dismantling time. The developed system provided a 95% advantage over the conventional method in terms of labor-loss. The Textile & Clothing industry needs to stop being a labor-intensive industry in the increasingly widespread industry 4.0 era and adapt to digitalization with such minimal integrations.

5. REFERENCES

[1] LUU, HA; FERREIRA, FERNANDO; MARQUEX, ANTÓNIO DINIS. Digitisation and Industry 4.0 in the Portuguese T&C sector. 2019.

[2] LEE, JAE-YONG, ET AL. Study on sensing and monitoring of sewing machine for textile stream smart manufacturing innovation. In: 2017 24th International Conference on Mechatronics and Machine Vision in Practice (M2VIP). IEEE, 2017. p. 1-3.

[3] ABEYSOORIYA, R. P., & WICKRAMASINGHE, G. L. D. Regression model to predict thread consumption incorporating thread-tension constraint: study on lock-stitch 301 and chain-stitch 401. *Fashion and Textiles*, 2014, *1*(1), 14.

[4] SAMUEL WESLEY, D. POOJITHA, V. A simple system for the online detection of skip/loop stitches in single needle lockstitch sewing machines. AUTEX Research Journal, 2010, 10: 69-72.

[5] KINOSHITA, H. MASAHITO, H. Sanki Engineering Co Ltd., Sewing machine bobbin thread detecting device. JPH0924176A, 1997.01.28.

[6] KINOSHITA, H. RYUZO, S. TADASHI, K. KINOSHITA SEIMITSU KOGYO KK. Bobbin thread detecting device. JP2017035127A, 2017.08.03.

[7] ISO 4915:1991, Textiles - Types de points – Classification et terminologie

THE USE OF RECYCLED COTTON FIBERS FOR SUSTAINABLE TEXTILE PRODUCTION

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ABSTRACT

Due to the depletion of natural resources and climate change, sustainability and recycling of textile wastes have become part of the agenda all over the world. However, reuse or recycling of consumed products is still at very low levels.
Within the scope of this study, pre-consumer cotton textile wastes such as cutting scraps, ball heads or damaged fabrics, which are released during textile production in the industry, are transformed into fibers and mixed with natural colored cotton fiber, raw cotton fiber and viscose fiber Breaking strength, breaking elongation, yarn count and uster tests of the resulting yarns are reported.

Keywords: Sustainability, Natural colored cotton, Recycled cotton.

1. INTRODUCTION

Sustainability is of great importance for the producer and the final consumer in the textile industry[1]. While developing and growing economically, it should be one of the most realistic responsibilities of all countries to make important moves in terms of sustainability, to be responsible for the environment, society and the ecosystem. It is necessary to constantly find solutions to reduce the damage of this effect.

There are four main approaches to sustainable textile production which are summarized below:

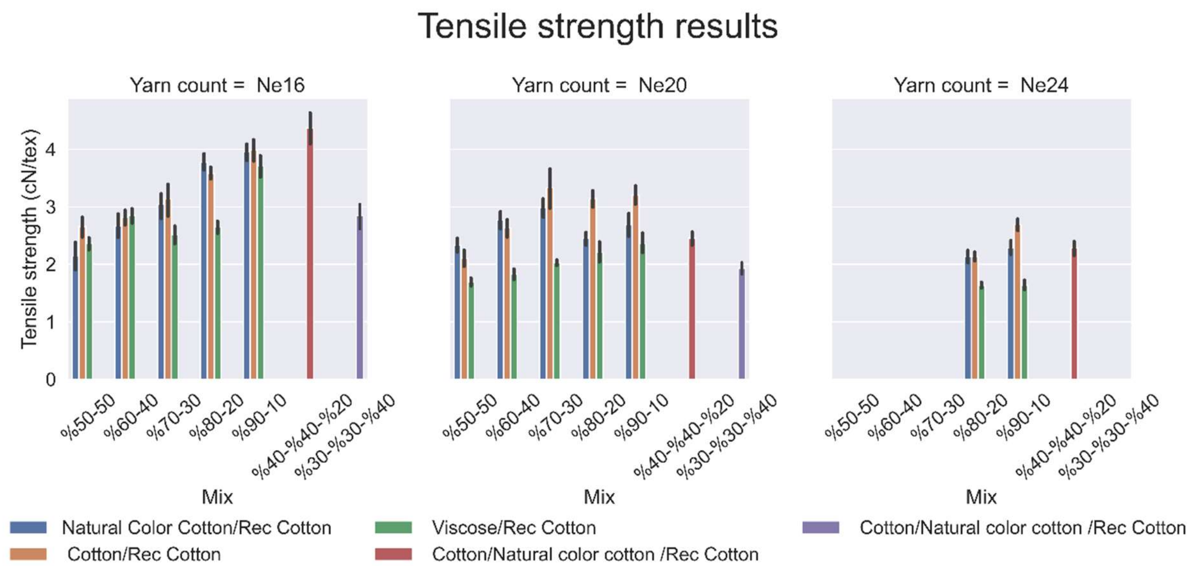
1. Substitution of Fibers: Synthetic fibers from renewable resources are seen as more sustainable alternatives in the future to replace natural fibres. For example, cellulose-based Lyocell and Qmilch fibers from milk protein are considered alternatives from renewable resources [2].
2. Integrated Production of Natural Fibers: The integrated production system works on reducing environmental impacts by using less pesticides, fungicides, chemical fertilizers and water. Certification systems such as "Cotton made in Africa" and initiatives such as the "Better Cotton Initiative" provide examples of this approach [3].
3. Organic Fibers: Organic cotton production aims to produce cotton through a material flow that is compatible with the natural environment. Chemical fertilizers, drugs and genetically modified organisms are not used [3].
4. Using Recycled Fibers: Recycling cotton is still underutilized by textile and apparel manufacturers and retailers. While polyester is the most widely used material in recycling applications, recycling cotton is still a new topic [4].

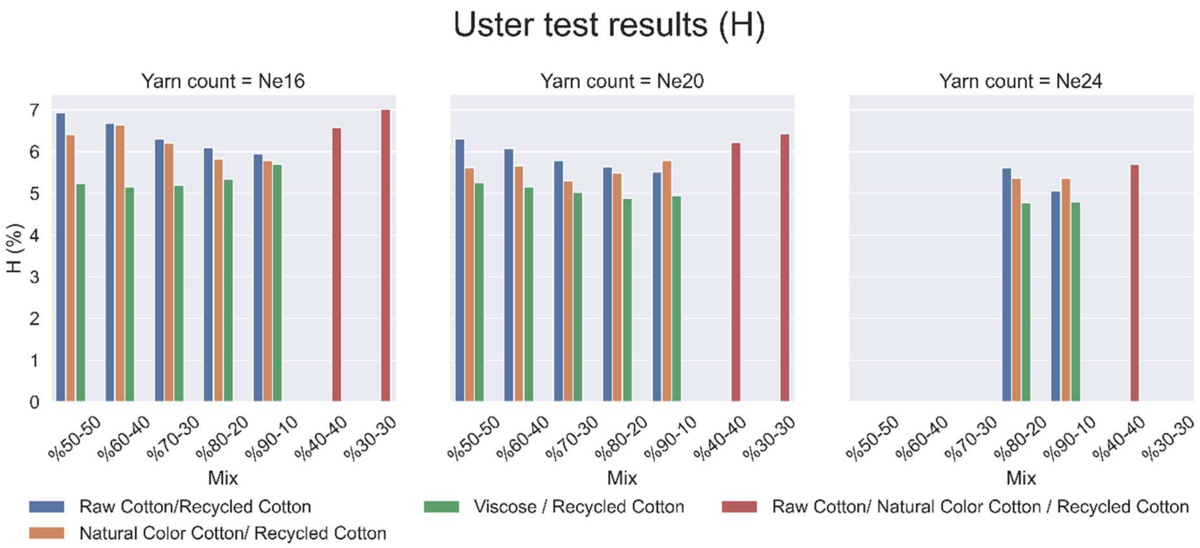
The goal of the current work is to help minimize the use of chemicals in cotton production and to highlight the importance and feasibility of the use of more renewable materials by analyzing the key properties of various mixtures of recycled cotton fibers.

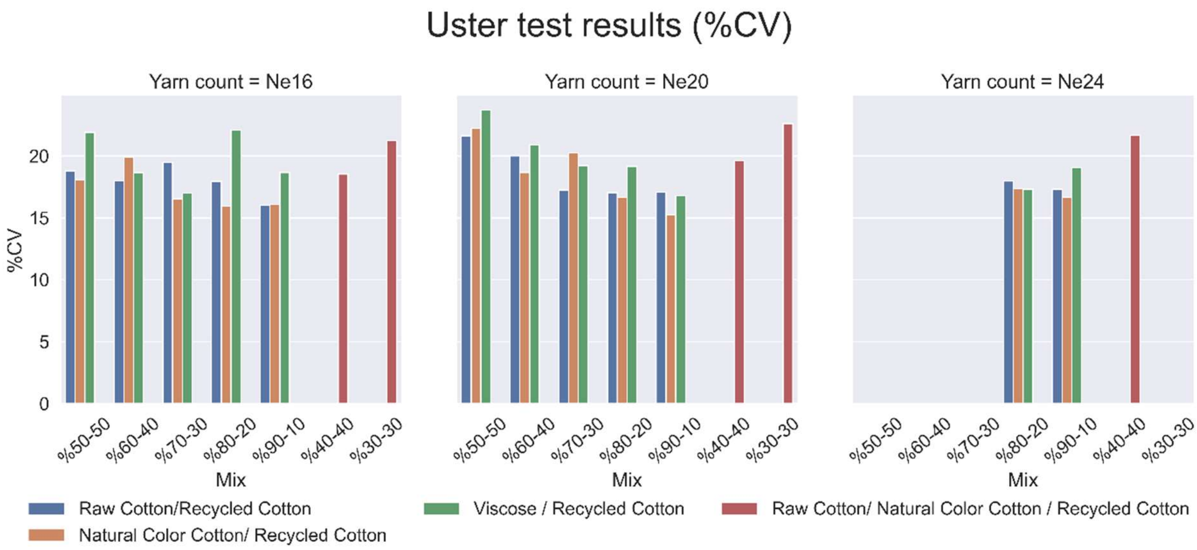
2. MATERIALS AND METHODS

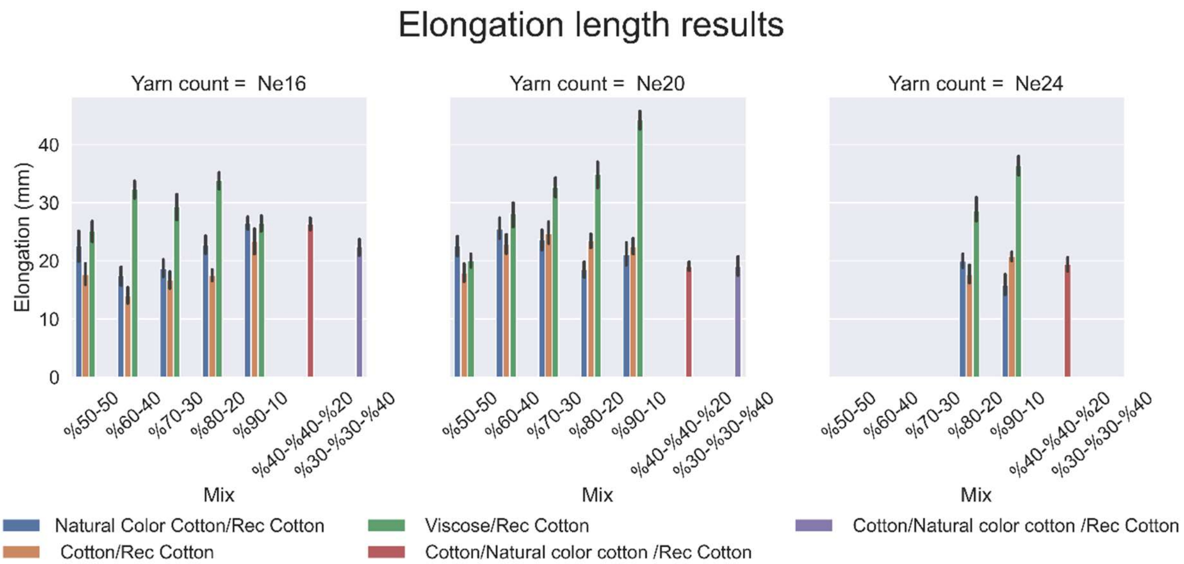
In the current work, recycled cotton fiber, natural colored cotton fiber, raw cotton fiber and viscose fiber were used. Recycled cotton fiber was blended with other fibers in five ratios (%50-50, %60-40, %70-30, %80-20, %90-10), resulting in 15 different fiber mixtures. Three different yarn counts were obtained from the blended fibers (Ne16, Ne20, Ne24), resulting in a total of 45 different yarns. The yarns obtained were subjected to the following tests: tensile strength and elongation, Uster evenness test and yarn count test. 30 cm knitted fabrics were produced from Ne20 number yarns for visual evaluations.

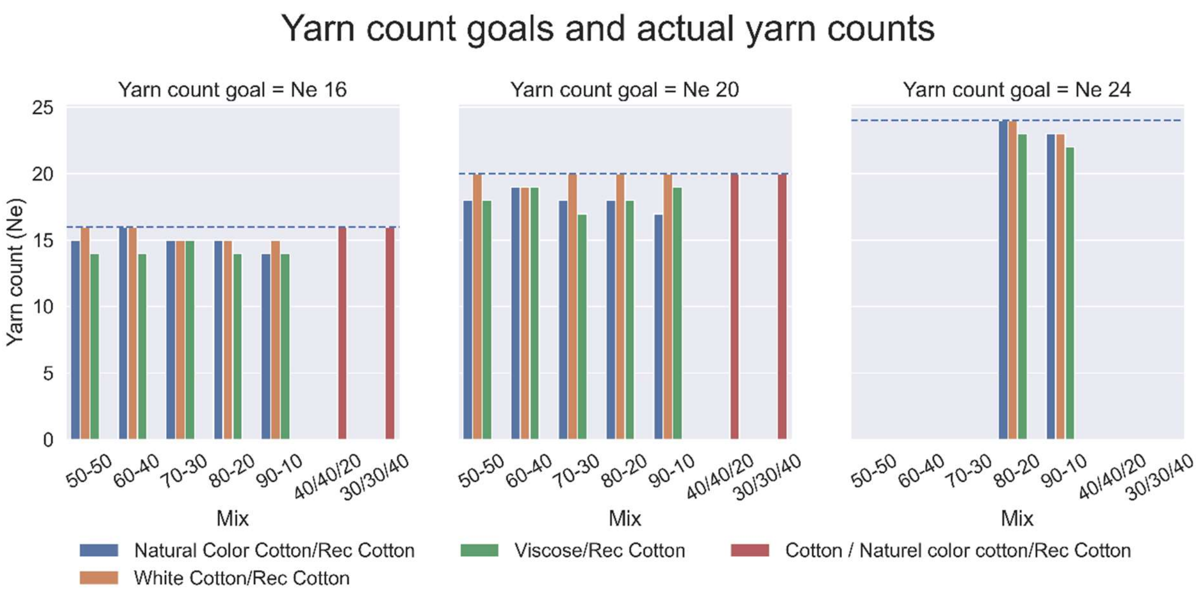
3. RESULTS






Uster test results (%CV)
Yarn count = Ne16
Yarn count = Ne20
Yarn count = Ne24
%CV
Mix
%50-50
%60-40
%70-30
%80-20
%90-10
%40-40
%30-30
Raw Cotton/Recycled Cotton
Natural Color Cotton/ Recycled Cotton
Viscose / Recycled Cotton
Raw Cotton/ Natural Color Cotton / Recycled Cotton


Elongation length results
Yarn count = Ne16
Yarn count = Ne20
Yarn count = Ne24
Elongation (mm)
Mix
%50-50
%60-40
%70-30
%80-20
%90-10
%40-%40-%20
%30-%30-%40
Natural Color Cotton/Rec Cotton
Cotton/Rec Cotton
Viscose/Rec Cotton
Cotton/Natural color cotton /Rec Cotton
Cotton/Natural color cotton /Rec Cotton


Yarn count goals and actual yarn counts
Yarn count goal = Ne 16
Yarn count goal = Ne 20
Yarn count goal = Ne 24
Yarn count (Ne)
Mix
50-50
60-40
70-30
80-20
90-10
40/40/20
30/30/40
Natural Color Cotton/Rec Cotton
White Cotton/Rec Cotton
Viscose/Rec Cotton
Cotton / Naturel color cotton/Rec Cotton

4. CONCLUSION AND DISCUSSION

Thanks to the data we obtained from the statistical evaluation in all mixing ratios, the following inferences were made:

1. When the breaking strength values are examined: Using yarn count Ne24, raw cotton/recycled cotton as raw material, 90/10 as a blending ratio for double blends and 40/40/20 for triple blends produced the highest breaking strength.
2. When the elongation at break values are examined: Using yarn count Ne20, viscose/recycled cotton as raw material, 90/10 as a blending ratio in double blends and 40/40/20 as a blending ratio in triple blends produced the highest elongation at break.
3. When the irregularity (%CV) values are examined: Using yarn count Ne20, raw cotton/natural colored cotton/recycled cotton as a raw material, 30/30/40 as a blending ratio and 50/50 (viscose/recycled cotton) as a blending ratio for binary blends produced the highest unevenness.
4. When the hairiness (H) values are examined: Yarn count Ne16, as raw (virgin) cotton/natural colored cotton/recycled cotton, as a blending ratio of 30/30/40 and in binary blends as a blending ratio of 50/50 (raw (virgin) cotton/recycled cotton) out produced the highest hairiness.

While yarn count, raw material variety and raw material ratio do not affect each other, i.e., they do not show any interaction effects in terms of breaking strength, elongation at break and hairiness; yarn count and raw material variety show an interaction when examining unevenness.

The results of the tests in this study are of great importance, especially in terms of sustainability. Two major problems in the textile industry have been addressed from different perspectives. First, ideas are given about the use of waste that emerges during the pre-consumer production phase. Secondly, colored yarns and fabrics were obtained by mixing natural colored cotton fiber with raw cotton fiber in order to eliminate dyeing and chemical washing processes that cause serious carbon footprints in the textile industry. The prototypes were subjected to the necessary tests and were deemed suitable for usability. Thanks to the necessary reinforcements in the future, yarns and fabrics that can have serious repercussions in the textile industry have been obtained.

5. REFERENCES

[1] MANGIR, A.F. Fast and Slow Fashion For Sustainable Development. Journal of Selcuk University Vocational School of Social Sciences, 2016, Volume:19, 41st Anniversary Special Issue pp.143-154, Article Submission Date: 05/11//2016 – Acceptance Date: 20/12/2016.
[2] SHİSHOO, R. The use of renewable resource based materials for technical textiles applications, Ecotextiles: The Way Forward for Sustainable Development in Textiles, Miraftab, M. and Horrocks, A.R. (Eds), Woodhead Publishing, 109-127, Cambridge, 2007. s. 208p.

[3] HANSEN, E.G. AND SCHALTEGGER S. 100 Per Cent organic? A sustainable entrepreneurship perspective on the diffusion of organic clothing. Emerald Group Publishing Limited, ISSN 1472-0701,VOL. 13 NO. 5 2013, pp. 583-598,Corporate, 2013. s. 583-598.
[4] WANG, Y. Recycling in Textiles, Woodhead Publishing Ltd. Cambridge, UK., 2006. s. 248p.

CLEANER PRODUCTION PRACTICES IN THE TEXTILE SECTOR

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General Directorate of Environmental Management

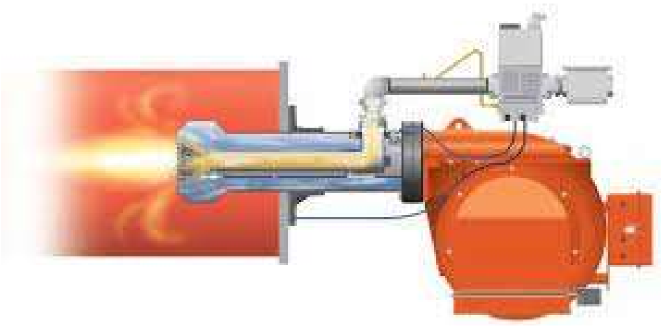
Reference: 41203884-010.06/5406660
Clean Production Practices in the Textile Sector
CIRCULAR
(2022/20)

As known, efforts related to minimizing industrial pollution, reducing pollution at its source, minimizing adverse environmental impacts, and ensuring environmentally compatible management are conducted by our Ministry within the framework of the Environmental Law No. 2872 and the regulations issued based on it.

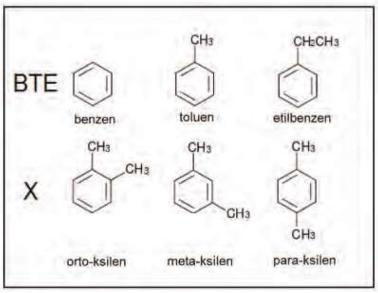
This Circular has been prepared with the aim of implementing clean production technologies for the textile sector activities to minimize their potential adverse effects on the environment, prevent air and water pollution, and reduce water and energy consumption.
In this context, all textile facilities engaged in any of the following activities without capacity limit, such as the production of textile materials (fiber, filament, yarn, fabric, including non-woven fabrics), textile pre-treatment (washing, including scouring, bleaching, mercerization, etc.), printing and dyeing processes, as well as all textile facilities involved in fabric mercerization, are included:

1. To reduce energy consumption and air emissions, the following techniques must be applied:
1.1. Continuous measurement of the humidity content of the air discharged from the scutching machines (rameuses) and optimizing humidity levels accordingly.

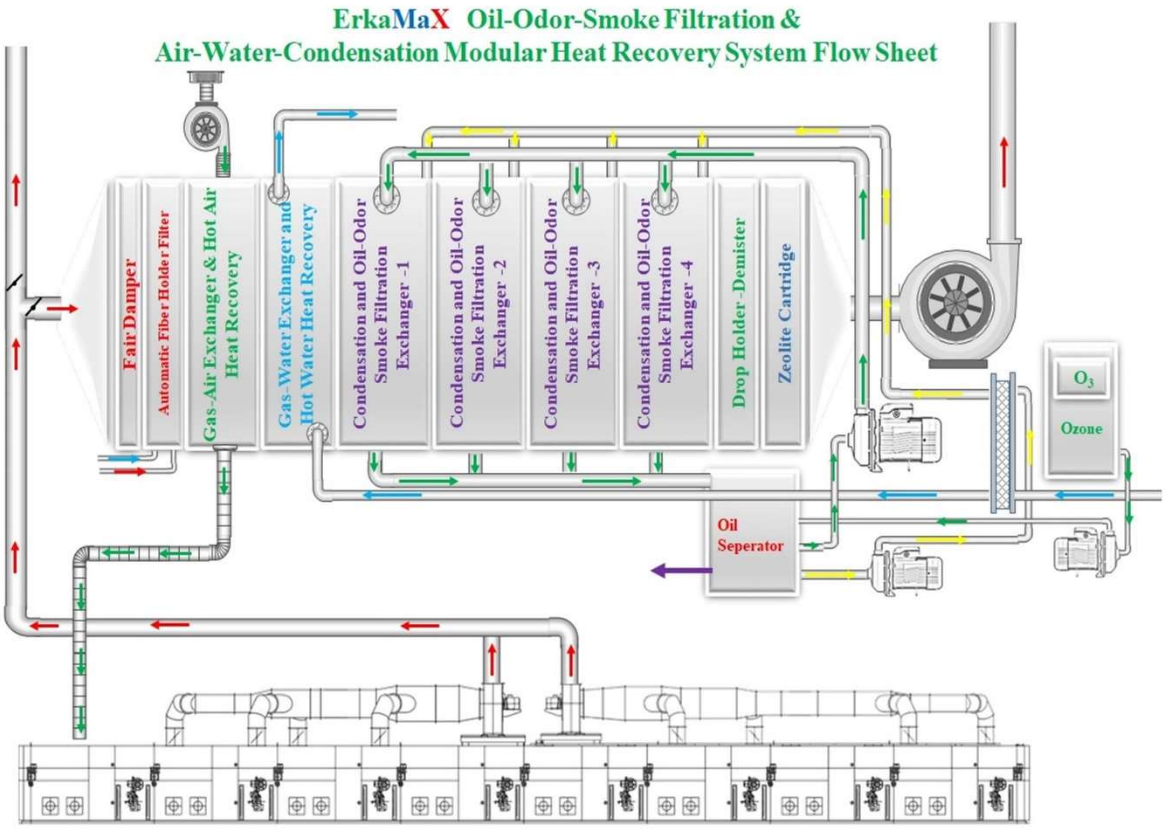
1.2. The energy consumption per MWh for 1 ton of textile production at the facility:
1.2.1. Shall be reported to the Provincial Directorate every year before March 31st, starting from the publication date of this Circular, based on data from the previous calendar year. 1.2.2. Shall be minimized through methods such as insulation, the use of mechanical pre-drying (squeezing) devices, optimization of flame burners and air direction systems in the scutching machines.



1.3. Adherence to the principles for reducing VOC (Volatile Organic Compound) emissions originating from scutching, printing, dyeing, and drying stacks in units where thermal processes related to coating, dyeing, lamination, printing, and finishing occur.
1.3.1. Ensuring that the Total Organic Carbon (TOC) emission quantity does not exceed 20 mg/Nm³.



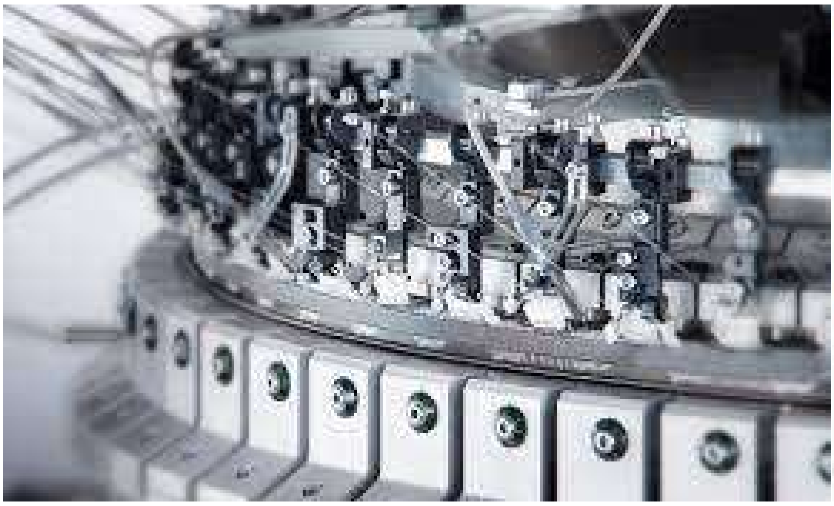
1.3.1. Ensuring that the Total Organic Carbon (TOC) emission quantity does not exceed 20 mg/Nm³.



a) Pre-washing to remove spinning oils and waxes from the fabric, thereby reducing the pollutant emission load.
b) Implementation of exhaust gas treatment systems that allow for separate collection of oils and enable energy recovery in the control of stack gas emissions. These systems may include techniques such as thermal combustion, catalytic combustion, oxidation techniques like heat exchangers, condensation techniques incorporating systems like wet scrubbers, electrostatic precipitators, and Volatile Organic Compound (VOC) removal techniques like activated carbon.

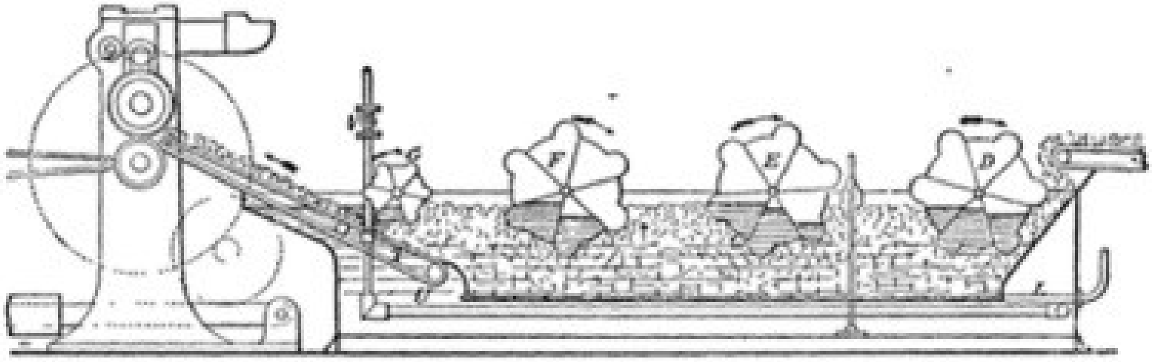
1.4. Implementation of particulate matter removal techniques, such as cyclones, electrostatic precipitators, or bag filters, in drying stacks (excluding scutching) to ensure that the dust emission quantity does not exceed 10 mg/Nm³.

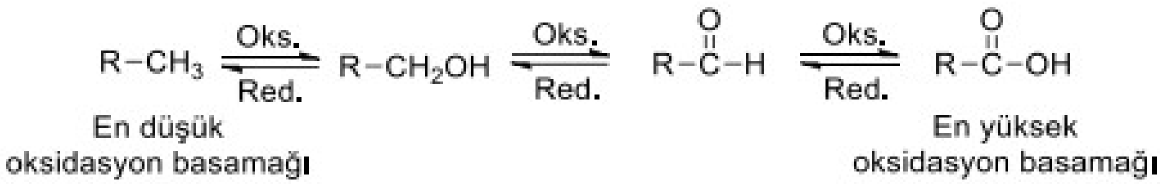
1.5. Using water-based or synthetic organic oil-based knitting oils with high biodegradability, which result in fewer air emissions and less odor than mineral oil in knitting machines and can be removed in the washing process before thermo-fixation.



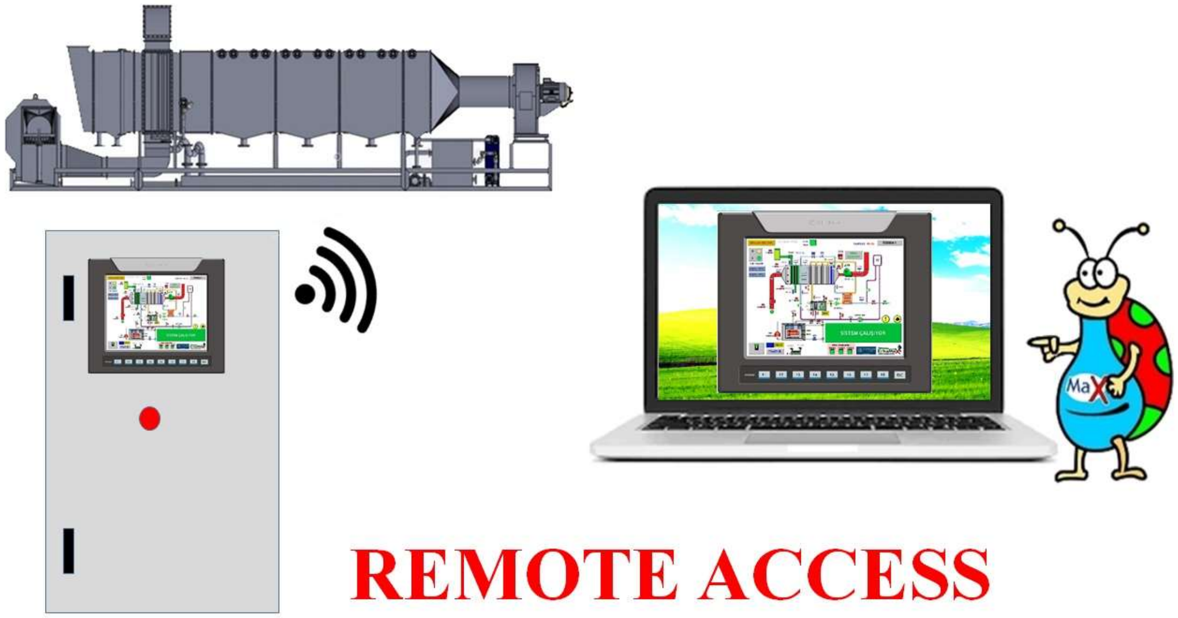
Water Based or Organic Oil Based

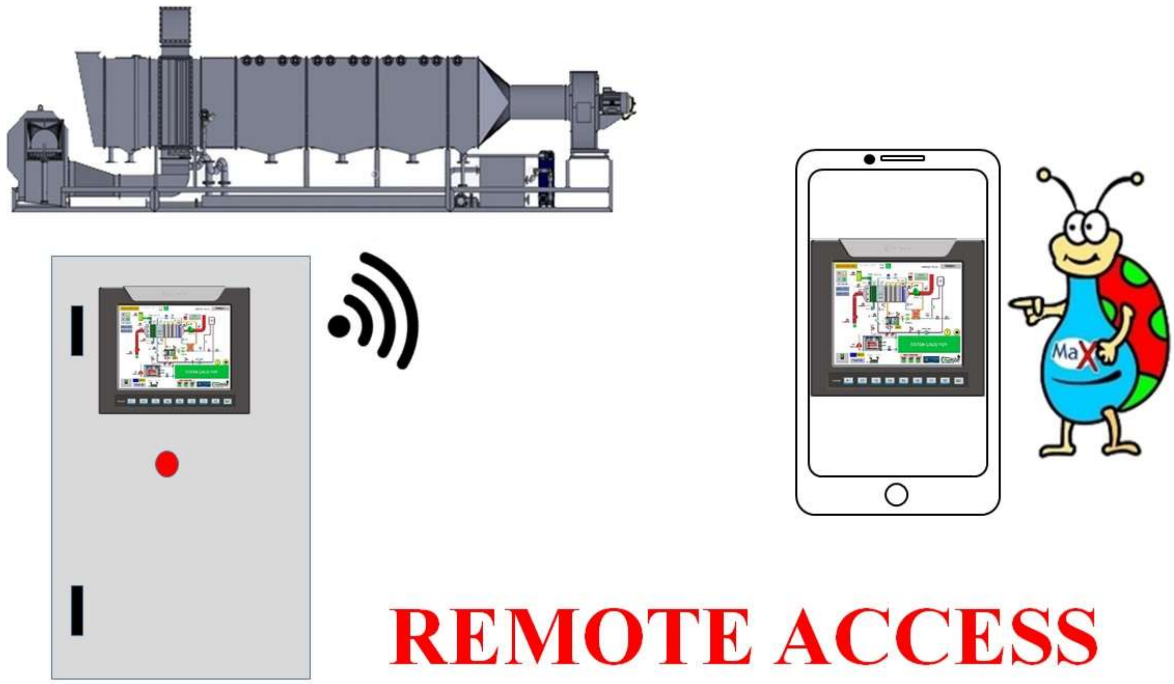
1.6. Utilizing closed-loop equipment and advanced oxidation processes to reduce/prevent air emissions resulting from halogenated solvents in wool pre-processing.





1.7. Continuous monitoring of emission control systems by Provincial Directorates through online monitoring using appropriate information technologies to ensure that they are operating continuously.

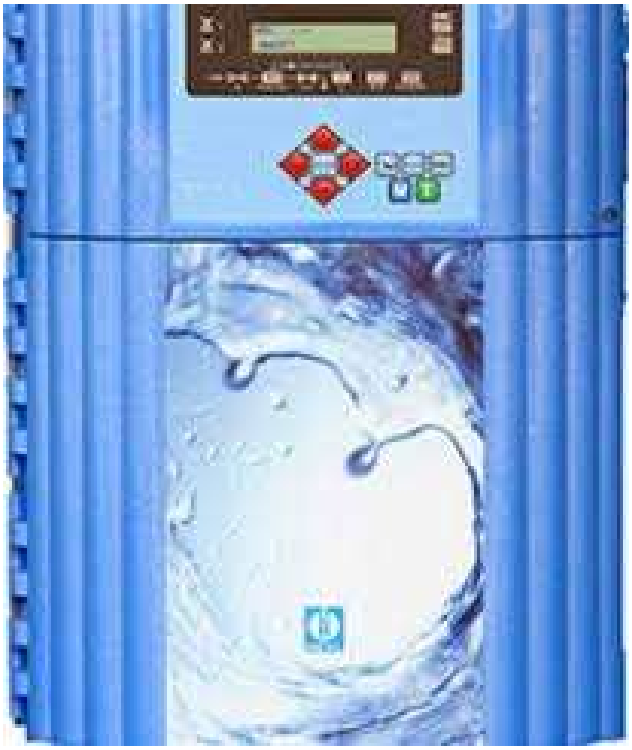




To reduce water consumption and pollutant load in wastewater, the following techniques are mandatory:
2.1. Use of techniques in textile facilities engaged in dyeing that involve color removal in dye bath wastewater, enabling the reuse of brine (salty water) in fabric dyeing and washing.

2.2. The use of brine (salty water) obtained after appropriate removal of the ions contained in the regenerant used in water softening systems, in the regeneration process or in suitable processes.

2.3. Monitoring the hardness level of the softened water (output water) and the washing water after regeneration with hardness sensors in water softening systems, allowing for the optimization of rinsing times and regeneration frequencies to prevent the use of higher quality water than necessary.



2.4. Regular tracking of water consumption on a process basis within the facility, continuous monitoring of total wastewater discharge flow, establishment of a monitoring system for these purposes, and maintenance of monitoring records.

2.5. Facilitating the reuse of treated wastewater in possible areas after purification to conserve water and energy, collecting and reusing cooling water and low pollutant load wastewaters as separately as possible.
2.6. Using water flow control devices and automatic shut-off valves in machines that operate continuously.

2.7. Employing distribution systems where chemicals are distributed in separate lines and mixed immediately before application.

2.8. In facilities where mercerization is carried out, recovering caustic from mercerization rinsing water through methods like evaporation, membrane filtration, or reusing caustic-containing wastewaters in other pretreatment processes.

2.9. In regions with limited water resources, ensuring that facilities operating within an Industrial Zone (OSB) source their process water needs from the Industrial Zone, as well as facilitating the reuse of treated wastewater from the Industrial Zone's wastewater treatment facility.

The provisions mentioned above must be implemented as follows:

- Facilities with an installed capacity of 10 tons/day or more: Starting from January 15, 2024.
- Facilities with an installed capacity between 5 tons/day and 10 tons/day: Starting from January 15, 2025.
- Facilities with an installed capacity of less than 5 tons/day: Starting from January 15, 2026.

These timeframes may be advanced and stricter limit values may be set based on the local Environment Council decision, considering the local air quality and water resources.

Facilities falling under the scope of this Circular are obliged to submit their work termination plans to the provincial directorates within three months from the publication date of this Circular. The implementation of these Work Termination Plans should be monitored by the Provincial Directorates, and developments must be reported to the Ministry by March 31st each year.

I request the information and requirements.

INVESTIGATION OF BLEACHING AND DYEABILITY OF KNITTED FABRICS BY FOAM APPLICATION METHOD

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1. INTRODUCTION

Day by day, our sensitivity to the environment is increasing with the increase in social awareness. accordingly, not only as consumers but also as producers, we are oriented towards more environmentally friendly products in almost every field. When we consider textile wet treatment processes, the textile is one of the most environmentally damaging industries. Therefore, more environmentally friendly approaches are gaining importance in the textile industry day by day. Briefly, when he conventionally used wet processing processes are examined, we come across impregnation and exhaust methods. these methods, which are very widely used, use a large amount of water, chemicals, and energy, while leaving a large amount of wastewater to the environment. When the methods that will be an alternative to these methods are examined, it can be seen that the foam application method gets popular [1]–[6]. To make more environmentally friendly applications in the textile industry, the bleaching and dyeing processes were carried out with the foam application method within the scope of the study. The effects of the concentrations of the chemicals used in the bleaching processes and the % pick-up values on the bleaching process were examined. In order to make a comparison, the bleaching and dyeing processes were carried out with conventional impregnation and exhaustion methods as well as foam application method. When the data obtained accordingly were examined, it was seen that the desired Berger whiteness index values could be achieved with the foam application method. As for the foam dyeing, the dyeing process carried out successfully and it was seen that it can be used as an alternative method to the conventional dyeing processes.

2. MATERIAL AND METHOD

2.1. Material

The raw and bleached Ne 30/1 suprem knitted fabrics were used in the study. In the study, peroxide, NaoH, wetting agent, sequesting agent, foaming agent and stabilizer was used in the foam bleaching process. In addition, Setazol Golden Yellow NG Conz, Setazol Navy WRG Conz, Setazol Red NG Conz dyes, and NaOH, soda, foaming agent were used in the foam dyeing processes.

2.2. Method

The bleaching and dyeing recipes for the foam application methods are given in Table 1. The foam formation for both bleaching and dyeing was achieved by mixing with a mixer at 3000 rpm. The blow ratio of the foam was 1/8. The foam was transferred onto the fabric using a laboratory type coating machine. The foam was transferred onto the fabric via knife over air coating method and the coating thickness was adjusted as 0.05 mm. After the foam application, the fabrics were steamed with saturated steam at 102°C during 5 minutes for fixing of reactive dyes and activating of the bleaching recipes. After both bleaching and dyeing processes, the fabric washed in five steps and dried at 120°C for 4 minutes on the laboratory stenter.

Table 1. The content of bleaching and dyeing recipes

Bleaching Recipe		Dyeing Recipe	
Chemical	**Concentration (g/L)**	**Chemical**	**Concentration (g/L)**
NaOH	50-60-70-80-90-100-110-120	Setazol Golden Yellow NG conz	2.25
Peroxide	50-60-70-80-90-100-110-120	Setazol Navy WRG conz	16.5
Wetting agent	2	Setazol Red NG conz	8
Sequesting agent	1	NaOH	25
Foaming agent	50	Soda	100
Stabilizer	4	Foaming agent	30
		Wetting agent	2

2.3. Test and Analyses

The bursting strength (TSE EN ISO 13938-2), pilling (TS EN ISO 12945-2), abrasion resistance (TS EN ISO 12947-2), whiteness value, color measurement and hydrophilicity tests for bleached fabrics, and the color fastness to washing (TS EN ISO 105-C06), water (TS EN ISO 105-E01) and perspiration fastness tests (TS EN ISO 105-E04) and color measurements were carried out for dyed samples.

3. RESULT

3.1. The Determination of Bleaching Processes

The Berger value of the fabrics was measured after bleaching with foam application. It was seen that the Berger value of the conventional bleached fabric 69.40 (Table 2), while the Berger value of the fabrics reached up to 56,23 with the foam application method. Though foam bleaching method had less Berger value than the conventional method, it could be said that the Berger value of the foam bleached fabric could reached desired Berger value by optimizing operating conditions (% pick-up, concentration and etc.)

Table 2. The Berger values of the bleached fabrics

Berger Value	Untreated	Reference (Conventional bleaching)	NaOH/ Peroxide Concentration g/L							
			50/50	**60/60**	**70/70**	**80/80**	**90/90**	**100/100**	**110/110**	**120/120**
	10.10	69.40	56.23	54.05	55.23	48.78	42.08	46.74	49.23	45.95

On examining of the burst strength of the bleached fabric (Table 3), the burst strength of the foam bleached fabric was 458.2 kPa while the burst strength of the conventional bleached fabric was 430.50 kPa. It could be concluded from that the bleaching process with foam application causes less damage to the fabric than the bleaching process performed by the conventional method.

Table 3. The Burst strength of the bleached fabrics

Burst Strength	Reference (Conventional bleaching)	Foam Application NaOH/ Peroxide Concentration (g/L)							
		50/50	**60/60**	**70/70**	**80/80**	**90/90**	**100/100**	**110/110**	**120/120**
	430.5	445.6	441.6	458.2	452.0	444.5	433.8	432.7	437.9

The pilling tests were applied at 250-500-1,000-1,500 and 2,000 revolutions to the bleached fabrics (Table 4). The pilling result results showed that there was not any difference at all revolutions.

Table 4. The pilling values of the bleached fabrics

Sample		Revolutions				
		250	**500**	**1000**	**1500**	**2000**
Untreated		5	5	4/5	4/5	4
Reference (Conventional bleaching)		5	5	5	4/5	4/5
Foam Application NaOH/ Peroxide Concentration (g/L)	**50/50**	5	5	5	4/5	4/5
	60/60	5	5	5	4/5	4/5
	70/70	5	5	5	4/5	4/5
	80/80	5	5	5	4/5	4/5
	90/90	5	5	5	4/5	4/5
	100/100	5	5	5	4/5	4/5
	110/110	5	5	5	4/5	4/5
	120/120	5	5	5	4/5	4/5

The abrasion resistance tests were applied at 250-500-1000-1500-2000-3000-4000-5000-6000 revolutions to the bleached fabric (Table 5). The abrasion resistance results showed that there was no difference at any revolutions between samples.

Table 5. The Abrasion resistance values of the bleached fabrics

Sample		Revolutions								
		250	**500**	**1000**	**1500**	**2000**	**3000**	**4000**	**5000**	**6000**
Untreated		5	5	5	4/5	4/5	4/5	4	4	4
Conventional bleached fabric		5	5	5	5	4/5	4/5	4/5	4	4
Foam Application NaOH/ Peroxide Concentrations (g/L)	**50/50**	5	5	5	5	4/5	4/5	4/5	4	4
	60/60	5	5	5	5	4/5	4/5	4/5	4	4
	70/70	5	5	5	5	4/5	4/5	4/5	4	4
	80/80	5	5	5	5	4/5	4/5	4/5	4	4
	90/90	5	5	5	5	4/5	4/5	4/5	4	4
	100/100	5	5	5	5	4/5	4/5	4/5	4	4
	110/110	5	5	5	5	4/5	4/5	4/5	4	4
	120/120	5	5	5	5	4/5	4/5	4/5	4	4

3.1. The Determination of Dyeing Processes

The CIELab values obtained from the dyeing recipe according to the exhaustion method were accepted as the reference color, and the fabrics dyed according to the foam application method were compared with the reference one (Table 6). When the CIELab values are examined (Table 6), it is thought that there is a color difference between the reference sample and the color of foam dyed samples. According to the results shown in Table 6, the foam dyed samples is lighter than the conventional ones. In addition, the novel samples are measured greener and bluer than the samples dyed according to the conventional ones. The calculated dE values is very high, it means that there is important color differences between the samples dyed with foam and conventional techniques. The color strength of foam dyed samples is less than the conventional because the adsorption, exhaustion and fixation of the dye molecules become weaker. According to the results, the dyeability of the specimens with foam application was proved although color differences.

Table 6. Color measurement of the dyed fabric

Dyeing Method	CIELab Values			Color Difference Values			
	L*	a*	b*	dL*	da*	db*	dE
Exhaustion	20.19	2.39	-12.80	-	-	-	-
Impregnation	20.59	2.45	-12.89	0.40	0.06	-0.09	0.41
Foam	24.70	0.13	-13.99	4.33	-2.14	-1.59	5.08

The burst strength of the untreated raw fabric 408.3 kPa. After dyeing process, it was seen that burst strength values of the fabric reduced. The burst strength values of the dyed fabrics were 342.1 kPa, 340.7 kPa and 375.7 kPa for foam, exhaustion and impregnation dyeing methods, respectively because of chemical applications. We could not find dramatic differences between the performances of the samples in terms of dyeing methods.

The pilling tests were employed at 250-500-1000-1500 and 2000 revolutions to the dyed fabrics (Table 7), and the abrasion resistance of the dyed fabric were showed in Table 8. The abrasion resistance tests were applied at 250-500-1000-1500-2000-3,000-4000-5000-6000 revolutions to the dyed fabric (Table 8). The results showed that there was not any difference at all revolutions for two tests.

Table 7. The Pilling values of the dyed fabric

Dyeing Method	Revolutions				
	250	500	1000	1500	2000
Exhaustion	5	5	4/5	4/5	4
Impregnation	5	5	4/5	4/5	4
Foam	5	5	4/5	4/5	4

Table 8. The Abrasion resistance values of the dyed fabric

Dyeing Method	Revolutions								
	250	500	1000	1500	2000	3000	4000	5000	6000
Exhaustion	5	5	5	5	4/5	4/5	4	4	4
Impregnation	5	5	5	5	4/5	4/5	4	4	4
Foam	5	5	5	5	4/5	4/5	4	4	4

The color fastness to washing performances of the dyed fabrics were given in Table 9 and there was not any difference regardless of the dyeing method.

Table 9. The Color fastness to washing of the dyed fabrics

Dyeing Method	Color Fastness to washing					
	Wool	Acrylic	Polyester	Nylon	Cotton	Acetate
Exhaustion	5	5	5	4/5	4/5	5
Impregnation	5	5	5	4/5	4/5	5
Foam	5	5	5	4/5	4/5	5

The color fastness to water of the dyed fabric was given in Table 10. According to the results, the fastness performance did not dramatically change with foam dyeing methods.

Table 10. The Color fastness to water of the dyed fabrics

Dyeing Method	Water Fastness					
	Wool	Acrylic	Polyester	Nylon	Cotton	Acetate
Exhaustion	2	4/5	4	2/3	3	4
Impregnation	2	4/5	4	2	3	4
Foam	2	4/5	3/4	2/3	3	4/5

The color fastness to perspiration values of the dyed fabrics were given in Table 11 and Table 12. The fastness evaluation of the dyed fabric (acid) showed that impregnation method had the best fastness value. There are no important differences between the exhaust and foam dyed samples. However, the half grade differences were measured for the fastness evaluation of the dyed fabric (alkaline) and it was determined minor variation in term of dyeing method.

Table 11. The color fastness to perspiration of the dyed fabrics (acid)

Dyeing Method	Acid					
	Wool	Acrylic	Polyester	Nylon	Cotton	Acetate
Exhaustion	1	4	3/4	1	1	2
Impregnation	3	4/5	3/4	2/3	3	3/4
Foam	1	4	4	2/3	2	2/3

Table 12. The color fastness to perspiration of the dyed fabrics (alkaline)

Dyeing Method	Alkaline					
	Wool	Acrylic	Polyester	Nylon	Cotton	Acetate
Exhaustion	2	4/5	4	2/3	3	4
Impregnation	2	4/5	4	2	3	4
Foam	2	4/5	3/4	2/3	3	4/5

After the dyeing process, a drop test was performed on the dyed fabrics to examine the hydrophilicity behavior of the fabrics (Figure 1). When the results obtained were examined, it was determined that all dyed fabrics and PFD (prepare for dying fabric) were hydrophilic regardless of the dyeing process method and the water drops showed a circular and homogeneous distribution on the fabric surface.

Untreaed fabric | PFD fabric | Exhaustion | Impregnation | Foam Application

Figure 1. Hydrophilicity behavior of the fabrics

4. CONCLUSION

In the study, the bleaching and dyeing processes were carried out by foam application method, which is an alternative method to the conventional wet processes. The data obtained from foam applications were compared with conventional methods. Accordingly, it was determined that the bleaching and dyeing can be performed with foam application method. However, it was also seen that the recipe maintenance studies must be research for the successful wet processes via foam compared with conventional methods. In addition, it is thought that the water, energy, chemical and dye consumptions, and wastewater potential can be significantly reduced by spreading of this method in the textile industry.

5. REFERENCES

[1] Z. O. BASYIGIT, D. KUT, AND P. HAUSER, "Development of multifunctional cotton fabric via chemical foam application method," *Text. Res. J.*, vol. 90, no. 9–10, pp. 991–1001, 2020.

[2] S. SHANG, E. HU, P. POON, S. JIANG, C. W. KAN, AND R. KOO, "Foam Dyeing for Developing the Wash-out Effect on Cotton Knitted Fabrics with Pigment," *Res. J. Text. Appar.*, vol. 15, no. 1, pp. 44–51, 2011.

[3] M. MOHSIN *ET AL.*, "Performance enhancement of water and energy efficient foam dyeing and finishing through different foaming agents," *J. Nat. Fibers*, vol. 20, no. 1, 2023.

[4] M. KAYHAN, "Köpük aplikasyon tekniği ile aktarılan silikon kimyasalının bazı mekanik işlemler ve yıkamalar sonrası denim kumaş performansına olan etkisinin incelenmesi," Kahramanmaraş Sütçü İmam Üniversitesi, Kahramanmaraş, 2019.

[5] İ. AKMAN, "Köpük Aplikasyon Tekniği İle Su İticilik Apresi Uygulanmasi ve Denim Kumaş Performansina Etkisinin İncelenmesi," Kahramanmaraş Sütçü İmam Üniversitesi Fen Bilimleri Enstitüsü Tekstil Mühendisliği Anabilim Dalı, 2018.

[6] S. YAVUZ, "%100 Pamuklu İpliklerin Denim Sektörü için Köpük Aplikasyon Yöntemi ile Renklendirilmesi Sıddık Yavuz," Kahramanmaraş Sütçü İmam Üniversitesi Fen Bilimleri Enstitüsü Tekstil Mühendisliği Anabilim Dalı, 2016.

INVESTIGATION OF UV RESISTANCE PROPERTIES OF BICOMPONENT YARNS PRODUCED WITH DIFFERENT ADDITIVES

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ABSTRACT

In this study, core/sheath bicomponent yarns were produced by adding titanium dioxide (TiO_2) and triazine based UV absorber at different dosages to the core and the sheath side of the yarn, respectively. Standard textile analysis such as elongation at break, tenacity, dtex and shrinkage were applied to 5 yarns produced with different additive combinations. Also, differential scanning calorimetry (DSC) analysis was performed on all samples to determine thermal properties. The UV weathering test was applied to the yarns for 1000 hours according to ISO 105-B04. It was observed that the tenacity of all fully drawn yarns decreased by approximately 70% after 500 hours. While the tenacity of the yarns containing 1,2% TiO_2 couldn't be measured after 1000 hours of UV weathering test due to the significant deterioration, the yarns containing 2% UV absorber maintained the tenacity of 21% after 1000 hours of UV weathering test.

Key Words: Bicomponent yarns, core/sheath, uv resistance, uv weathering test, tenacity

1. INTRODUCTION

Polyethylene terephthalate (PET) yarns, an important member of the polyester family, is the most widely used chemical fiber in the world [1]. PET yarns have a wide range of uses in industrial applications due to their properties such as high strength, moderate elongation, high glass transition temperature, good resistance to deformation and chemicals [2,3]. However, they have some inherent negative properties such as low water absorption capacity, high pilling tendency, static charge accumulation tendency and lower abrasion resistance [4,5].

Some researchers focus on finding a new polymer or improving the properties of existing polymers to use in technical textiles. There are some difficulties such as expensive raw materials and high investment costs in finding a new polymer and producing yarn. So, it is more preferable to improve the properties of already produced synthetic yarns by changing in the processes [6,7]. Bicomponent yarn production is one of the most attractive method in the scientific world. Also, special additives can be added in the PET chips during the extrusion to improve the existing properties and obtain new functionality.

UV radiation reaching the earth's surface consists of 6% of the total solar radiation with wavelengths ranging from 290-400 nm [8]. Human skin can be adversely affected by direct or indirect exposure to UV radiation [9]. The use of UV protective clothing is very important to ensure human health and safety [10]. UV radiation causes the breakdown of chemical bonds in polymeric structures. In certain instances, UV radiation is absorbed by photoinitiators instead of polymers, instigating degradation through their transformation into free radicals. This photodegradation process results in a reduction in the molecular weight of the polymer as a consequence of bond cleavage. Thus, the polymers' mechanical properties are adversely affected over time [11].

Bicomponent yarns can be produced from two polymers by using two different extruders and have unique cross-sections including side-by-side, sea/island, core/sheat etc. [12].

In this study, the first step was to produce bicomponent fully drawn yarns (FDYs) at the same denier and parameters by using 24 holes core/sheath cross-section spinnerets. Super bright PET raw materials were used for both the core side and the sheath side. Also, two different dosages of titanium dioxide (TiO_2) were added in the core side and two different dosages of triazin based UV absorber were added in the sheath side. The yarns produced were classified in two headings based on TiO_2 and UV absorber (Table 3 and 4). Standard textile analysis such as elongation at break, tenacity, linear density and shrinkage were applied to 7 different yarns. Moreover, differential scanning calorimetry (DSC) analysis was performed on the core/sheath FDYs to determine thermal properties of the yarns. The second step was to apply UV weathering tests to all yarns according to ISO 105-B04 standard. Elongation at break and tenacity measurements were made to each yarns after 500 hours and 1000 hours to calculate the decrease in the mechanical properties.

2. EXPERIMENTAL

2.1 Material

In this study, the super bright PET chips were supplied by SASA Polyester Sanayi in Adana, Türkiye. Titanium dioxide (TiO_2) added masterbatch and triazine based UV absorber added masterbatch were supplied from SETAŞ Kimya A.Ş in Tekirdağ, Türkiye.

2.2 Method

Bicomponent FDYs were produced with production parameters in Table 1 by using 24 holes core/sheath spinnerets on Jwell brand bicomponent melt spinning machine in Polyteks Tekstil Sanayi Araştırma ve Eğitim AŞ. The bicomponent yarns are classified in two headings based on the ratio of titanium dioxide (TiO_2) and UV absorber (Table 2 and 3).

The reference FDYs added UV absorber were produced by using 24 holes round cross-section spinnerets on Barmag brand monocomponent melt spinning machine in Polyteks (Table 4).

Table 1. The production parameters of the fully drawn yarns

Parameters		Values	Units	Parameters		Values	Units
Temperatur	**Extruder A**	285 - 285 - 285 - 285	°C	**Speed**	**Godet 1/2**	1050	m/min
	Extruder B	285 - 285 - 285 - 285	°C		**Godet 3/4**	4240	m/min
	Godet 1/2	85 - 85	°C		**Winder**	4200	m/min
	Godet 3/4	120 - 120	°C				

Table 2. The samples according to the UV absorber ratio in the sheath side of the yarns

Yarns	Core Side	Sheath Side
S-1	Bright PET + 1,2% TiO_2	Bright PET
S-2	Bright PET + 1,2% TiO_2	Bright PET + 2% UV Absorber
S-3	Bright PET + 1,2% TiO_2	Bright PET + 4% UV Absorber

Table 3. The samples according to the TiO_2 ratio in the core side of the yarns

Yarns	Core Side	Sheath Side
S-4	Bright PET	Bright PET + 2% UV Absorber
S-5	Bright PET + 0,3% TiO_2	Bright PET + 2% UV Absorber
S-2	Bright PET + 1,2% TiO_2	Bright PET + 2% UV Absorber

Table 4. The reference fully drawn yarns

References	Polymer (w%)	Masterbatch (w%)
R-1	Bright PET	2% UV Absorber
R-2	Bright PET	4% UV Absorber

2.3 Tests and Analysis

Linear density of FDYs were measured with a winding reel and a Mettler Toledo brand precision scale according to DIN EN ISO 2060 standard. Also, tensile properties (elongation at maximum load and tenacity) of these yarns were determined by Textechno brand Statimat Me+ model tensile tester according to DIN EN ISO 2062 standard in Polyteks Company. The UV weathering test was applied to the yarns according to ISO 105-B04 standard in SETAŞ Company. After 500 hours and 1000 hours of the UV weathering test, the tensile properties of these yarns were measured once again in order to calculate the tenacity reductions of the yarns.

Thermal anaylsis of the FDYs were performed via heating of the samples from 30 to 300°C at 10°C/min under nitrogen atmosphere by using Hitachi 7020 DSC device according to ASTM E 1356-03.

3. RESULTS

Firstly, the linear densities were measured as 145-146 gr/10000m for all type of yarns. The tenacity and elongation (at F_{max}) results were determined by the tensile test in Table 5. The tensile tests were applied all the yarns after UV weathering test for 500h and 1000h to calculate the decrease of mechanical properties of the yarns (Table 6). Moreover, the graphs of the percentage decreases in the elongation and tenacity values of the yarns after the UV conditioning test are as shown in Figure 1 and 2.

Table 5. The results of the tensile test of the all yarns

Yarns	Dtex (gr/10000m)	Tenacity (cN/dtex)	Elongation (%)	Shrinkage (%)
R-1	145	3,2	41,3	11,9
R-2	145	3,3	40,3	12,5
S-1	146	3,1	32,8	13,2
S-2	145	3,0	40,0	12,9
S-3	146	3,1	45,0	13,2
S-4	145	3,2	40,4	13,1
S-5	146	3,2	41,0	12,0

Table 6. The results of the tensile test after UV Weathering test of the all yarns

Yarns	Tenacity (cN/dtex)	Elongation (%)

	Before UV Weathering	After 500h UV Weathering	After 1000h UV Weathering	Before UV Weathering	After 500h UV Weathering	After 1000h UV Weathering
R-1	3,2	2,2	1,2	41,3	26,6	11,8
R-2	3,3	2,4	1,9	40,3	27,8	20,6
S-1	3,1	0,9	-	32,8	9,5	-
S-2	3,0	1,1	-	40,0	4,92	-
S-3	3,1	1,1	-	45,0	13,2	-
S-4	3,2	1,0	0,7	40,4	14,2	4,9
S-5	3,2	1,1	0,7	41,0	8,0	3,2

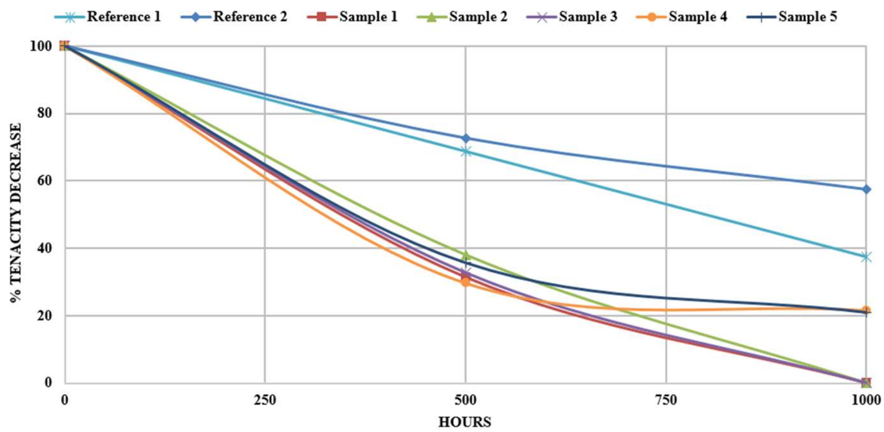

Figure 1. The graph of the tenacity decrease of FDYs after UV Weathering Test

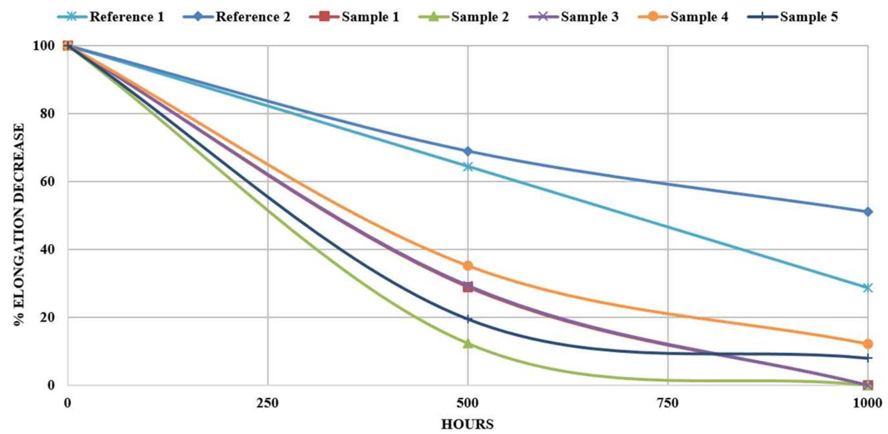

Figure 2. The graph of the elongation decrease of FDYs after UV Weathering Test

It has been observed the endothermic peak due to the melting temperature (T_m) and baseline shift due to the glass transition temperature (T_g) in the DSC curves for the core/sheath FDYs in Figure 3. Moreover, the melting enthalpy values (ΔH_m) that is a function of the interchain forces were calculated from the DSC graphs (Table 7).

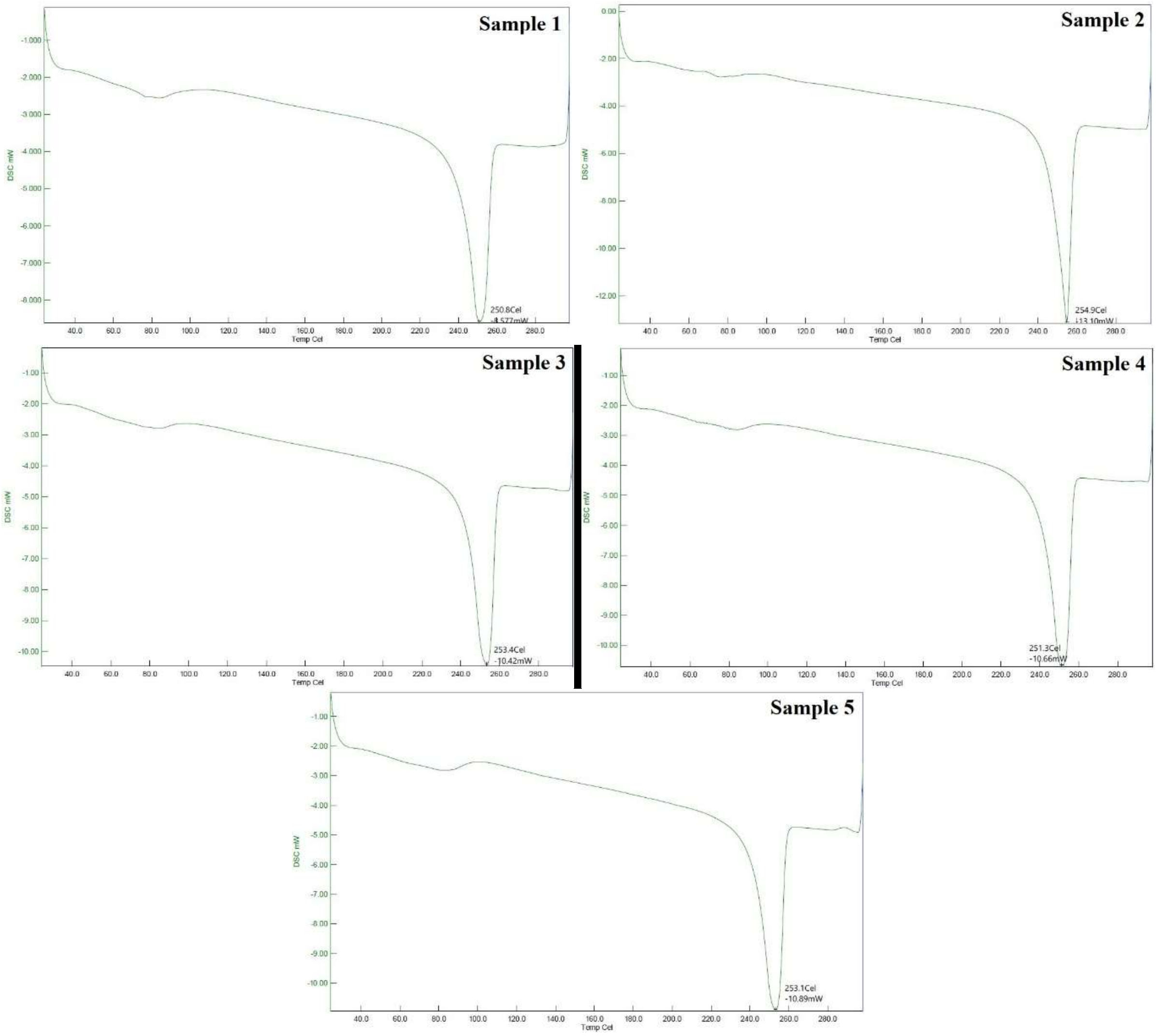

Figure 3. The DSC graphs of the core/sheath FDY samples

Table 7. The thermal values of the core/sheath FDYs in DSC analysis

Yarns	T_g (ºC)	T_m (ºC)	ΔH_m (mJ/mg)	**Yarns**	T_g (ºC)	T_m (ºC)	ΔH_m (mJ/mg)
S-1	83,3	250,8	57,4	**S-4**	83,9	251,3	61,5
S-2	85,8	254,9	54,4	**S-5**	84,8	253,1	55,3
S-3	86,3	253,4	59,1	**S-2**	85,8	254,9	54,4

4. CONCLUSION

The primary objective of this study was to produce a bicomponent filament yarn with a core/sheath structure through the incorporation of diverse additives, namely titanium dioxide (TiO_2) and a UV absorber, applied separately to the core and sheath components. Furthermore, this study sought to assess alterations in the mechanical properties of the yarns subsequent to undergoing UV weathering tests for durations of 500 and 1000 hours. Additionally, the thermal characteristics of these yarns were evaluated using a DSC apparatus.

It was observed that the tenacity of all core/sheath FDYs decreased by approximately 70% after 500 hours. While the tenacity of the yarns containing 1,2% titanium dioxide couldn't be measured after 1000 hours of UV weathering test due to the significant deterioration of the yarns, the yarns containing 2% UV absorber could be maintained the tenacity of 21% after 1000 hours of UV weathering test. There was no difference in the tenacity of the yarn after 500h and 1000h UV weathering test when the TiO_2 content in the core side of the yarn was increased from 0% to 0,3%. It was determined that the elongation of all core/sheath FDYs decreased by minimum 70% after 500 hours. The elongation of the yarns containing 1,2% TiO_2 couldn't be measured after 1000 hours of UV weathering test due to the significant deterioation of the yarns. Furthermore, the yarns containing 2% UV absorber maintained the elongation of 10% after 1000 hours of UV weathering test.

The findings of this study indicate that FDYs which have higher TiO_2 content exhibit elevated values of both melting temperature and glass transition temperature, accompanied by decreased melting enthalpy, as evidenced by the DSC profiles. Conversely, FDYs characterized by heightened UV absorber content display elevated values for melting temperature, glass transition temperature, and melting enthalpy.

The core/sheath FDYs presented more than 50% lower performance in terms of mechanical properties against UV radiation when compared to the reference monocomponent FDY yarns.

5. REFERENCES

[1] INCORNATO, L., SCARFATO, P., DI MAIO, L., ACIERNO, D. Structure and rheology of recycled PET modified by reactive extrusion. Polymer, 2000, vol. 41, pp 6825–6831.
[2] SCHEIRS, J. Modern Polyesters: Chemistry and Technology of Polyesters and Copolyesters, Wiley Series in Polymer Science. John Wiley & Sons, Sussex, England. 2003.
[3] SEVENTEKİN, N. Kimyasal Lifler. Ege Üniversitesi Tekstil ve Konfeksiyon Araştırma-Uygulama Merkezi Yayını, İzmir, 2003, pp 52-69.
[4] KOÇ, S.K., HOCKENBERGER, A.Ş. Investigation of Air-Jet Texturing Of Technical Polyester Yarns. Tekstil ve Konfeksiyon, 2010, vol. 4, pp 299-305.
[5] MILITKY, J., VANICEK, J., KRYSTUFEK, V., HARTYCH, V. Modified Polyester Fibres, Textile Science and Technology. Elsevier, Ch., 1991, vol. 10, pp 15-140.
[6] DUZYER, S. UV Işınlarının Farklı Teknik Poliester İpliklerin Özellikleri Üzerine Etkisin İncelenmesi. Uludağ Üniversitesi Mühendislik Fakültesi Dergisi, 2019, vol.24(1), pp253-264.
[7] SINHA, V., PATEL, M.R., PATEL, J.V. Pet Waste Management by Chemical Recycling: A Review. Journal of Polymers and the Environment, 2008, vol.18, no.1, pp 8–25.
[8] CHIN, J.W., KARBHARI, V., HUNSTON, D.L., BENMOKRANE, B. Durability Gap Analysis for Fiber-Reinforced Polymer Composites in Civil Infrastructure. Journal of Composites for Construction, 2003, vol. 7(3), pp 238-247.
[9] MATSUMURA, Y., ANANTHASWAMY, H.N.Toxic effects of ultraviolet radiation on the skin", Toxicology and Applied Pharmacology, 2004, vol. 195(3), pp 298-308.
[10] HUSTVEDT, G., CREWS, P.C., (2005), The ultraviolet protection factor of naturally-pigmented cotton. Journal of Cotton Science, 2005, vol. 9(1), pp 8.
[11] BREESE, R.R. General Effects of Aging on Textiles. Journal of American Institute for Conversation, 1986, vol. 25, pp 39-48.
[12] PARSONS, T. Multicomponent Fiber Extrusion Technology Applied to Precursors. Carbon Fiber R&D Workshop, Buffalo, NY, 25-26th July 2013.

PASSIVE SMART CELLULOSIC KNITTED FABRICS WITH ENHANCED PERMEABILITY AND ABSORPTION FEATURES

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ABSTRACT

Recently, studies on developing adaptive comfort features for sports and protective clothing, have been taking attention of both manufacturers and consumers. In this manner, possibility of developing passive smart cellulosic knitted fabrics based on temperature-water sensitive finishing treatment for dynamic breathability and absorption functions by keeping acceptable fabric hand, was investigated. According to dynamic air permeability and water absorption capacity results, temperature-water sensitive nanocomposite treated cellulosic fabrics, especially viscose and modal ones gained passive smart function by keeping acceptable fabric hand. Also, SEM and FT-IR analyses proved the polymer coating on fiber and fabric-nanocomposite interactions, in turn.

Key Words: Passive smart, cellulosic fabric, air permeability, absorption capacity.

1. INTRODUCTION

Consumer expectations have changed in recent years in the direction of 'maintaining comfort in all conditions', a situation supported by the increasing market shares of sports and leisure clothing [1]. The next stage of the comfort studies especially for functional sports and protective clothing is to provide comfort dynamically according to the changes in environment and body conditions, other than the classical approach aiming to keep body dry and warm/cool under static conditions. In this context, shape memory polymers/nanocomposites [2] enabling a change in shape, porosity, etc. of the material adaptively depending on temperature and water (sweat in vapour or liquid forms) attract attention. For developing smart textile materials having dynamic clothing comfort; knitted cotton and regenerated cellulosic fabrics for sports and leisure wear were treated with temperature-water sensitive shape memory nanocomposite for dynamic breathability and absorption functions by keeping the acceptable fabric hand features.

2. EXPERIMENTAL

Single jersey knitted fabrics were produced with cotton, regenerated cotton, viscose, modal, lyocell, and bamboo Ne 30/1 ring spun yarns on a Pilotelli Circular Knitting Machine. Cellulosic knitted fabrics were treated with shape memory nanocomposites for optimum temperature-water sensitive dynamic functions at acceptable fabric bending rigidity limits. The shape memory nanocomposites were produced with commercial SMPU polymer matrix, having appropriate transition temperature (T_{trans}) of 32°C, suitable for body temperature, and CNWs as water responsive nano-reinforcing switch. Tween®80 (Sigma Aldrich), nonionic surfactant, was used for ensuring homogeneous nanoparticle distribution in hydrophobic polymer matrix. All chemicals were analytical grade and used as received without further purification or modification.

To prepare nanocomposite suspensions, SMPU polymer was dissolved in dimethyl acetamide, an eco-friendly solvent at 8wt% concentration according to preliminary studies (optimizing bending rigidity) for 6 h using a magnetic stirrer at 400 rpm and 60°C (Sci Finetech, Korea) operating at 400 rpm for 6 h. As second step, this solution was mixed with CNW-dimethyl acetamide-surfactant suspension having nanoparticle concentration, 20 wt% of polymer (SMPU-CNW20), were mixed by means of ultra-sonication (Sonopuls HD 2200, Bandelin Sonopuls Corp.) for 1 h at 40 Watt, 40% amplitude. In the third step, the prepared nanocomposite solutions were applied to the fabrics by a pad-dry-cure process at 3 bar pressure, 2 m/min speed, 90% wet pick up value. Finally, all treated fabrics were dried at 90°C and cured at 120°C for 5 min. Fabrics with different raw materials are abbreviated as CO for %100 cotton, re-CO for 15% recycled cotton/85% cotton, CV for viscose, MD for modal, LYC for lyocell, and BAM for bamboo.

Surface morphologies and chemical structure/fabric-nanocomposite interactions of the fabrics were detected by SEM and FT-IR analysis, respectively. Areal density and bending rigidity tests were carried out according to TS EN 12127 and ASTM D 1388-92:2002, respectively for determining nanocomposite treatment effect. Shape memory based dynamic air permeability of the fabric was measured according to TS 391 EN ISO 9237 at different fabric temperatures (20°C and 40°C) using the Textest FX 3300 Air Permeability Tester. Fabric temperature of 40°C was adjusted by a hotplate having a set function and determined with a thermal camera (Fluke Ti100). Dynamic absorption capacity tests were conducted with different water temperatures (20°C and 40°C) according to AATCC TM 199. All samples were conditioned for 24 h at standard atmospheric conditions according to the TS EN ISO 13934-1:2013 before tests.

Statistical analysis was carried out using a Univariate ANOVA method followed by Student-Newman-Keuls post hoc test using SPSS 22.0 for Windows statistical software (IBM, Armonk, USA) with p value of 0.05

3. RESULTS and DISCUSSION

The surface morphologies of the SMPU, SMPU-CNW nanocomposite treated fabrics were examined by SEM images (Figure 1). According to the images, the characteristic fibre properties of untreated samples of all fabrics with different raw materials can be seen. SMPU and SMPU-CNW nanocomposite treatment formed smooth and thick coating on/among fibres and also fiber-fiber bonding especially on re-CO, CV, and MD fabrics. CNW particles can be detected on the fiber surfaces of SMPU-CNW nanocomposite treated fabrics. SMPU and SMPU-CNW nanocomposite treatment created a thinner coating on/among fibres for LYC and BAM ones compared to other all fabrics. It was concluded that SMPU and SMPU-CNW nanocomposite treatment were successfully immobilized on/among fibers of all fabric types.

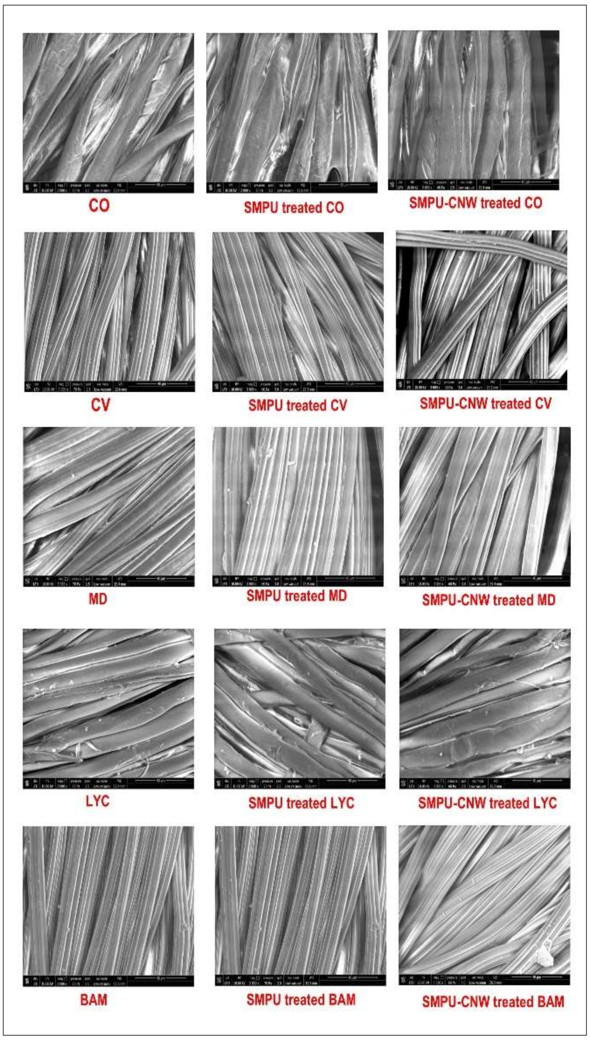

Figure 1. SEM images of fabric

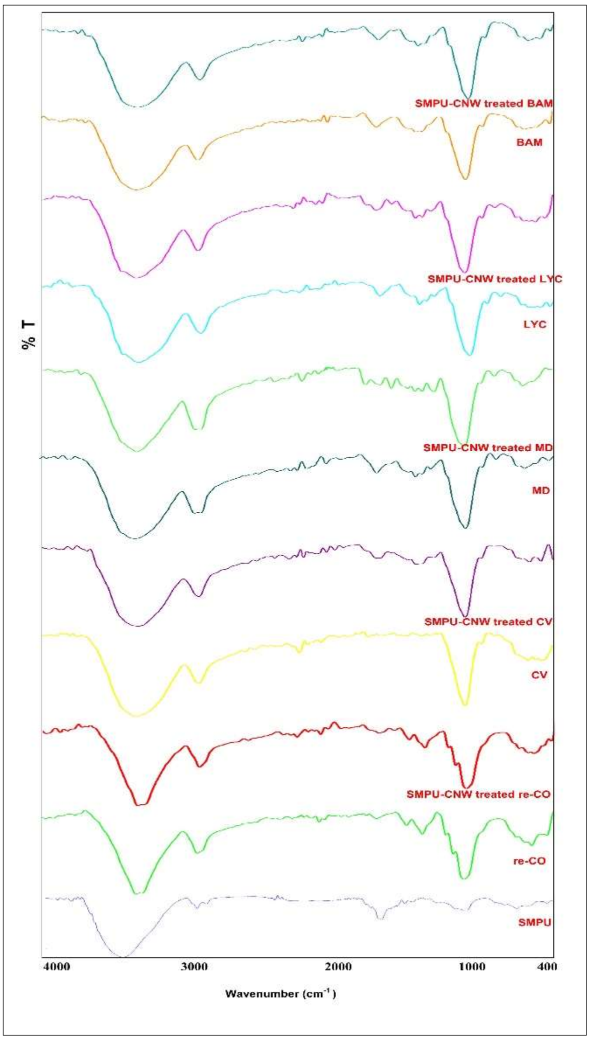

Figure 2. FT-IR spectrum of reference and SMPU and SMPU-CNW nanocomposite treated fabrics

To confirm the presence of SMPU-CNW nanocomposite on the fabrics, reference and SMPU-CNW nanocomposite treated samples were analysed by FT-IR spectroscopy and IR spectrums are given in Figure 2. (-NH) stretching vibration of urethane at around 3449 cm^{-1}, (-CH_2) stretching at 2861 cm^{-1} and 2927 cm^{-1}, free (C=O) stretching at 1737 cm^{-1}, other modes of (-CH_2) vibrations at 1463, 1406, 1345, and 1294 cm^{-1} and (-NH) 1544 cm-^{1} seen in IR spectrum of SMPU granules are characteristic peaks of SMPU polymer. In addition, characteristic peak at 10541 cm^{-1} was attributed to ether group (-C_2H_4-O-C_2H_4-). As expected, (-OH) stretching band at 3200-3400 cm-1 and (C-H) stretching peak at 2900 cm^{-1} belonging to hydrocarbon structure of hemicellulose, were detected in the IR spectrums of all untreated all fabric due to the cellulose raw materials of the samples. Meanwhile, SMPU-CNW treated fabrics display the hydrogen-bonded urethane (C=O) group at approximately 1700 cm^{-1}serving as polymer presence in the fabric structure. For cellulosic materials, chemical reactions take place by three free OH groups in β-D-glucose unit of cellulose molecules and as a result hydrogen bond density of cellulose polymer decreases [3]. It is noteworthy that intensity of the (-OH) stretching band at 3200-3400 cm^{-1} and (-OH) in-plane stretching band at 900-1200 cm^{-1} of untreated samples decreased as compared to the untreated ones, indicating that hydrogen bonds were formed between SMPU polymer and (-OH) groups of all cellulose-based fabrics. SEM and FT-IR analysis results confirmed coating and fabric-nanocomposite interactions in turn.

Areal density and bending rigidity values of the reference and SMPU and SMPU-CNW nanocomposite treated fabrics were given in Table 1. As seen in Table 1, the fabric areal density values significantly changed with treatment type (SMPU/SMPU-CNW nanocomposite), raw material, and two-way interactions of them and had the maximum value for MD. Bending rigidity which is one of the main components for the wearability performance of fabrics, exhibited similar trend and changed significantly with treatment type and raw material. As expected, besides the minimum values detected for reference samples, the maximum and minimum bending rigidity values belonged to CO and MD, respectively. Among all the cellulose-based fabrics used in the study, the highest crystallinity of cotton fibres and lower inter-fiber movement as a result of specific cross-section and surface features compared to the regenerated samples [4] could cause this trend. Through SMPU treatment, the bending rigidity values significantly increased and reached the maximum for CO (5.62x) and re-CO ones (5.42x), like as their reference forms. As seen in SEM images (Figure 1), SMPU polymer layer on/among fibres provides fiber-fiber bonding which prevents relative fiber movement, hence increase in bending rigidity. On the other hand, SMPU-CNW nanocomposite application led a significantly (*$p=0<0.05$*) decrease in fabric bending rigidity as compared to SMPU treated ones. Relative decrease in bending rigidity of all fabrics with nanocomposite treatment may be due to the plasticisation effect of hydrophilic CNW particles with ambient relative humidity. According the data in Table 1, among SMPU-CNW treated samples; maximum bending rigidity increase belonged to CO samples (4.48x) in harmony with SMPU treated forms as the minimum value was detected in MD (0.68x) followed by CV, meaning that MD and CV fabrics kept their hand characteristics besides gathering a passive smart function.

Table 1. Areal density and bending rigidity of cotton and regenerated cellulosic fabrics

Sample code	**Areal density (g/m^2) [S.D]**			**Bending rigidity (mg.cm) [S.D.]**		
	Reference	**SMPU**	**SMPU-CNW nanocomposite**	**Reference**	**SMPU**	**SMPU-CNW nanocomposite**
CO	200^{a} [1.48]	195^{a} [7.21]	200^{a} [7.94]	120.44^{cd} [53.29]	773.62^{h} [121.91]	660.15^{g} [119.31]
re-CO	195^{a} [1.87]	202^{a} [3.21]	199^{a} [4.78]	115.51^{cd} [40.19]	739.38^{h} [91.92]	660.51^{f} [112.75]
CV	199^{a} [3.91]	195^{a} [7.83]	211^{ab} [2.55]	49.92^{a} [21.49]	163.16^{d} [36.19]	99.05^{bc} [19.13]
MD	203^{c} [3.21]	222^{ab} [6.68]	244^{d} [5.09]	24.04^{a} [2.90]	103.35^{bcd} [16.23]	40.31^{a} [10.23]
LYC	214^{abc} [3.40]	215^{a} [3.67]	230^{cd} [1.02]	60.94^{ab} [2.89]	148.96^{cd} [1.57]	120^{cd} [28.32]
BAM	224^{c} [1.41]	218^{c} [13.96]	231^{cd} [19.75]	36.84^{a} [7.19]	219.57^{e} [32.29]	154.41^{cd} [20.33]

*: Different superscript letters show statistically significant differences.

Air permeability, the easiest way for determining fabric porous structure, is a feature that allows to adjust the insulation and permeability of the fabric system through pore change, with temperature. Therefore, the dynamic air permeability based on the shape memory characteristic of the fabrics were determined at different fabric temperatures and results were given in Figure 3. Air permeability of the fabrics statistically changed with treatment type (SMPU/SMPU-CNW nanocomposite), raw material, temperature and two-way interactions of them. Air permeability values increased with temperature (above T_{trans} of SMPU) and reached a maximum for SMPU and SMPU-CNW treated modal fabrics. At 40°C above $T_{trans}=T_g$ of SMPU, polymer chains activate and form pores as a result of temperature sensitive free volume and micro-Brownian molecular motion hence shape memory effect. Also, the possible stretching and disruption of hydrogen bonds among CNWs lead to create additional permanent micro-voids in the polymer amorphous phase or increase in the size and number of micro-voids hence higher permeability for SMPU-CNW treated samples compared to reference ones.

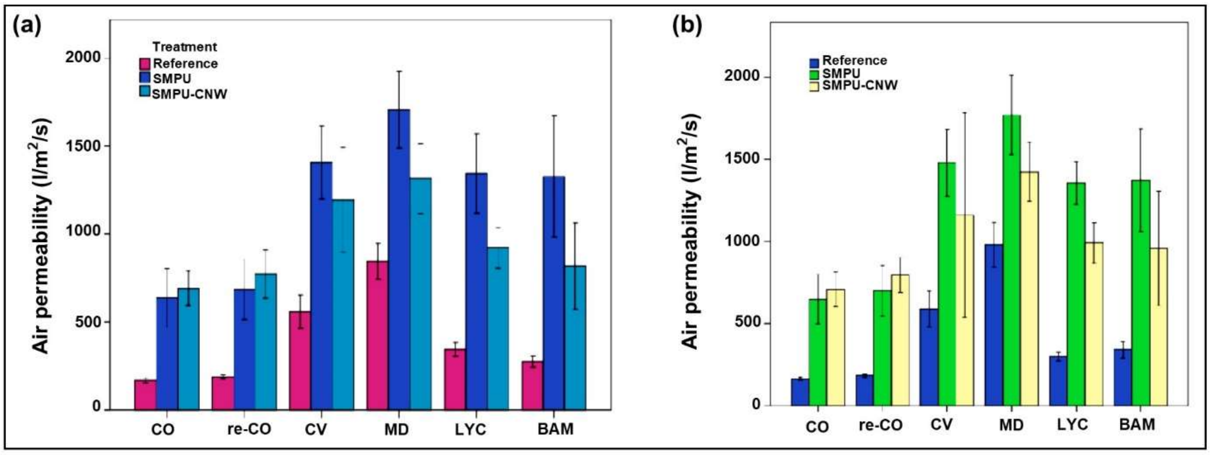

Figure 3. Air permeability values of cellulosic fabrics at 20°C (a) and 40°C (b)

Absorption capacity, a property affecting the feeling of wetness caused by sweating after intense activity hence comfort, was measured at different water temperature for determining ability of absorbing body sweat with temperature change and results were given in Figure 4. In harmony with dynamic air permeability and physical features, the absorption capacity of the fabrics differed significantly ($p<0.05$) with all the investigated parameters and their interactions. SMPU-CNW nanocomposite treated fabrics exhibited adaptive water absorption feature as a result of increasing values with temperature. Among SMPU-CNW nanocomposite treated fabrics; CV, BAM, and MD had the maximum and statistically identical values, even higher than their reference forms. The water absorption capacity values dynamically changed with temperature due to interacting water molecules with hydrophilic nanoparticles in crystalline regions as well as the amorphous regions for SMPU-CNW treated fabrics. Additionally, formation of porous structure resulting from temperature-sensitive free volume change in soft segments of SMPU matrix and molecular mobility at higher temperature contributes to obtaining high water absorption capacity by providing more water molecule absorption. Summing up the absorption capacity results, the dynamic water absorption features of SMPU-CNW nanocomposite treated MD and CV single jersey fabrics could provide a drier feeling hence comfort under dynamic temperature conditions.

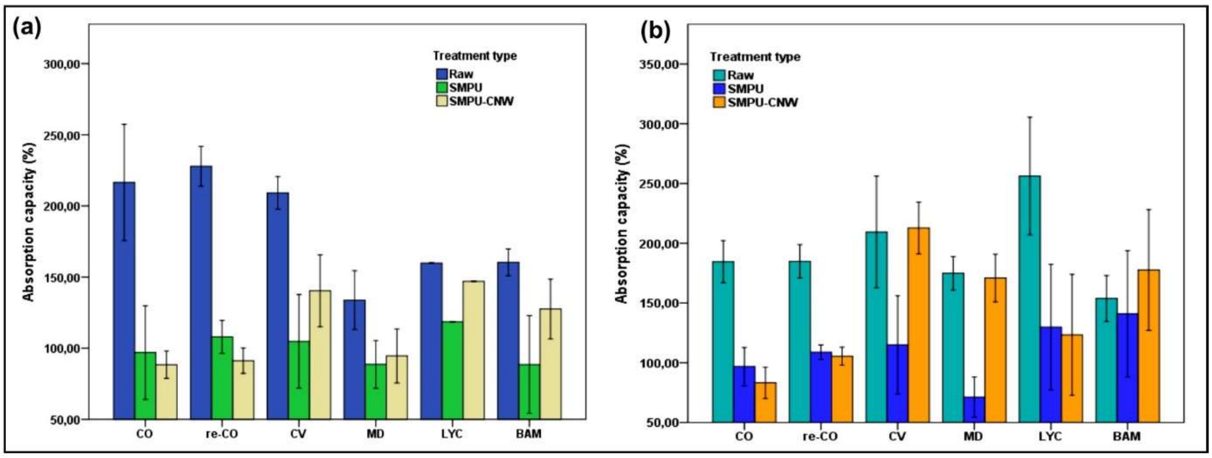

Figure 4. Water absorption capacity of the fabrics at 20°C (a) and 40°C (b)

4. CONCLUSIONS

In conclusion, the successful fabrication and characterization of passive smart cellulosic knitted fabrics based on temperature-water sensitive finishing treatment have been demonstrated for improving human body thermal comfort. The use of SMPU especially SMPU-CNW nanocomposite for surface treatment of cellulosic fabrics was found to be effective, as confirmed by analysis and measurement in dynamic conditions. The results showed that temperature-water sensitive nanocomposite treated cellulosic fabrics especially the ones produced from viscose and modal gained passive smart function such as dynamic air permeability and water absorption capacity changing within acceptable fabric hand. Summing up, shape memory nanocomposite treatment, sensitive to multiple stimuli, may be suggested to enable enhanced thermal comfort under dynamic conditions for commonly used cellulosic knitted fabrics.

ACKNOWLEDGEMENTS
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5. REFERENCES

[1] https://www.textiletoday.com.bd/global-market-sports-fitness-clothing-amounts-221-3-billion-2019-2026/
[2] GARG, H., MOHANTY, J., GUPTA, P., DAS, A., TRIPATHI, B. P., KUMAR, B. Effect of heat-set temperature on the crease recovery behavior of cotton fabric dip-coated with shape memory polyurethane, Materials Chemistry and Physics, 2022, 126952.
[3] KURU, A., AKSOY, S. A. Cellulose-PEG grafts from cotton waste in thermo-regulating textiles, Textile Research Journal, 2014, 84(4), 337-346.
[4] RIAZ, M. T., KHAN, M. I., SHAKER, K., NAWAB, Y., UMAIR, M., Effect of cellulosic material and weave design on comfort performance of woven fabrics, Journal of Natural Fibers, 2023, 20(1), 2163030.

DESIGN OF A DRYSUIT WITH IMPROVED THERMAL MANAGEMENT PROPERTIES FOR COLD WATER APPLICATIONS

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ABSTRACT

Drysuits are designed to protect water sports professionals from the cold, reduce injuries and increase buoyancy. They work by creating an insulating effect using a thin pocket of water between the neoprene and skin. Traditional drysuits have a three-layer construction where the interior layer wicks water away from the skin, the middle layer provides insulation, and the outer layer acts as a barrier to convective heat loss. In order to prevent heat loss to the environment, the interior section of the wetsuit must be made of materials with low thermal conductivity, and literature findings show that alternative advanced materials can improve performance in that respect. Accordingly, this study was conducted to propose an innovative design of drysuit with improved thermal properties for water sports enthusiasts. The performance of the drysuit was evaluated using a multiphysics modelling approach using Computational Fluid Dynamics (CFD) analysis. The results of the simulation contributed to a better understanding of the material properties which supported the design stage of the drysuit.

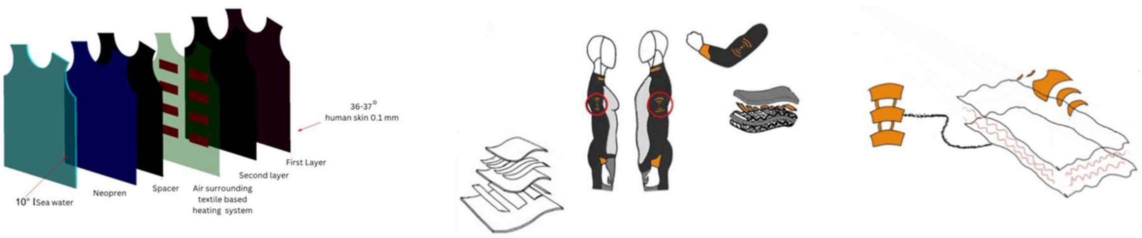
Key Words: Heating system, water sports apparel, dry suits, semi-dry suits, neoprene, simulation, CFD, multiphysics modelling

1. INTRODUCTION

Water sports professionals who are exposed to cold water environments face a lot of challenges that may impact their performance, safety, and overall well-being negatively. The alteration in body temperature experienced in such conditions can lead to physiological effects, including increased strain on the cardiovascular and respiratory systems, decreased muscular endurance and manual dexterity, and a reduced swimming capacity. To mitigate these adverse effects, apparel manufacturers specialized in cold water applications continually seek for new materials and/or solutions to enhance the thermoregulatory properties of their drysuit products. These specialized garments of drysuits are engineered to shield water sports enthusiasts from the cold aquatic environments, reducing the risk of injuries and enhancing buoyancy [1-5]. A fundamental principle underlying the functionality of drysuits is the creation of an insulating barrier, often in the form of a thin pocket of water between the neoprene fabric and the wearer's skin. Traditional drysuits have a three-layer construction wherein the interior layer effectively wicks water away from the skin, the middle layer provides insulation, and the outer layer acts as a barrier against convective heat loss [6]. In order to prevent heat loss to the environment, the interior section of the wetsuit must be made of materials with low thermal conductivity [7-8], and literature findings show that alternative advanced materials can improve performance in that respect [9]. One important challenge parameter in designing effective drysuits is countering the substantial heat loss amount encountered during aquatic activities. The factors contributing to this challenge are multifaceted, encompassing not only the rapid conductivity of heat by water in comparison to air but also the dynamic variations in hydrostatic pressure with increasing water depth [10]. This change in pressure, coupled with reduced exposure to sunlight, gives rise to a host of potential health issues for divers, including chills, disturbances in body temperature regulation, pressure-related physiological changes, and the peril of hypothermia. Furthermore, prolonged exposure to a wet environment can result in fungal infections and recurring skin health problems [11]. The impact of these challenges is particularly pronounced in individuals with lower levels of body fat, who are more sensitive to the frigid temperatures experienced in deep-water diving. This basic vulnerability is worsted by the fact that the thermal conductivity of water significantly surpasses that of air, causing the human body to lose heat at a rate approximately 25 times faster when submerged in water compared to on land [12]. On the other hand, diving presents complex physiological challenges, particularly concerning the solubility and behavior of nitrogen gas within the human body, governed by fundamental gas laws. Boyle–Mariotte law, describing the inverse relationship between gas volume and pressure under constant mass and temperature, impacts bodily tissues and air-filled cavities, leading to diving-related barotrauma and air embolism due to pressure variations during dives. Complementing this, Henry's law, which correlates gas dissolution with partial pressure in a liquid, explains decompression sickness and nitrogen narcosis. Recognizing these complexities, proactive measures like a thermal system are crucial to safeguard divers [13-15]. Considering these multifarious challenges, this study proposes an innovative drysuit design with improved thermal properties, targeting professional and semi-professional water sports enthusiasts. Aim has been to contribute to the development of drysuit solutions that not only protect against the rigors of cold water exposure but also optimize the performance and well-being of water sports professionals in demanding conditions.

2. EXPERIMENTAL

In the realm of wetsuit and drysuit construction, two distinct design approaches emerge, where one focuses on the fabric compositions and layers, and the second one comprising a sophisticated system that integrates textile-based heating elements and electronic components. Within alternative fabric layer designs, an important role is assigned to the middle layer, which serves as the foundation for seamlessly integrating heating systems, resulting in a structurally resilient configuration, largely owing to its sheltered sandwich structure. This middle layer is thoughtfully positioned alongside the heating system components, containing specialized textile materials and an innovative layering scheme. The heating system design is a core element of this innovative garment, consisting of a conductive textile surface, an Arduino serial module equipped with integrated TCP/IP network software, touch and temperature sensors, a Peltier module, and a dedicated power supply. These integrated components work in unison to regulate and maintain thermal comfort. Complementing the heating system, the textile layers utilized in this model are selected for their specific attributes. Figure 1 A shows the four layered structure of the proposed design in which the top layer of the neoprene (2 mm) wetsuit is made of classic silicone neoprene, while the first intermediate layer is a 1.5 mm spacer fabric instead of the typically used foam. Spacer fabric has a surface that carries the electronic heating circuit (Figure 1.B). A sensor is integrated into the spacer fabric under the neoprene (Figure 1.C). The second intermediate layer is a single jersey (reprieve ocean) with elastane and the bottom layer is a pique structure with elastane made of 100% recycled fibers using 37.5 yarns. This wetsuit has been engineered to meet the needs of performance athletes, with its hybrid thickness design featuring 3 mm arms, 5 mm body, and 4 mm legs, creating a balance between comfort and performance. The integration of Gator Tech Pro material, boasting a 1 mm thickness in the knee region, contributes significantly to the product's longevity, particularly in high-wear areas like the knees, where resistance to rapid wear due to impacts and falls is crucial. The rear zipper, a critical component for ease of wear, is sourced from YKK, a renowned zipper manufacturer, and an additional protective layer is thoughtfully applied to the ankle area for enhanced resilience and user comfort.



A B C

Figure 1.A Four Layered structure of the drysuit ; **B** Heating system activation mechanism ; **C** Sensor related activation mechanism

The activation mechanism of the heating system in this experiment is designed to be user-centric and intuitive, without the need for traditional buttons or screens. Activation is initiated through touch sensors thoughtfully positioned in the triceps area, allowing users to engage the system by applying pressure to their arms. This activation method capitalizes on the natural and instinctive response of the body, as users tend to embrace themselves when feeling cold. The heating system, therefore, aligns with the user's natural behavior, responding to their thermal comfort needs without the need for manual controls. This user-centric approach not only enhances convenience but also ensures that the system operates in harmony with the wearer's comfort preferences. The touch sensors are seamlessly integrated into the garment and are connected to LiPo (Lithium-Polymer) batteries. These LiPo batteries power both the textile-based heating elements and the Peltier module, fostering efficient and responsive heat regulation. Importantly, the LiPo battery and heater are strategically positioned between the second and third intermediate layers of the garment, optimizing thermal distribution and minimizing any discomfort to the wearer. This placement ensures that the heating system functions effectively while maintaining the garment's overall comfort and functionality. Moreover, the heating system incorporates an intelligent thermal management feature. When the wearer begins to feel too warm, the system responds to their body language and automatically deactivates the heater, promoting a comfortable and balanced thermal experience. This adaptive approach to temperature control further enhances the user's comfort and safety during aquatic activities.

2. NUMERICAL ASSESSMENT

The performance of the developed suit has been simulated using Multiphysics a modelling approach using CFD analysis. The obtained knowledge through the results has been transferred for design suggestions in the proposed body suit model. For the CFD analysis, a fluid flow velocity of 0.4 m/s, a human body surface area of 0.2652 m^2, and a heat transfer coefficient (H) of 170 W/m2-K for water has been considered as essential parameters governing the heat transfer behavior (Table 1). To emulate practical scenarios, the initial suit and environmental temperatures were set at 22° C, representing a common starting point for divers. Also, the decision to submerge the suit from the legs (Figure 2) allows us to closely observe and analyze how temperature evolves over time, accurately capturing the dynamics experienced by divers as they encounter seawater at 10°C. The presence of a 22°C environment surrounding the remaining part of the suit drives the heat exchange process, closely mimicking conditions often encountered during dives in lakes or similar bodies of water, even in relatively shallow depths (10-15m).

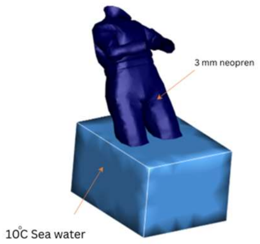


Figure 2. Practical scenario for the preliminary calculations

Table 1. Data used for CFD Analysis

	Thickness [mm]	Volume [m^3]	Surface area[m^2]	λ [W/m-K]	Cp [j/kg-K]	ρ [kg/m^3]
Human skin	0.1	2.65E-05	0.2655	0.21	3370	1000
First Layer	0.61	0.0001424	1.37E-03	0.0635	1006	1380
Second Layer	0.61	0.0002256	1.37E-03	0.0635	1006	1380
Heater	1.4(+air)	7.64E-06	3.14E-03	700	4000	2267
Spacer	2.85	0.0007524	6.34E-02	0.0329	1006	1380
Neoprene	3	0.000795	0.006725	0.19	1120	1500
Sea water	-	0.002653247	0.01346	0.6	3640	1030

3. RESULTS & DISCUSSION

The CFD analysis of the developed suit revealed crucial insights, including the identification of maximum and minimum temperature points shedding light on the thermal performance characteristics of the suit. Table 2 illustrates the results considering heater temperatures of 40°C, 45°C and 50°C. The predictions show that the temperature distribution across the first layer which is in contact with the skin maintains temperatures. Moreover, the results reveal that there is potential for improving the performance by decreasing the power as well as optimizing the thicknesses of the layers.

Table 2. Simulation results of the heater samples

Heater	40^{0}C	45^{0}C	50^{0}C
First Layer	Max: 39^{0}C Min: 35^{0}C	Max: 42^{0}C Min: 34^{0}C	Max: 46^{0}C Min: 33^{0}C
Second Layer	Max: 40^{0}C Min: 34^{0}C	Max: 45^{0}C Min. 33^{0}C	Max: 46^{0}C Min: 33^{0}C
Spacer	Max: 40^{0}C Min: 15^{0}C	Max: 45^{0}C Min:15 ^{0}C	Max 50^{0}C Min 15^{0}C
Neoprene	Max 19^{0}C Min 13^{0}C	Max 21^{0}C Min 13^{0}C	Max 22^{0}C Min 13^{0}C

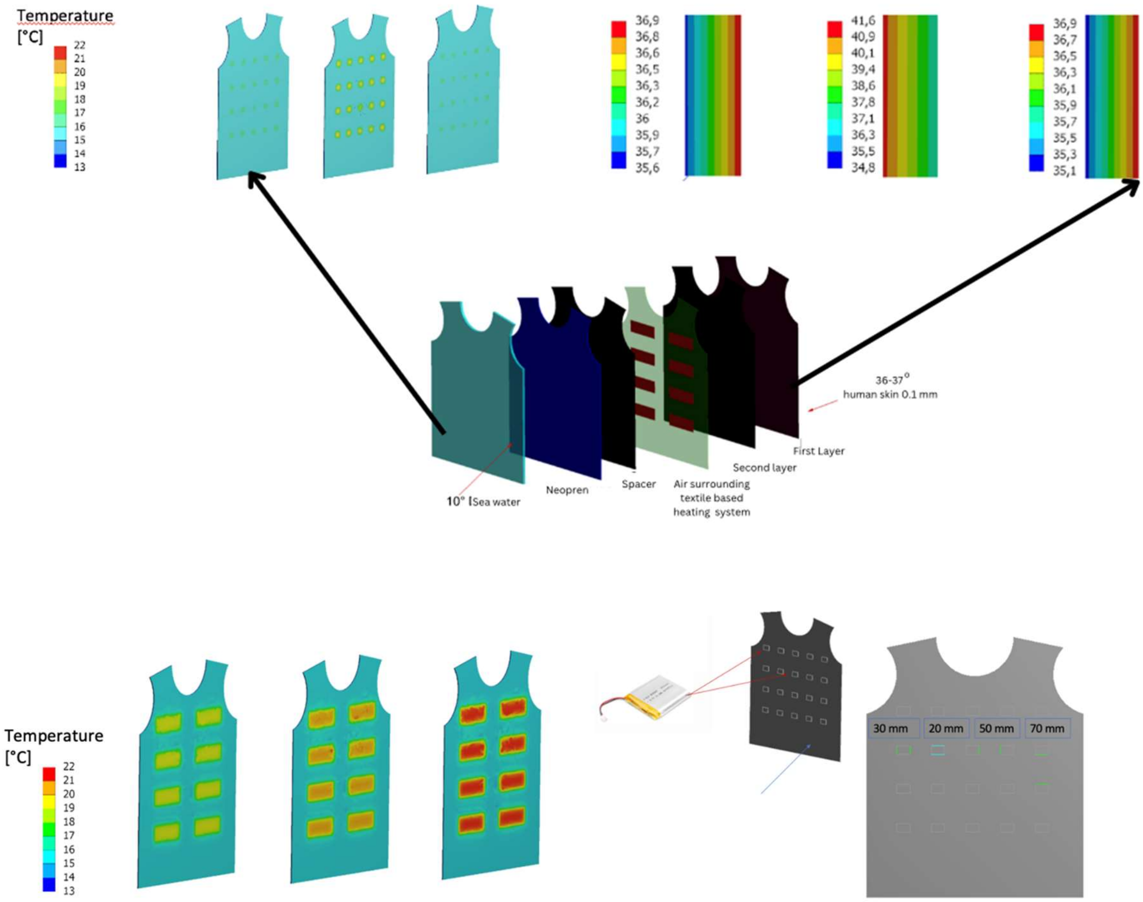


Figure 3. A. Composite layer thermal management. **B.** Details of the middle layer

For better understanding of the system's thermal behaviour, the focus of the simulation was shifted into the hottest patch zone—the region where the localized temperature extremes were the most significant ones. A cross-sectional analysis in this zone was carried out, aiming to uncover the factors responsible for the observed temperature variations (Figure 3A - B). Also a full transient analysis using an in-depth Computational Fluid Dynamics (CFD) analysis was performed using the model set up depicted in Figure 2. The full body model analysis of the neoprene layer comprised the transient thermal behaviour. The preliminary calculations revealed noticeable differences within one hour of the analysis. The contrast between 3 mm and 5 mm neoprene layers showed insignificant temperature differences over this duration. However, a 7 mm thickness reveals a substantial 3-4°C variation in the same time frame, which suggests a potential for optimizing the layered material thickness (Figure 4). The simulation of the full model has the advantage that is considers the thermal mass of a whole suit that is required to comprehend the transient performance of the suit within a real-life case. This has been used for a second case where the full suit is submersed. An hour time has been simulated, which is typical for one dive with standard equipment; especially, for sports purposes. In that respect, the simulation conducted for the full submersion of the suit at 10°C seawater with an initial temperature of 22°C, provided also valuable insights into the thermal behavior of the layering design materials. (Figure 5).

It should be noted that the influence of the internal heating is ignored to assess the thermal behaviour of the material solely based on the thickness and properties.

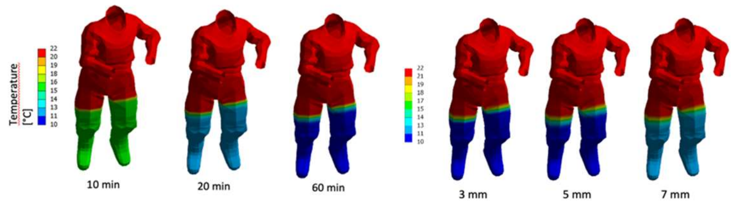


Figure 4. Preliminary calculation within real simulation

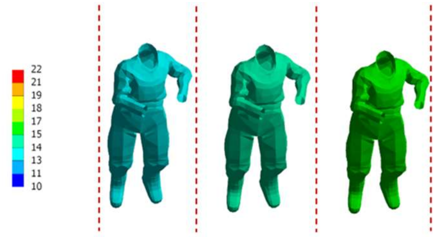


Figure 5. Calculations for the full submersion of the suit into water

The observed temperature differences, particularly the significant variation in the 7 mm thickness neoprene, underscore the potential for optimizing neoprene layer thickness to enhance thermal performance in submerged suits.

4. CONCLUSIONS

This study aims to propose an innovative drysuit design with enhanced thermal performance for both professional and semi-professional water sports enthusiasts. This design integrates advanced electronic components and textiles to provide exceptional comfort, warmth, and user-friendliness. To achieve this goal, a layered structural concept was developed and multiphysics simulations have been performed using Computational Fluid Dynamics (CFD).

The results of our simulations contribute significantly to our understanding of material properties, and design aspects which, in turn, can guide decision-making in the design and selection of layers for these specialized diving suits. Furthermore, our study highlights the substantial potential of this drysuit in the market, meeting the precise needs and expectations of serious water sports athletes by effectively regulating body temperature underwater and ensuring exceptional durability.

ACKNOWLEDGEMENT

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5. REFERENCES

[1] CORONA, L. J., SIMMONS, G. H., NESSLER, J. A. and NEWCOMER, S. C. (2018). Characterisation of regional skin temperatures in recreational surfers wearing a 2-mm wetsuit. *Ergonomics*, 61(5), 729–735. Stable Link to Article (https://doi.org/10.1080/00140139.2017.1387291)

[2] ENANDER, A. (1987). Effects of moderate cold on performance of psychomotor and cognitive tasks. *Ergonomics* 30, 1431–45.
[3] HEUS, R., DAANEN, H. A. M. and HAVENITH, G. (1995). Physiological criteria for functioning of hands in the cold. *Appl Ergon* 26, 5–13.
[4] PIEDRAHITA, H. (2008). Working in cold conditions indoors: effects on musculoskeletal symptoms and upper limb movements (Ph.D), Technical University, Luleå.
[5] HOLMÉR I. (2009). Evaluation of cold workplaces: an overview of standards for assessment of cold stress. *Industrial health* (3), 228–234. Stable Link to Article (https://doi.org/10.2486/indhealth.47.228)
[6] PENG, L., SU, B., YU, A. and JIANG, X. (2019). Review of clothing for thermal management with advanced materials. Cellulose (London), Vol.26 (1), p.6415-6448. Stable Link to Article (https://doi.org/10.1007/s10570-019-02534-6)
[7] LAFÈRE, P., GUERRERO, F., GERMONPRÉ, P. and BALESTRA, C. (2021). Comparison of insulation provided by dry or wetsuits among recreational divers during cold water immersion (< 5°C). *International maritime health*, 72(3), 217–222. (https://doi.org/10.5603/IMH.2021.0040)
[8] MATUSIAK, M. & KOWALCZYK, S. (2014). Thermal-Insulation Properties of Multilayer Textile Packages. *Autex Research Journal.* 14. 299-307. 10.2478/aut-2014-0030.
[9] NAVODYA, U., KEENAWINNA, G., and GUNASEKERA, U. (2020) The Development of Sustainable Alternative to Neoprene Wetsuit Fabric. *Moratuwa Engineering Research Conference (MERCon),* Moratuwa, Sri Lanka, 2020, pp. 465 -469, doi:101109/MERCon50084.2020.9185195
[10] ARSLAN, A. Chapter 2: Barotravmalar: Kulak Ve Sinüs. Eğitmenler İçin Dalış Sağlığı, Edited by AKTAŞ Ş. Türk Deniz Araştırmaları Vakfı (TÜDAV), 2019, pp 34.
[11] BENEDICT, K. and PARK, B.J. Invasive Fungal Infections after Natural Disasters. Emerg Infect Dis, 2014, 20(3), pp 349-355
[12] TARLOCHAN, F. and RAMESH, S. Heat Transfer Model for Predicting Survival Time in Cold Water Immersion. Biomedical Engineering-Applications, Basis & Communications, 2005, 17, pp 159-166.
[13] WEST, J.B. The Original Presentation of Boyle's law. Journal of Applied Physiology, 1999, 87(4), 1543 -1545
[14] LEAL, S., LEAL, J.P. and FERNANDES, H. A blended-learning approach to the Boyle-Mariotte Law, Proceedings fo the 1st Experiment International Conference, 11, pp 200-203
[15] SANDER, R. Compilation of Henry's law constants (version 4.0) for water as solvent, Atmos. Chem. Phys., 2015, 15, 4399-4981.

HEAT ON-THE-GO: DESIGN OF A BABY BOTTLE WARMER BAG WITH A TEXTILE-BASED HEATER SYSTEM

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ABSTRACT

This article presents the conceptual design of a baby bottle heater based on the 2015/17738 patent, showcasing a 3-layer structure incorporating advanced materials and mechanisms. The study highlights the integration of a textile-based heating system, controlled temperature regulation, and the achievement of optimal temperature ranges for baby milk warming. The experimental study showed that the temperature range of 30 to 45 °C can be achieved with an appropriate selection of the voltage applied on the heater for baby milk, though as a future work the design of the system needs to be improved by focusing each and every layer.

Key Words: Heating system, Baby bottle, Warmer bag, Wearable heating technologies, Dip coating technique

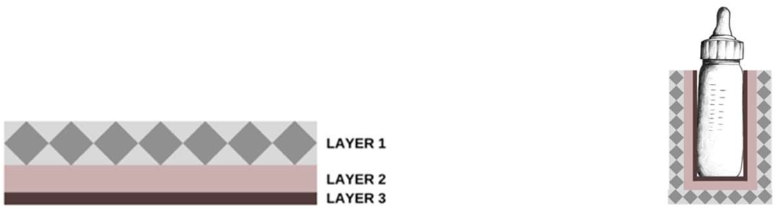
1. INTRODUCTION

Consumer preferences and market demand make up important portion on value of a product's success. So, for a product to success in achieving, the product design must be meeting the demand and exceeding consumer expectations. To be a "good" product, it is crucial that it satisfies two fundamental attributes. The first of these attributes related to the fulfillment of basic performance criteria, including the product's physical functionality. The second attribute revelances to the improving of an aesthetically and usefully design [1,2]. Multifunctional, high-performance wearable heaters hold great promise to design for various human related applications in the future [3,4]. However, their development has been impeded by challenges such as limited flexibility, inadequate air-permeability, and a lack of clothes-knittability [3,5]. In response to these limitations, this study focuses on the textile-based design of a baby bottle heater system with a polymeric wearable heater [6]. With the help of this innovative approach, it is aimed to unlock new possibilities for advanced wearable heating technologies [7]. In the realm of baby feeding, ensuring the optimal temperature of liquid baby food is of importance for the health and comfort. Traditional methods of heating baby bottles, such as using microwave ovens, may be inconvenient and imprecise [8]. To address these challenges, portable textile-based heater systems offering uniform heat distribution, temperature control, and safety features, have emerged as a promising solution [9]. Parents face the perpetual challenge of ensuring that their baby's milk or formula is at the right temperature when on the go. Traditional methods have limitations, leading to the development of innovative solutions. This article presents the design and mechanisms of a baby bottle heater bag that utilizes a textile-based heating system. Considering these needs of consumers, this study proposes an innovative baby bottle warmer bag with improved system properties, targeting parents. Aim has been to contribute to the development of baby bottle warmer solutions that not only provide the heating system but also optimize the weight of the textile based heater and well being of the consumers.

2. EXPERIMENTAL

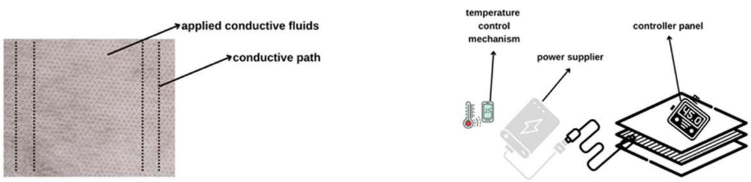
The baby bottle heater bag's design centers on a 3-layer textile structure. The outer layer (Layer 1) utilizes commercially available weft knitted spacer fabric 1.7 mm, providing both cushioning and thermal insulation. Layer 2 comprises a textile-based heating system, developed from a non-woven material incorporating synthetic fibers (polyester (PES), polyamide (PA), and polypropylene (PP), carbon fibers, and carbon nano graphite powders) in determined ratios based on the dimensional requirements. These materials enhance conductivity and distribute heat evenly. Powder adhesives which are incorporated into the structure through the lamination process secure these layers together, ensuring stability and integration (Figure 1 and Figure 2A). The technology of this very layer is inspired by the methods defined in TP 2015/17738 patent [10]. Finally Layer 3, i.e. the inner layer, uses a commercial Lacoste (knitted) fabric made from Thermolite fiber (supplied from Tepar, İstanbul Tr) for durability and aesthetics.

The structured design incorporates key mechanisms for optimal functionality. A temperature control mechanism maintains the desired heat output, ensuring that the baby bottle contents are heated to a suitable temperature without nutrient loss or scalding. A reliable power supply system ensures efficient energy delivery to the heating system. The controller panel provides user-friendly controls, allowing parents to adjust the temperature as needed. The heating system activation mechanism initiates the heating process efficiently, further enhancing user convenience (Figure 2 B).



A **B**

Figure 1. A. 3 Layered textile structure of the baby bottle heater **B.** Bottle application sample.



A **B**

Figure 2. A. Textile based heating system structure **B.** Heating system activation mechanism

For the measurement of the temperatures, a portable thermal camera was utilized FLIR ON PRO LT has thermal resolution of the 4800pixel IR images at a thermal sensitivity of 100mK and measure temperatures from -20C to 120C (-4F to 248F).

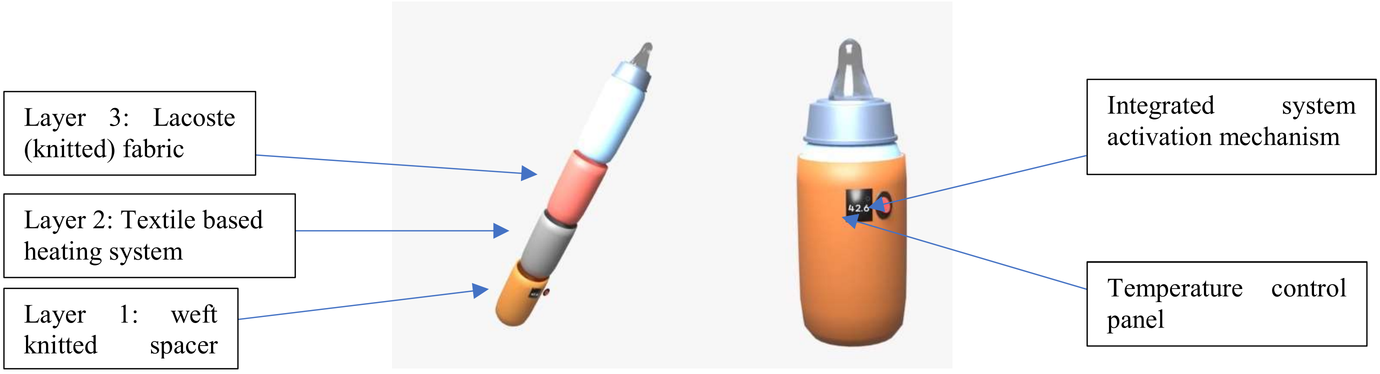


Figure 3. Exploded view and 3D modelling

Figure 4. Power supplier

The power supply provided to the system can be connected to the power bank or with any power via USB. Integrated activation mechanism and temperature control panel in the outer layer was embedded (Figure 3 and Figure 4).

3. RESULTS & DISCUSSION

In our experimentation, we achieved a temperature range of 30 to 45 °C by carefully selecting the voltage applied to the heater. This temperature range aligns with recommended degrees of warming baby milk, ensuring both safety and nutritional integrity [11]. Table 1A shows the recorded time intervals from the textile surface to attain the designated temperature when using the textile-based heater within the layered structure, whereas Table 1B presents the computed time for the liquid food in a commercially available baby bottle to reach the desired temperature.

Table 1. A. The time to reach the target temperature of the heated surface in the layered structure **B.** Calculated time to reach the target temperature of the liquid food in the bottle

A

The time to reach the target temperature of the heated surface in the layered structure	
Temperature °C	**Time** (seconds)
30	15
35	39
40	48
45	55

B

Calculated time to reach the target temperature of the liquid food in the bottle	
Temperature °C	**Time** (seconds)
30	59.5
35	101
40	753
45	1508

As may be seen from Table 1, the temperature range of 30 to 45 °C can be achieved with an appropriate selection the voltage applied on the heater for baby milk using the specific heating methods.

Figure 3 demonstrates the temperatures measured using FLIR ON PRO LT. As may be seen from the figure the Layer 2 which is the part of the baby bottle system can be successfully heated within the range of 30-50ºC by optimizing the ratios of components in the nonwoven namely, polyester (PES), polyamide (PA), and polypropylene (PP), carbon fibers, and carbon nano graphite powders.

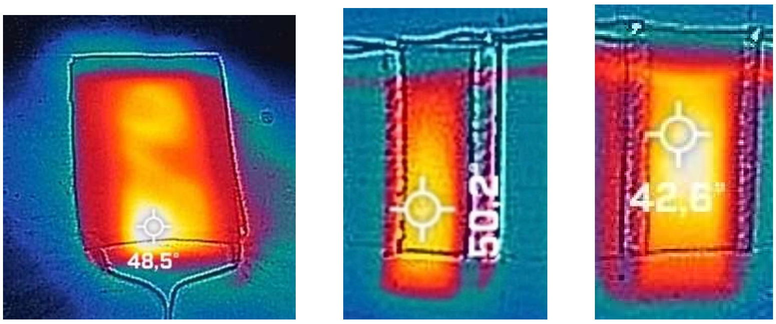


Figure 3. Temperature measurements from Layer 2

4. CONCLUSIONS

The conceptual design of the baby bottle heating bag, with its integrated textile-based heating system and optimal functionality mechanisms, represents a significant step forward in meeting the needs and demands of parents on the go. This innovative solution offers both convenience and safety, ensuring that baby milk is consistently warmed to the desired temperature range. Future developments in this field hold the promise of further improving energy efficiency and usability, ultimately benefiting both parents and infants. In future work, the focus will be on improving the heater design layer by layer such that higher energy efficiency levels can be achieved.

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5. REFERENCES

[1] NAGAMACHI, M. (1999). Kansei Engineering; the Implication and Applications to Product Development, *Proceeding of System, Man, and Cybernetic*
[2] JANARI D. AND RAKHMAWATI A. (2016). Developing Baby Bag Design by Using Kansei Engineering Method, *Material Science and Engineering*, 105, 0120319
[3] LIU, X., JIN X., LI L., WANG J., YANG Y., CAO Y. and WANG W. (2020). Air-permeable, multifunctional, dual-energy-driven MXene-decorated polymeric textile-based wearable heaters with exceptional electrothermal and photothermal conversion performance, *Journal of Materials Chemistry A,* 25(8), 12526-12537. https://doi.org/10.1039/D0TA03048A
[4] WANG, X., LEI, Z., MA, X.J., HE, G., XU, T., TAN, J., WANG, L., ZHANG, X., QU, L. and ZHANG, X. (2022). A lightweight MXene-Coated nonwoven fabric with excellent flame

Retardancy, EMI Shielding, and Electrothermal/Photothermal conversion for wearable heater. *Chemical Engineering Journal,* 430(1), 132605. https://doi.org/10.1016/j.cej.2021.132605
[5] ZANG, H., CAO Y., ZHEN Q., XU Q.G., SONG W.M. and QIAN X.M. (2022). Large-Scale Preparation of Micro–Nanofibrous and Fluffy Propylene-Based Elastomer/Polyurethane@Graphene Nanoplatelet Membranes with Breathable and Flexible Characteristics for Wearable Stretchy Heaters. *ACS Appl. Mater. Interfaces,* 14(42), 1944-8244. https://doi.org/10.1021/acsami.2c15449
[6] OJSTRŠEK A., JUG L. and PLOHL O. (2022). A Review of Electro Conductive Textiles Utilizing the Dip-Coating Technique: Their Functionality, Durability and Sustainability. *Polymers.* 14(21):4713. https://doi.org/10.3390/polym14214713
[7] FARUK M.O., AHMED A., JALIL M.A., ISLAM M.T., SHAMIM A.M., ADAK B., HOSSAIN M.M. and MUKHOPADHYAY SM. (2021). Functional textiles and composite based wearable thermal devices for Joule heating: progress and perspectives, *Applied Materials Today,* 23, 101025, 2352-9407. https://doi.org/10.1016/j.apmt.2021.101025
[8] EHLERT K.A., BEUMER C.W.E. and GROOT M.C.E. (2007). Migration of bisphenol A into water from polycarbonate baby bottles during microwave heating, *Food Additives & Contaminants,* 25(7), 904-910. https://doi.org/10.1080/02652030701867867
[9] SIMIC M., STAVRAKIS A.K. and STOJANOVIC G.M., (2022). Portable Heating and Temperature-Monitoring System with a Textile Heater Embroidered on the Facemask, *American Chemical Society,* 7(50), 47214-47224 https://doi.org/10.1021/acsomega.2c06431
[10] ŞIŞMAN, A. (2015)Köprü Viyadük ve Otoyollarda Donmayı Geciktirmeye veya Engellemeye Yönlik Tülbent Esaslı (Non-Woven) Sentetik Malzeme Geliştirilmesi (TP Patent No: 2015/17738) Türk Patent
[11] American Academy of Pediatrics (2017) Tips for Introducing Solid Foods, *Healthy Children*

DIGITAL TRANSFORMATION AND ITS EFFECTS ON PRODUCTIVITY IN A CLOTHING COMPANY

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ABSTRACT

In the clothing industry with a labor-intensive structure, the common problem of the enterprises is that the productivity level is not at the desired level. This level can be determined and evaluated at the end of the day, not at the expected instant time. In this context, the aim of the study is to effectively manage sewing lines and increase productivity by optimizing them with the correct data. Since the data collected from the operators with manual or semi-automatic systems in the existing structure show excessive deviations and give erroneous results, in the study it is aimed to record 100% accurate data without relying on people. In this direction, there was an increase of 8,02 % in production productivity, an increase of 14,21 % in packaging productivity, and an increase of 9,52 % in general operating productivity with the system developed within the scope of the study, within a 3-month period in the company.

Keywords: Clothing industry 4.0, ERP, MES, IOT, digital transformation

1. INTRODUCTION

60% of all personnel in a clothing company work in the production department [1]. In this department, difficult, complex machines or apparatuses, each with different features, are used by the operators. However, all the activities performed are highly dependent on the dexterity and performance of the operator [2]. The fact that the data obtained from all the activities carried out in the production department (such as the number of production) is human-dependent, means that these entries depend on a subjective structure [3].

The common problem of apparel enterprises is that there is a lower efficiency than the planned values. In this direction, the managers cannot reach the desired and correct data promptly. When the sector practices are examined, it is found that no integrated system provides the automatic calculation of standard work times, the creation of an operation-related cycle time bank, the elimination of order-related production line imbalances, and the control of stocks in the line. In the scope of the study, it is planned to develop a digital system that can monitor and calculate operational efficiency and operator performances, respond to problems immediately, and perform line balancing.

The studies obtained in the literature review on this subject are as follows. In a study conducted by Lee et al. in 2017, it was emphasized that parameters such as the control of the sewing thread bobbins on the sewing machines, the control of the thread breakage, and the active sewing times of the machine can be monitored instantly with IoT-based devices [4]. In 2017, by Liu et al. an IoT-based system was proposed in order to ensure the following of semi-automatic production processes, which are implemented based on manpower, and to monitor production efficiency [5]. Guisti et al. proposed an IoT-based system for remote monitoring of the efficiency of small-scale production companies in 2018 [6]. Barksdale et al., in their studies in 2018, aimed to equip the machines used for production purposes in the industry with IoT systems, so that their status during operation can be monitored in real-time, and thus, possible malfunctions and breakdowns that may occur in these machines can be detected quickly [7]. With the system they designed in 2019, Lee and Mun enabled real-time monitoring of the power consumption values of industrial production machines by using IoT technologies [8]. Udayangani et al., with the system developed for sewing machines and employees in the apparel industry in 2019, the cycle time of production processes, machine usage times, and operator working times can be tracked [9]. The study carried out in 2019 by Dai et al., provides an overview of Internet of Things (IoT) systems for manufacturing sectors. It has been stated that it is possible to obtain information about the systematics of the production by analyzing the data that can be collected thanks to IoT from the production factors used [8] [10].

In this context, the study aims to effectively manage sewing lines and increase productivity by optimizing them with the correct data. Since the data collected from the operators with manual or semi-automatic systems in the existing structure show excessive deviations and give erroneous results, in the study it is aimed to record 100% accurate data without relying on people. With this study, in line with the industry 4.0 vision;

- In the context of Internet of Things (IoT) technology, the number of manufactured products can be followed instantly in the digital environment over the data coming from the sensors,
- Able to accurately detect lost times, automatically receive operator information with RFID technology,
- Able to keep work study bank records over actual operation times,
- Optimizing the stocks in the line on the system,
- Develop a system that can create an operation plan and monitor compliance with this plan.

2. MATERIAL AND METHOD

2.1. Material

The material of the study is the sewing department of a clothing company. There are 14 production lines in total in the department where the study was carried out and all production lines were digitized. 1 production line was selected as the pilot line and the IoT systems were set up on all sewing machines. It was decided to install IoT systems only on the machines at the entrance and exit of the other 13 lines. In this direction;

The developed system was set up on a pilot line with 25-30 sewing machines, 3 quality control stations, and 1 packaging station, with an average of 40 operators, and was evaluated in 3 months. The other 13 lines, 2 sewing machines, 3 quality control stations, and 1 packaging station, with an average of 8 operators, were evaluated in a 3-month period.

2.2. Method

Within the scope of the study, the digitalization of the manually collected data was ensured in order to adapt all the processes of the production processes to the Industry 4.0 philosophy. The digitalization cycle is completed in 3 phases. These are digitization, digitalization, and digital transformation. Digitization occurs when a product becomes digital. Digitalization occurs when a business model becomes digital. Digital transformation, on the other hand, is the restructuring of the business world, society, economy, and institutions with a digital system [11].

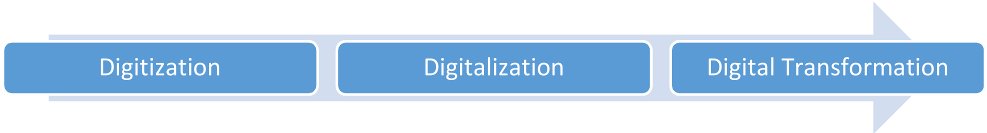

Figure 1. The digital transformation steps-the three amigos [11]

In the study, digital transformation was achieved in all processes of the production department by following these 3 steps in line with the Industry 4.0 philosophy. In the first step of the transformation, Internet of Things (IoT) data collection devices were developed under the title of digitization. Since there are many deviations in the data collected by manual-semi-automatic systems in the existing sewing enterprises and causes erroneous results, it is ensured that the correct data is obtained directly from all sewing machines, without being dependent on people, through sensors and RFID technologies. Three different IoT data collection devices were developed and set to cover the assembly line, quality control, and packaging processes in a sewing line.

In the second step of the transformation, a digital production management system "The MES platform" was developed, where instantaneous and online data collected from the line can be managed. With this platform, it has been ensured that the sewing lines are managed effectively, and productivity is increased by optimizing them with the correct data. In this direction, it is ensured that:

- Production data is collected with a notification system,
- Accurately detecting lost times,
- Keeping cycle time bank records over real operation times,
- Doing competence analysis by assigning the appropriate operator for the appropriate operation,
- Optimizing the stocks in the line on the system,
- Creating a line balancing plan that provides a balanced workload and a balanced flow and monitoring compliance with this plan.

In the last step of the transformation, the integration of the developed IOT and MES platforms both among each other and into the currently used ERP system was ensured. The technical infrastructure has been established for the flow of the data needed for production on the MES platform to the ERP system (Figure 2).

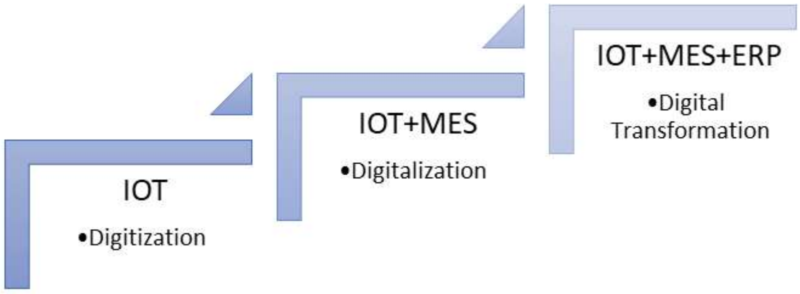

Figure 2. The digital transformation steps of the project

While designing the DOR IoT (IoT Device's Name for Sewing Machines) interface screens, interviews were held with the production teams and operators who sew directly, and the screens were developed considering the opinions of both operators and production supervisors. The target and the actual production numbers have been decided to show on the DOR IoT main screens during the day. Apart from this, since it is considered important for the operator to perform the correct operation on the correct machine, the relevant information is displayed on the main screen. In addition, the buttons for tracking various reasons for stopping production have been designed in larger sizes and operators' communication with DOR IoT has been facilitated.

Figure 3. Screen samples of the DOR IoT

In line with the new system developed, Quantum MES (Manufacturing Execution System) web application software has been developed with the functions of instantaneously monitoring, executing, and managing the order flow in the production facilities with the data received from the field hardware (DOR IoT).

Figure 4. Quantum MES login page and screen sample

The DOR IoT devices that instantly collect reliable data from the production site and the Quantum MES software, which manages the monitoring/execution activities of the production in the light of this data, complete the "Digital Transformation", which is aimed to be developed within the scope of the project, with the integration of the entire system into the existing ERP system.

3. FINDINGS

Counting devices developed within the scope of the project have been tested in each version both by researcher and technician personnel in the laboratory environment and by expert operators in the field. DOR IoT, the 6th version of the counting device, was developed by making continuous improvements and development activities in line with the feedback received from all users.

In order to observe the performance of the developed device prototypes, trial, and test studies were continued in the clothing company. The findings regarding the results of the data transfer test performed with more than 100,000 data for 3 months for version 6 are shown in Table 1.

Table 1. Data transfer test findings of the DOR IoT

	DOR IoT v6.0
Data Count Accuracy Rate	99,64%
Data Transfer Accuracy Rate	99,73%

There is the necessary notification and warning system. In line with conditions such as productivity, bottleneck operations, and repair rates, the system allows intervention in problems immediately by developing features for automatic notifications via mobile applications and sending end-of-day productivity reports via e-mail.

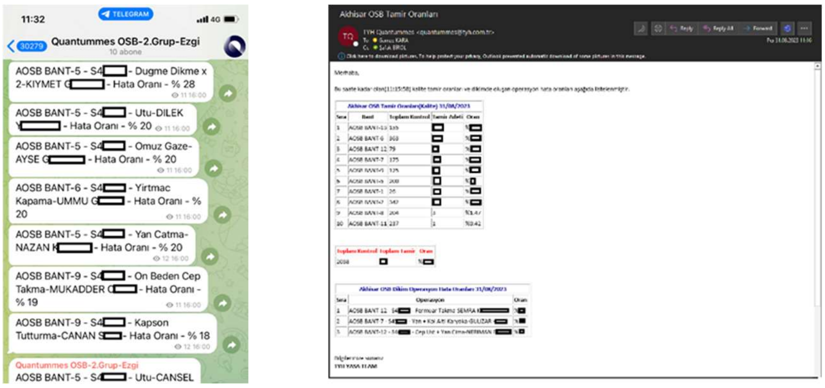

Figure 5. Quantum MES notifications and e-mail report samples

The YASA system (Digital Transformation System) was developed within the scope of the project; while the production of the pieces was in progress, automatic data was obtained with DOR IoT counting devices, the cycle time of the work, the performance of the operator, and the operating productivity were automatically calculated with the Quantum MES application software. The data obtained, the weak points and bottlenecks in the process were instantly identified, and alternative solutions were developed, thus improving the production processes.

When the data of the sewing department where the YASA system was established are examined, in the 3 months period and;

- 8,02 % increase in planting productivity,
- 14,21% increase in package productivity,
- 9,52 % in general operating productivity were provided (Figure 6).

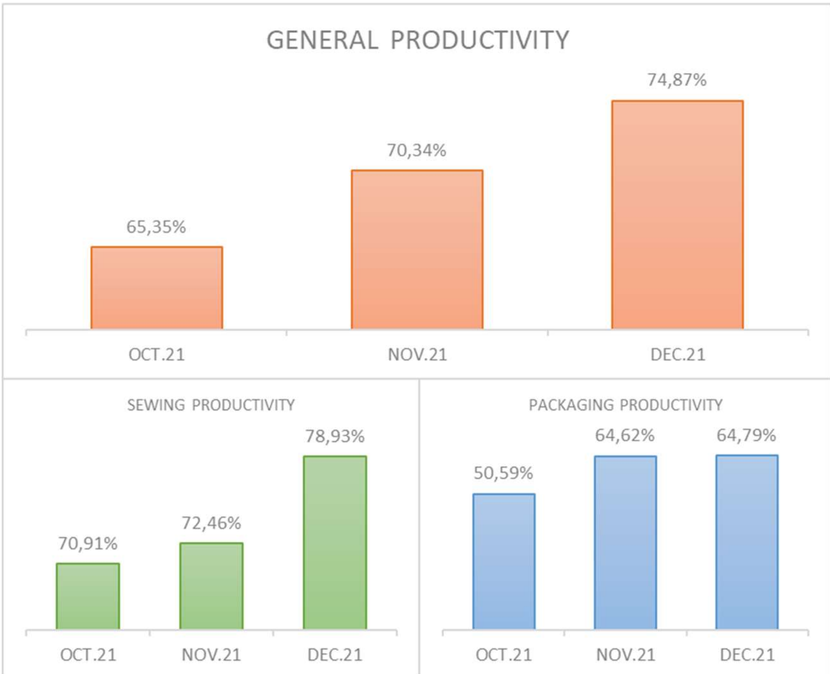

Figure 6. General productivity analysis

DOR IoT counting devices are set up at the entrance and exit of 14 production lines in the production facility. Moreover, the data of 1 selected line (line no: 2) were also analyzed.

In the line no-2 during 3 months;

- 14,75 % increase in planting productivity,
- 18,55 % increase in package productivity,
- 15,30 % increase in the overall efficiency (Figure 7).

This increase in productivity made it possible to detect bottleneck points instantly with the YASA system, to interve ne quickly in-line stocks formed between sewing operations, to instantly monitor the production-error-maintenance data from the enterprise, and to solve the problems in the production line quickly.

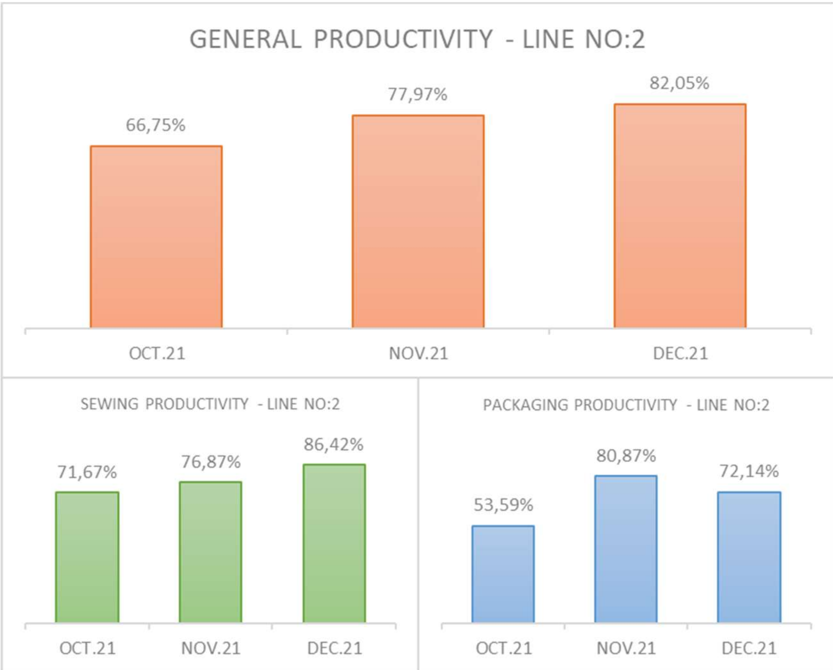

Figure 7. Line no:2 productivity analysis

In addition, the performance of the operators can be analyzed in detail by obtaining daily, weekly, and monthly reports, and the necessary practice can be provided for the operators to apply the right methods with the help of the Yasa system. In line with all these factors, sustainable development in sewing businesses is achieved with digital transformation.

4. CONCLUSIONS and RECOMMENDATIONS

With the system developed within the scope of the study, it has been shown that the Industry 4.0 philosophy can be applied even in a labor-intensive sector such as the clothing industry. Considering the results obtained in this way, the following points that the company gained accordingly can be listed.

- “Operation Bank” was prepared by listing more than 400 sewing operations. In this way, standardization and methodological improvement are provided in production.
- Owing to the model preparation module, a model can be created quickly with the operations that can be selected from the operation bank and the draft models that can be used on the basis of product type.
- Fast and realistic work assignments can be made with the multi-criteria operator competence analysis system (CAS) developed specifically for sewing operators.
- With the machine identification module, inventory lists that indicate which line the machines in the production facility belong to can be quickly created.
- With the developed line pre-setup module, the dynamic structure of the department can be captured and communication-related data losses that may occur can be prevented.
- Instant tracking of production data coming from DOR IoT can be done and an infrastructure is created for the transition to lean production with the in-line stock monitoring screen.
- With the Quantum MES web application, it is possible to convert sewing companies into knowledge-intensive production by managing the order, facility, sewing line, operator, operation, and productivity reports.

SWOT analysis was carried out for the general evaluation of the data obtained in the study and the system.

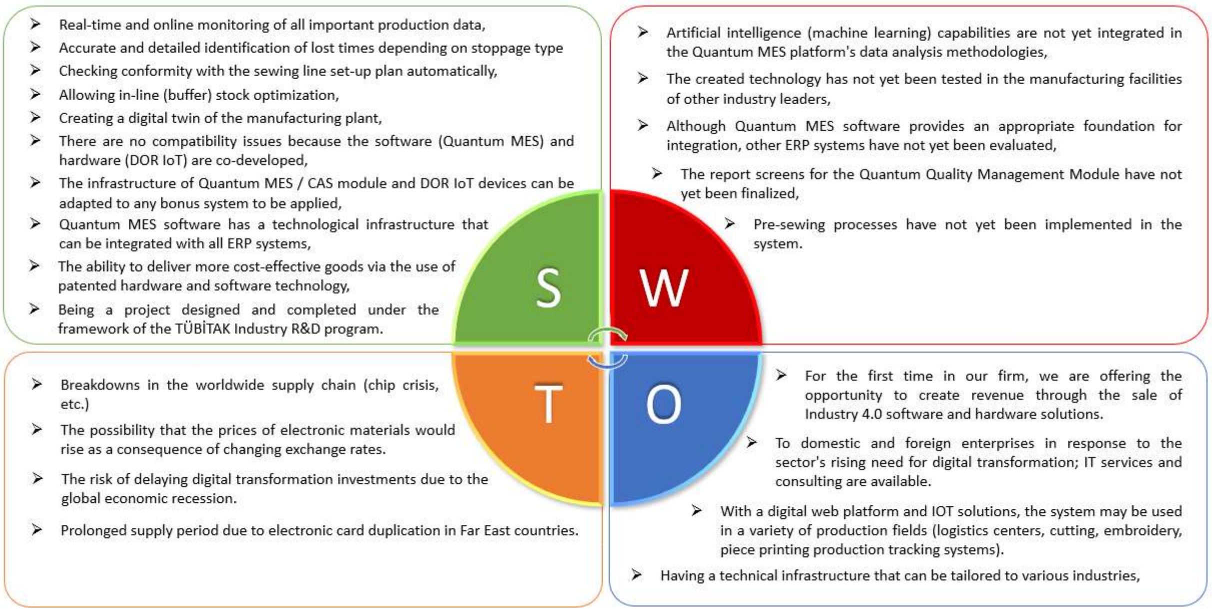

Figure 8. The SWOT analysis

The output of this study will be useful for the managers and owners of clothing companies, the clothing industry, and academicians who work in this field will gain from the results of this study.

ACKNOWLEDGEMENT

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REFERENCES

[1] KÜÇÜK M. AND GÜNER M., The productivity improvement studies with process analysis methods in a clothing company, Tekstil ve Mühendis, 2015, 22:98, 33-41.
[2] SNATKINA A., KARJUSTA K., MAJAKA J., ARUVÄLIA T., EISKOP T., Real time production monitoring system in SME, Estonian Journal of Engineering, 2013, 19:1, 62–75.
[3] ZERENLER, M., The performance measurement system design and a study on performance measurement of manufacturing systems, The International Journal of Economic and Social Research, Spring 2005, 1:1-36.
[4] LEE J-Y., LEE D-H., PARK J-H. AND PARK J-H., Study on sensing and monitoring of sewing machine for textile stream smart manufacturing innovation, 2017 24th International Conference on Mechatronics and Machine Vision in Practice (M2VIP), Auckland, New Zealand, 2017, pp. 1-3, doi: 10.1109/M2VIP.2017.8211433.
[5] LIU T-K., CHEN C-N., KUO Y-T., KUO M-H. AND HSUEH P-W., Developing a monitoring system of production effectiveness and traceability for semi-automatic production process, 2017 International Conference on Fuzzy Theory and Its Applications (iFUZZY), Pingtung, Taiwan, 2017, pp. 1-5, doi: 10.1109/iFUZZY.2017.8311804.
[6] GIUSTI F., BEVILACQUA M., TEDESCHI S. AND EMMANOUILIDIS C., Data analytics and production efficiency evaluation on a flexible manufacturing cell, 2018 IEEE International Instrumentation and Measurement Technology Conference (I2MTC), Houston, TX, USA, 2018, pp. 1-6, doi: 10.1109/I2MTC.2018.8409677.
[7] BARKSDALE H., SMITH Q. AND KHAN M., Condition Monitoring of Electrical Machines with Internet of Things, SoutheastCon 2018, St. Petersburg, FL, USA, 2018, pp. 1-4, doi: 10.1109/SECON.2018.8478989.
[8] LEE K.T. AND MUN H.K., Real-time power monitoring using field programmable gate array with IoT technology, IET Science, Measurement & Technology, 2019, doi: 10.1049/iet-smt.2018.5692.
[9] J. UDAYANGANI, I. KARUNANAYAKA AND R. ABEYSOORIYA, Industry 4.0 Elements and Analytics for Garment Assembly Production Lines, 2019 Moratuwa Engineering Research Conference (MERCon), Moratuwa, Sri Lanka, 2019, pp. 745-750, doi: 10.1109/MERCon.2019.8818882.
[10] DAI H-N., WANG H., XU G., WAN J. AND IMRAN M., Big data analytics for manufacturing internet of things: opportunities, challenges and enabling Technologies, Enterprise Information Systems, 2020 - Issue 9-10: Cognitive Computing for Big Data Systems over Internet of Things for Enterprise Information Systems.
[11] https://www.dbi.srl/solutions/digital-business-transformation/ (10.05.2023)

THE ADVANCED TECHNOLOGY FOR COMPRESSION GARMENT DESIGN

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ABSTRACT

The correct fitting of compression clothes to the individual geometry of the patient's body is an important aspect of compression therapy to achieve the desired therapeutic success. The 4D body scanning and related software is advanced tool for measurement accuracy of body shape and size. Furthermore, the scanning allows the quick estimation the compression stockings functionality that was investigated in this work. This study is initial stage for future development of for high quality compression garments based on individual concept.

Key Words: 4D body scanning, static and dynamic position, lower leg, body size and shape, compression stocking

1. INTRODUCTION

Compression garment are skin-tight elastic garment designed to apply pressure to a certain part of the body. It is widely used in professional sports for better performance and recovery after exercise [1], the garments with a slight pressure designed are becoming more popular for body shaping purpose [2]. And of course it have been utilized for medical reasons for many years [3],[4]: in the treatment of burns (scar management), low blood pressure, muscle strains and sprains; to accelerate the healing process and prevent deep vein thrombosis, oedema etc. The compression garment should be made in huge diversity of the sizes and the shapes to follow the body`s contours and to suit different body types and parts. The performance of such product (pressure level and rigidity) depends greatly on end-use and functionality.

The correct adaptation of compression clothes to the individual geometry of the body is an important aspect both compression effect and clothes comfort [5]. Ussually, the appropriate girths and lengths are collected with a measuring tape (for example, for the leg), and then the compression garment is selected according to the compression level and the size table of the current standard [6]. Pre-sized garments available from number of commercial companies in a variety of styles and sizes for all body parts, but they do not normally fit patients perfectly. The scientists around the world are working to improve understanding of the main points of designing compression clothing [7].

With improvement 3D scanning technology, new approach to design the compression garment was developed based on virtual method [9], which has few stages. The investigation of system "body-compression garments" is the most important one and less studied despite many works in the area [8]. They are mostly focused on flattening of the 3D surface that has ‘‘negative ease’’ compared to the surface of the avatar [9] or/and create the high accuracy model to predict the pressure at the intended points on the human body [10].

The main goal of this research is study the individual geometry of the lower leg and the changes of their sizes and shapes within wearing time of stockings and different activity as well as changes in pressure occurred at the same time. The study focuses on 4D body scanning as tool for high quality personal compression garments development.

2. EXPERIMENTAL

The modular photogrammetry based 3D/4D capture and analysis system MOVE 4D [11] at ITM TU Dresden make it possible to capture body movement with frequency 20 frame per sec. Three volunteers with the same 25 hosiary size [12] were scanned.The scanning was done for control leg and within stocking wearing at standing position and different activity (Figure 1). Conventional stocking and two classes of compression stockings (I CCl and II CCl) were used. The scanning was performed just after putting on stockings (0 hour) and after 1 and 4 hour wearing. The persons did their usual ruitin activity between scanning

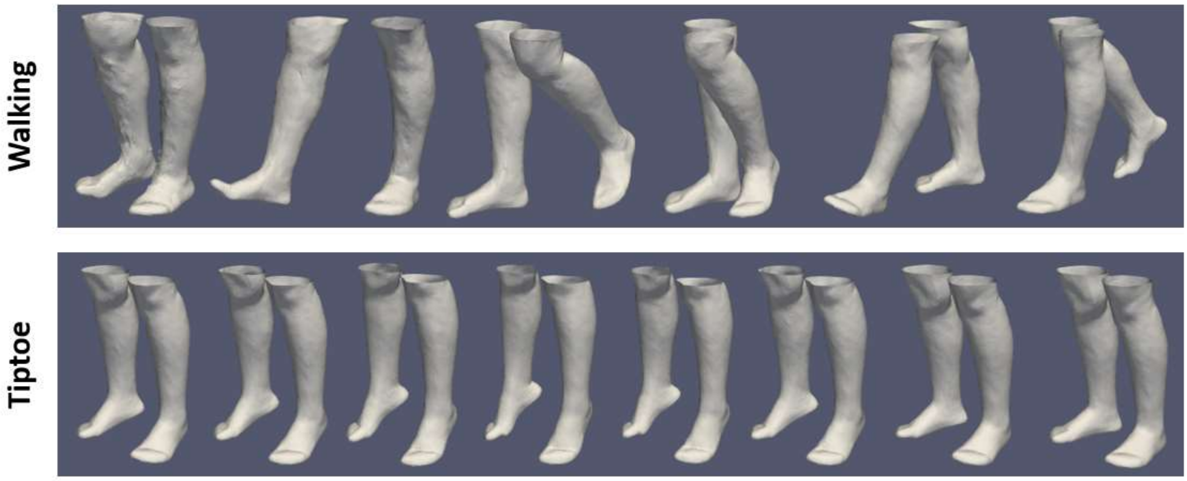


Figure 1. Examples of captions of lower leg during activity

The measurements were done between ankle (10 cm from floor) and calf (30 cm from floor). MeshLab and ParaView software was used for data processing, measuring leg sizes changes and comparisons the legs shapes.

The texsens force and pressure measuring device developed by novel.de were used. Measurement time was 60 sec (1 min) with 0.02 sec frequency.

3. RESULTS AND DISCUSSION

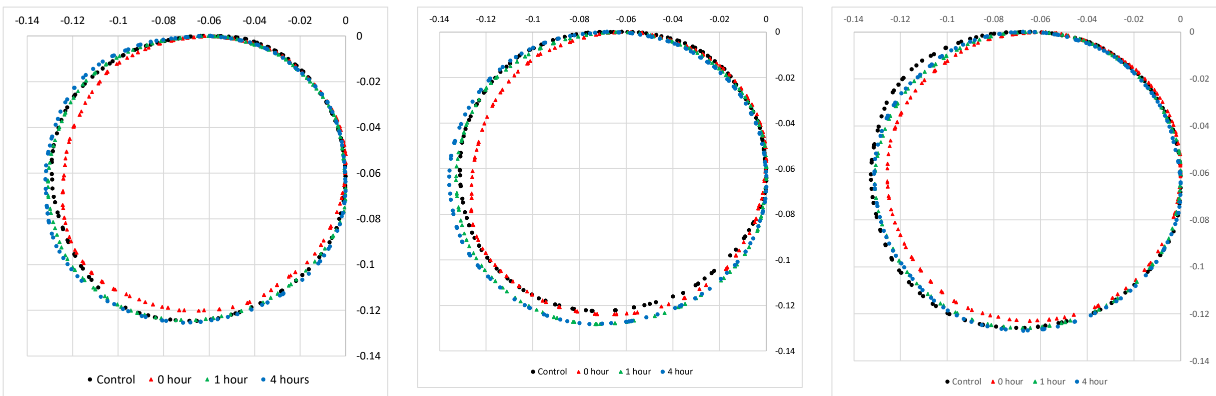
Research results of legs area at 30 cm site for the first volunteer are presented in Table 1 and in Figure 2. The area`s changes was compared to control leg. It is clear that there is increasing in leg`s size within wearing time of conventional stocking. It is due to leg`s swelling. The area increases up to 9 %, 11 %, 12 % at the calf and up to 15 %, 16 %, 18 % at the ankle for second, first and third volunteer respectively.

Just after put on compression stocking the legs area decrease due to compression effect. But within the wearing time there is different tendencies for different people. For the first and third volunteers the area increased while wearing I CCl stocking and was similar to control leg while wearing II CCl stocking. For the second volunteer the area kept size similar to control leg while wearing I CCl stocking even. Thus, I CCl stocking was recommended for second volunteer and II CCl stocking was recommended for others.

Table 1. Right leg area at 30 cm site (first volonteer)

Activity	Time	Conventional		I CCl		II CCl	
		S [cm^2]	Δ [%]	S [cm^2]	Δ [%]	S [cm^2]	Δ [%]
Static position	Control	119	–	128	–	134	–
	0 hour	119	0	126	-1.9	124	-7.9
	1 hour	130	9.1	136	6.3	131	-2.1
	4 hours	133	11.1	138	7.5	131	-2.4
Walking (max value)	Control	119	–	128	–	129	–
	0 hour	119	0	126	-1.6	126	-2.3
	1 hour	130	9.2	133	3.9	127	-1.6
	4 hours	132	10.9	135	5.5	131	1.6
Tip toe (max value)	Control	118	-	122	-	128	-
	0 hour	118	0	121	-0.8	123	-3.9
	1 hour	127	7.6	130	6.6	127	-0.8
	4 hours	128	8.5	131	7.4	127	-0.8

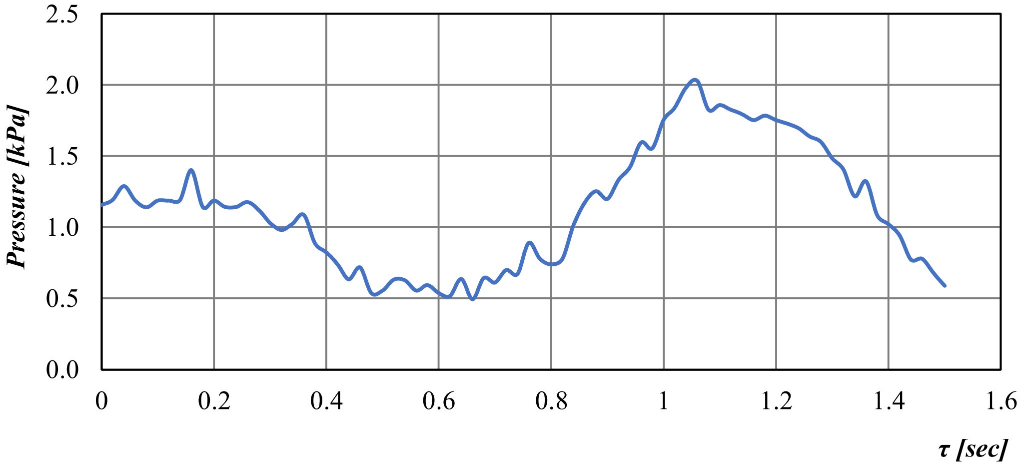
The legs scans and appropriate software give quick compare of legs shape during wearing time and different activity. The evaluation can be done not only by leg area at certain cite, but by the cross-sectional contours (Figure 2) and circumferences as well. It allows evaluate legs part changed more and even calculate the curvature radius.



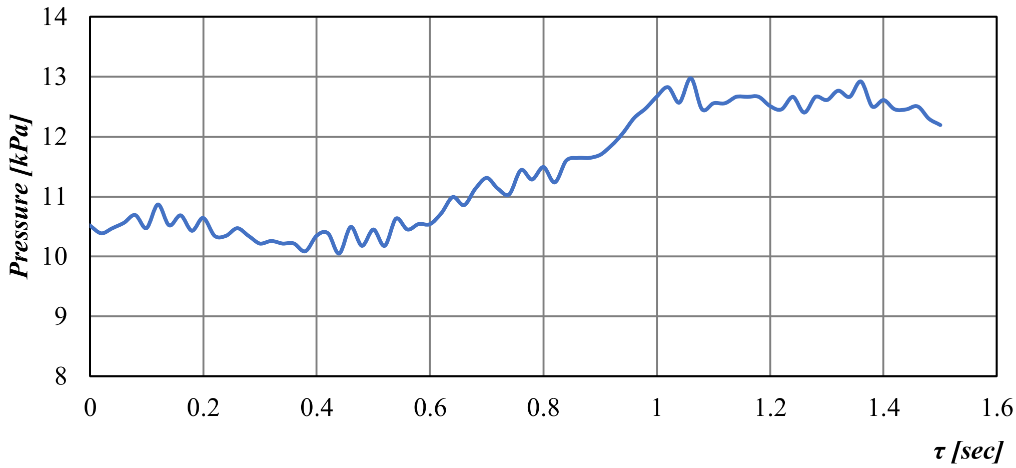
a. Conventional b. I CCl c. II CCl

Figure 2. Changes in the right leg`s shape at 30 cm level at the static position

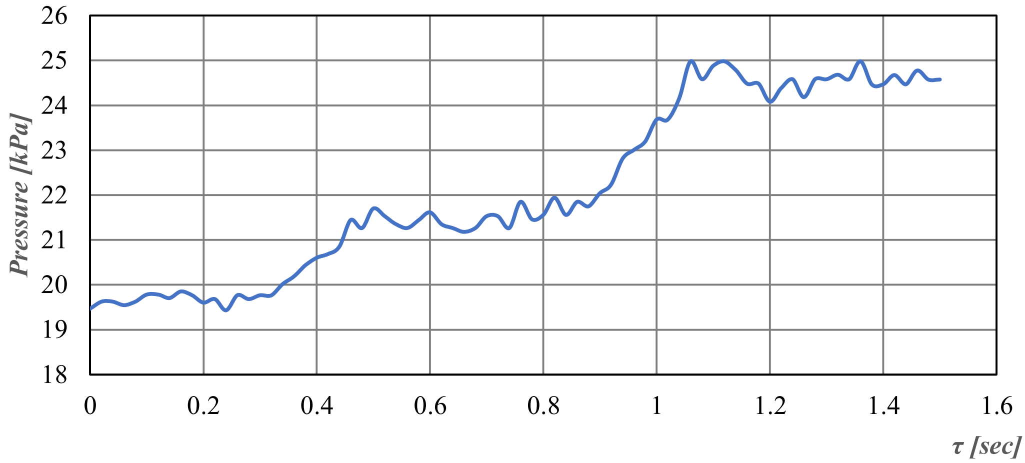
The leg size and shape changes not only during time but during different activity as well. The plot in Figure 4 presents results of changes in leg girth at 30 cm level during standing up to tip toe position. The maximal difference is 7 mm that is 1.8 %. This change leads to changes in stocking`s pressure on lower limb (Figure 3).



a. Conventional stocking



b. I compression class



c. II compression class

Figure 3. Pressure at 30 cm level within standing up to tip toe position (0 hour)

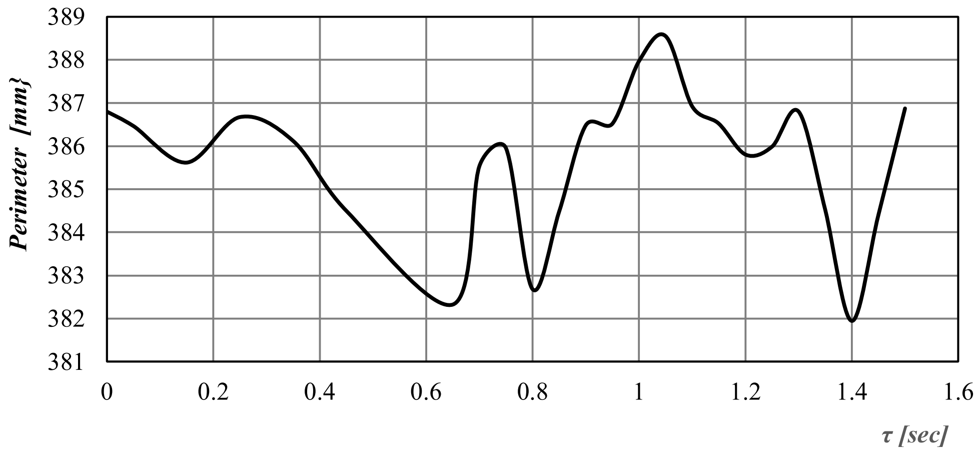


Figure 4. Changes in the right leg`s girth at 30 cm level within standing up on tip toe

The study results and scanned legs are the basis for development of graduated compression stocking design on individual concept.

4. CONCLUSIONS

The research results show that changes in leg size (circumferences and areas) leads to changes in pressure level delivered by stockings. By processing data it was clarified the compression stocking of which class more effective and more useful for scanned person. It could be conclude that the scanning allows the quick estimation the compression stockings functionality. The avatar of certain person and the real data of his sizes are the initial point for individual stocking creation and it will be followed by development a tool for high accuracy ready-to-wear compression garments design.

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5. REFERENCES

[1] ENGEL, F., SPERLICH, B., editors. Compression garments in sports: Athletic performance and recovery. Geneva, Switzerland: Springer International Publishing; 2016 Jul 12. https://doi.org/10.1007/978-3-319-39480-0
[2] YAMADA, T., MATSUO, M. Clothing Pressure of Knitted Fabrics Estimated in Relation to Tensile Load Under Extension and Recovery Processes by Simultaneous Measurements. Textile Research Journal, 2009, vol. 79, no 11, pp: 1021-1033. doi:10.1177/0040517508099387
[3] XIONG, Y., TAO, X. Compression Garments for Medical Therapy and Sports. Polymers, 2018, vol. 10, no 6, 663, pp: 1-19. https://doi.org/10.3390/polym10060663
[4] GOKARNESHAN, N. Design of compression/pressure garments for diversified medical applications. Biomedical Journal of Scientific & Technical, 2017, vol. 1, no 3, pp: 1-8. DOI:10.26717/BJSTR.2017.01.000309
[5] ABOALASAAD, A.R.R., KOLČAVOVÁ, B.S. and BERK, G.G. Effect of Compression Bandages on Muscle's Behavior, 18th World Textile Conference (AUTEX 2018) 20–22 June

2018, Istanbul, Turkey, IOP Conference Series: Materials Science and Engineering. 2018, vol. 460, 012034 DOI 10.1088/1757-899X/460/1/012034

[6] RAL GZ 387-1: 2008. Medical compression hosiery. Quality assurance. Deutsches Institut F. Guetesicherung und Kennzeichnung

[7] LIU, R., GUO X., LAO T.T. and LITTLE T. A critical review on compression textiles for compression therapy: Textile-based compression interventions for chronic venous insufficiency. Textile Research Journal, 2017, vol. 87, no 9, pp: 1121-1141. doi:10.1177/0040517516646041

[8] TYURIN, I., GETMANTSEVA, V. and ANDREEVA, E., 3A1_0366_ The finite-element modelling of compression sportswear, Autex 2019 : 19th World Textile Conference : Textiles at the crossroads, 11-15 June 2019, Ghent, Belgium, Proceedings, 2019, 2. https://openjournals.ugent.be/autex/article/id/63797/

[9] KUZMICHEV, V.E., TISLENKO, I.V. and ADOLPHE D.C. Virtual design of knitted compression garments based on bodyscanning technology and the three-dimensional-to-two-dimensional approach, Textile Research Journal, 2019, vol. 89, no 12, pp: 2456-2475. doi:10.1177/0040517518792722

[10] JARIYAPUNYA N., and MUSILOVÁ, B. Predictive modelling of compression garments for elastic fabric and the effects of pressure sensor thickness, The Journal of The Textile Institute, 2019, vol. 110, no 8, pp: 1132-1140, DOI: 10.1080/00405000.2018.1540285

[11] KUEHN, T. and KYOSEV, Y. 4D Scanning of Clothed Humans - Preliminary Results. In Proc. of 3DBODY.TECH 2021 - 12th Int. Conf. and Exh. on 3D Body Scanning and Processing Technologies, Lugano, Switzerland, 19-20 Oct. 2021, #25, https://doi.org/10.15221/21.25

[12] RAL GZ 387-1: 2008. Medical compression hosiery. Quality assurance. Deutsches Institut F. Guetesicherung und Kennzeichnung.

TEXTILE REINFORCED CONCRETE: A COMPREHENSIVE REVIEW

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ABSTRACT

Textile Reinforced Concrete (TRC) is an innovative building material that combines the durability of concrete with the strength, flexibility, and versatility of textiles. This review presents an analysis of TRC, covering its composition and manufacturing methods, mechanical properties, durability, and potential applications. It concludes with a discussion on some current challenges and future prospects of TRC. The review aims to enhance existing knowledge and highlight research advances in the area by providing valuable information for researchers and engineers in the textile and construction fields.

Keywords: Textile reinforced concrete; fiber; textile; matrix

1. COMPOSITION AND MANUFACTURING METHODS

TRC is generally manufactured by impregnating the textile reinforcement material with the concrete matrix. TRC consists of a combination of cementitious materials, fine and coarse aggregates, water, and textile reinforcement. The composition may vary based on the specific project requirements and desired performance characteristics. In TRC, technical textiles are used as reinforcement to carry the tensile forces. This eliminates the need for steel reinforcement in the concrete. As can be seen in Figure 1, TRC combines essential elements from both traditional steel-reinforced concrete and chopped fiber-reinforced concrete [1].

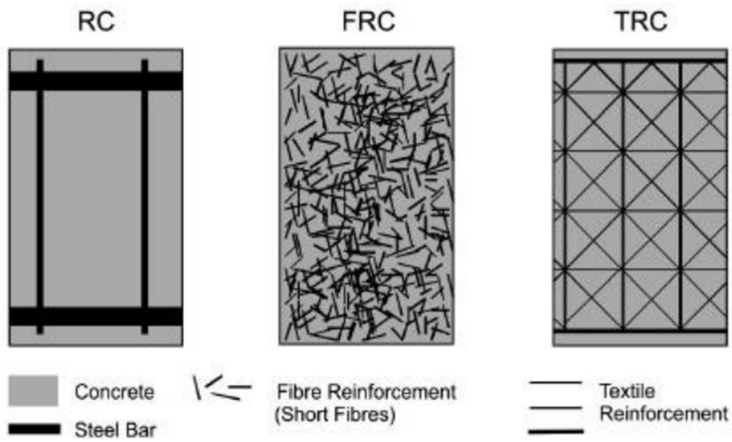

Figure 1: Comparison between different systems of reinforcement [2]

Cementitious materials, aggregates, water, textile reinforcement, adhesive or matrix: the proportions and mix design of the components mentioned above are crucial to achieve the desired mechanical properties and performance of TRC. Factors such as the specific application, required strength, durability, and environmental conditions need to be considered during the mix design process. It is important to follow recognized standards and guidelines to ensure a well-balanced and optimized composition of TRC [1].
The choice of fiber type, fiber content, and fiber orientation within the textile reinforcement depends on a number of elements, including the desired performance, structural requirements, and

environmental circumstances. To ensure the TRC performs at its best and lasts as long as possible, the fibers should be chosen in compliance with applicable norms and rules.
The textile reinforcement part consists of various types of fibers, including glass, carbon, aramid, basalt [3], and natural fibers, such as jute, flax, or hemp [4] (see Figure 2). These fibers are generally used in two forms: as staple fibers or as fabric [5].

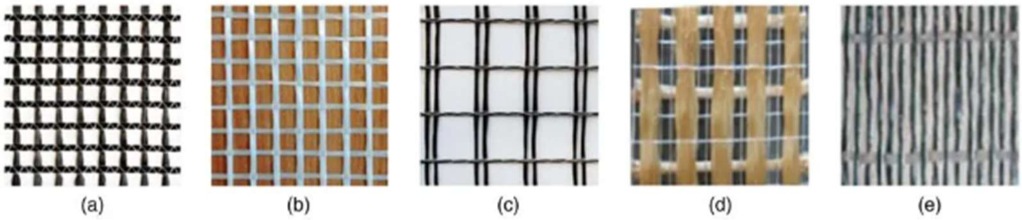

Figure 2. Textile fibre reinforcements: (a) carbon-fibre textile; (b) basalt-fibre textile; (c) glass -fibre textile; and (d) PBO-fibre textile [6]

Here are some commonly used fibers in textile reinforcement concretes:

Carbon Fibers
Carbon fibers are high-strength and lightweight fibers that provide excellent mechanical properties to TRCs. They have a high modulus of elasticity, low thermal expansion coefficient, and good resistance to chemical corrosion. The carbon fibers in carbon fiber reinforced concrete serve to provide the smart action as well as improved structural performance. Furthermore, the addition of carbon fibers to concrete can be achieved by simply using the conventional stone concrete mixer. The addition of carbon fibers to concrete increases the flexural strength, flexural toughness and freeze-thaw durability, and to decrease the drying shrinkage and the electrical resistivity [7].

Basalt Fibers
Basalt fibers are a type of reinforcing material that can be used in textile reinforced concrete (TRC). Zhou et al. conducted an experimental study on the basic mechanical properties of Basalt Fiber Reinforced Concrete (BFRC). The toughness and crack resistance performance of BFRC were evaluated using fracture energy, improved toughness parameters, and characteristic length. The results showed that basalt fiber significantly improves the toughness and crack resistance performance of concrete.
Basalt fibers have high interfacial bond strength with concrete, which increases the reinforcing effect of fiber-reinforced concrete. The fibers are perfectly distributed in the concrete, limiting the ability of the fibers to stretch. This combination of basalt fibers and concrete improves the overall mechanical properties of the composite material. Basalt fiber and carbon woven fabrics, both of which are widely utilized, are shown in Figure 3. Basalt fibers have drawn more attention in recent years because of their superior mechanical qualities [8].

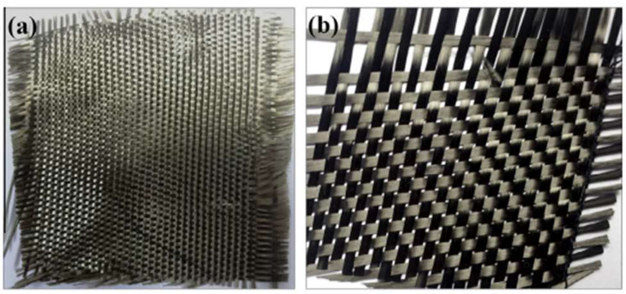

Figure 3. Woven fabrics: (a) basalt fiber fabric, (b) carbon fiber fabric [8]

Glass Fibers

Glass fibers are widely used in TRCs due to their relatively low cost and good mechanical properties. The combination of glass fibers with a cement-based matrix helps maintain their respective physical and chemical attributes, resulting in the creation of TRCs with diverse physical and mechanical properties [9]. In general terms, glass fibers play a role in improving the bending strength of TRCs, while cement based matrix provides the load transfer between the fibers. This synergy between glass fibers and the cement matrix allows for the customization of TRCs to achieve specific performance objectives [1].

Aramid Fibers:

Aramid fiber was the first organic fiber used as reinforcement in advanced composites with high enough tensile modulus and strength. When compared on an equal weight basis, aramid fibers surpass both steel and glass fibers in terms of mechanical properties. Particularly, aramid fibers possess inherent resistance to heat and flames, ensuring that these exceptional properties remain intact even under high-temperature conditions [10].

Natural Fibers

Natural fibers reinforced polymer composite materials are of great interest owing to their eco-friendly nature, lightweight, life-cycle superiority, biodegradability, low cost, and noble mechanical properties. Natural fibers, including jute, flax, hemp, and sisal, are gaining attention as sustainable alternatives for textile reinforcement in concrete [11].

2. MECHANICAL PROPERTIES OF TRC

Textile reinforced concrete (TRC) is a composite material consisting of concrete embedded with a textile reinforcement typically made of high-strength fibers such as glass, carbon, or basalt. These fibers improve the structural integrity of the TRC, allowing it to effectively withstand tensile, bending and impact loads. TRC's outstanding mechanical properties make it well suited for a variety of structural applications. Extensive research has been done on the mechanical properties of TRC, which consistently demonstrates its outstanding performance [12].

TRC exhibits significantly higher tensile and flexural strengths compared to conventional concrete, demonstrating its structural improvement potential. In addition, TRC sets it apart from conventional plain concrete by exhibiting exceptional impact resistance, a property critical to ensure both durability and longevity. In particular, it has been observed that increasing the fiber content or using high performance concrete mixes can further improve the mechanical properties of TRC. For example, Vignan et al. (2020) observed a 10% increase in the tensile strength and flexural strength of TRC when the fiber content was increased from 2% to 4% [13].

The tensile strength of TRC can reach 10 times that of standard concrete, and its bending strength can reach up to 5 times that of conventional concrete. In addition, TRC exhibits significantly improved fatigue behavior compared to conventional concrete.

Valeri et al. (2020) discovered that textile-reinforced TRC specimens exhibit superior energy absorption and greater damage resistance compared to their non-textile-reinforced counterparts. Moreover, their findings revealed that further improvements in impact resistance could be achieved by increasing the fiber content and concrete strength and adopting a lower impact loading rate. Impact resistance was found to be affected by variables such as textile reinforcement type and concrete mix design. This extensive research underlines TRC's outstanding mechanical properties, solidifying its position as a high-performance building material [14].

Durability

Similar to mechanical attributes, TRC's durability is influenced by various factors, encompassing textile reinforcement type, fiber content, resin variety, TRC thickness, and water pressure. The choice of impregnation material for TRC also plays a pivotal role in its durability.
TRC amalgamates textile mechanical properties with concrete's durability and load-bearing capacity. Given its practical application, long-term durability is a crucial consideration. The complex interplay of factors affecting TRC's efficacy is an ongoing area of research.

In essence, TRC stands as a robust material that can withstand diverse conditions [15]. To enhance TRC's durability, strategies encompass advanced concrete mixes, corrosion-resistant textile reinforcements, protective coatings, and cathodic protection. Ongoing research is exploring TRC's long-term endurance, considering environmental factors, impregnation materials, and prestressing. While TRC exhibits encouraging results in terms of durability, load-bearing capacity, and structural performance, further inquiry is essential to fully unravel and optimize its long-term durability for practical applications [16].

3. APPLICATIONS

Textile-reinforced concrete (TRC) finds multiple applications in construction. It serves as a retrofit solution for existing steel-reinforced concrete buildings, such as the restoration of structures on the National Register of Historic Places. TRC acts as a reinforcement layer for pre-existing structural elements and new projects alike. (Fig. 4) Its thin, high tensile strength layers make it a suitable choice for shell construction [17].

Figure 4. Reinforcement applications of textile reinforced structures [18]

TRC extends beyond buildings, bolstering masonry constructions and roadway pavements. It proves valuable for structural maintenance tasks, including strengthening, sealing, and protecting existing structures. Its adaptability to specific building requirements is an added advantage [19].

In summary, TRC serves various purposes in construction by reinforcing structural elements and retrofitting existing structures. Its compatibility with shell construction, robust tensile strength, and adaptability to architectural needs set it apart. Ongoing research aims to enhance TRC functionality and predict its mechanical behavior.

4. CONCLUSION AND FUTURE PROSPECTS

In the area of textile-reinforced concrete (TRC), significant steps have been made in terms of results and future expectations. Extensive research has revealed the impressive mechanical properties of TRC, showcasing its enhanced tensile, flexural, and impact strengths when compared to conventional concrete. These findings underscore TRC's potential for structural reinforcement and retrofitting applications.

Looking ahead, the future of TRC holds promise in multiple directions. Continued research is anticipated to refine TRC's composition, further enhancing its durability and load-bearing capabilities. Moreover, ongoing studies aim to predict TRC's long-term performance under varying environmental conditions, bolstering its practical utility in sustainable construction.
In essence, TRC's remarkable present achievements are shaping a future that aspirates to elevate its mechanical properties, expand its application domains, and solidify its standing as a cutting-edge solution for sustainable and resilient construction practices.

REFERENCES

[1] CHERIF, CHOKRI. "Textile materials for lightweight constructions." *Technol Methods Mater Proper* (2016).
[2] ALRSHOUDI, FAHED ABDULLAH S. *Textile Reinforced Concrete: Design Methodology and Novel Reinforcement*. Diss. University of Leeds, 2015.
[3] V. AFROUGHSABET, L. BIOLZI, T. OZBAKKALOGLU, High-performance fiber-reinforced concrete: a review, J. Mater. Sci. 51 (2016) 6517–6551. https://doi.org/10.1007/s10853-016-9917-4.
[4] L. YAN, B. KASAL, L. HUANG, A review of recent research on the use of cellulosic fibres, their fibre fabric reinforced cementitious, geo-polymer and polymer composites in civil engineering, Compos. Part B Eng. 92 (2016) 94–132. https://doi.org/10.1016/j.compositesb.2016.02.002.
[5] S.G. VENIGALLA, A.B. NABILAH, N.A.M. NASIR, N.A. SAFIEE, F.N.A. ABD AZIZ, Textile-Reinforced Concrete as a Structural Member: A Review, Buildings. 12 (2022). https://doi.org/10.3390/buildings12040474
[6] RAOOF, SAAD M., LAMPROS N. KOUTAS, AND DIONYSIOS A. BOURNAS. "Bond between textile-reinforced mortar (TRM) and concrete substrates: Experimental investigation." *Composites Part B: Engineering* 98 (2016): 350-361.
[7] CHEN, PU-WOEI, AND DEBORAH DL CHUNG. "Carbon fiber reinforced concrete for smart structures capable of non-destructive flaw detection." *Smart Materials and Structures* 2.1 (1993): 22.
[8] DHAND, VIVEK, ET AL. "A short review on basalt fiber reinforced polymer composites." *Composites Part B: Engineering* 73 (2015): 166-180.
[9] BAHADUR, A. M. E. D., AND NIHAT KABAY. "Glass fibre reinforced precast concrete containing high content pozzolanic materials." *Sigma Journal of Engineering and Natural Sciences* 37.2 (2019): 675-686.
[10] ERTEKIN, MUSTAFA, AND ERHAN KIRTAY. "Tensile properties of some technical core spun yarns developed for protective textiles." *Textile and Apparel* 25.2 (2015): 104-110.
[11] KHALID, MUHAMMAD YASIR, ET AL. "Natural fiber reinforced composites: Sustainable materials for emerging applications." *Results in Engineering* 11 (2021): 100263.
[12] RAWAT, PRASHANT, ET AL. "A state-of-the-art review on mechanical performance characterization and modelling of high-performance textile reinforced concretes." *Construction and Building Materials* 347 (2022): 128521.
[13] VIGNAN, G. SIVA, GOURISHETTY RUTHVIK, AND CHALLA DATTA KARTHIK. "Study on Mechanical Properties of Textile Reinforced Concrete." *i-Manager's Journal on Structural Engineering* 9.2 (2020): 25.

[14] VALERI, PATRICK, MIGUEL FERNÀNDEZ RUIZ, AND AURELIO MUTTONI. "Tensile response of textile reinforced concrete." *Construction and Building Materials* 258 (2020): 119517.
[15] KONG, KANHCHANA, ET AL. "Comparative characterization of the durability behaviour of textile-reinforced concrete (TRC) under tension and bending." *Composite Structures* 179 (2017): 107-123.
[16] GHIASSI, BAHMAN, AND ALI DALALBASHI. "Durability of Textile Reinforced Concrete: Existing Knowledge and Current Gaps." *Applied Sciences* 11.6 (2021).
[17] RAMPINI, MARCO CARLO, ET AL. "Mechanical behaviour of TRC composites: Experimental and analytical approaches." *Applied Sciences* 9.7 (2019): 1492.
[18] https://www.karlmayer.com/en/applications/technical-textiles/textile-reinforced-concrete/
[19] ORLOWSKY, JEANETTE, MARKUS BEßLING, AND VITALII KRYZHANOVSKYI. "Prospects for the Use of Textile-Reinforced Concrete in Buildings and Structures Maintenance." *Buildings* 13.1 (2023): 189.

TEA TREE OIL LOADED NANOFIBERS FOR WOUND DRESSING APPLICATIONS

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ABSTRACT

In this study, antibacterial nanofibrous surfaces were fabricated using thermoplastic polyurethane and tea tree oil by the electrospinning method. Morphological (Scanning Electron Microscope) and biological (antibacterial activity and cytotoxicity) characterization studies were carried out. The results demonstrate that tea tree oil can be used to confer antibacterial activity of TPU nanofibers.

Key Words: Essential oil, nanofiber, electrospinning, antibacterial, cytotoxicity

1. INTRODUCTION

The nanofibrous materials used in functional textile materials is becoming increasingly important, exclusively by means of their characteristics such as superior porosity, large surface area, and the usability of several polymer types [1]. There are many different techniques to fabricate of nanofibrous materials, such as electrospinning, template synthesis, phase separation, self-assembly, and drawing. Electrospinning is a widely used method for nanofiber production since it has many advantages, such as low cost and easy to apply [2].

Electrospun nanofibers demonstrate a novel category of materials that show great potential in various biomedical applications including drug delivery, tissue engineering, and wound healing. Electrospun nanofibrous surfaces can gain functional properties due to the type of polymer used or the active ingredients added to the polymer solution. [3]. Since increasing environmental and health problems in recent years, the use of natural ingredients has become more remarkable for the functionalization of electrospun nanofibers. Essential oils which are complex substances of natural volatile compounds that can functionalize the nanofibrous materials due to their antimicrobial, antifungal and anti-inflammatory etc. properties.

Tea tree oil, one of the essential oils, has high antimicrobial properties and has become used in many different areas such as packaging, filtration and medical textiles [4]. Tea tree oil (*Melaleuca alternifolia*) has an antimicrobial effect due to the terpinen-4-ol chemo types, 1,8-cineol and many other compounds in it [5]. However, the skin irritation can limit its direct topical application as a wound-healing material. Thus, in this study, tea tree oil loaded nanofibrous surfaces were produced to obtain antibacterial materials for wound dressing applications.

2. EXPERIMENTAL

Thermoplastic polyurethane was selected as polymer in the nanofiber production. The spinning solutions were prepared by adding tea tree oil to the polymer solution, and then nanofibers were produced by electrospinning method. Characterization of the nanofibrous surfaces were evaluated by scanning electron microscopy (SEM). The antibacterial activities and the cytotoxicity properties were evaluated by disk diffusion and extraction methods, respectively.

3. RESULTS AND DISCUSSION

The surface morphology of the nanofibers was investigated by SEM imaging. Bead free and uniform photochromic nanofibers were produced (Figure 1). Mean fiber diameters of the nanofibers were approximately 600-700 nm.

Neat nanofibers Tea tree oil loaded nanofibers

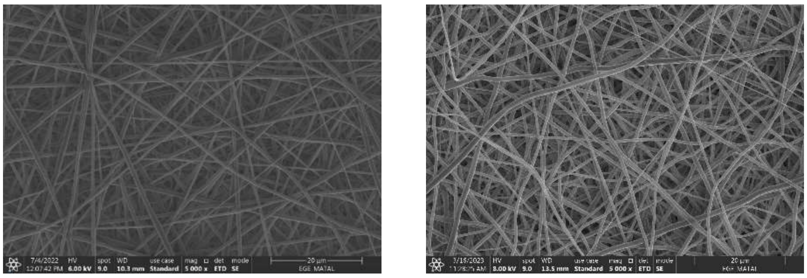

Figure 1. SEM images of the nanofibers

As a result of the antibacterial test, it was observed that the tea tree loaded nanofibers showed antibacterial activity against *S. aureus* and *E. coli* bacteria (Figure 2). In addition, in cytotoxicity tests, no toxicity was observed after 24 and 48 hours of incubation of the nanofiber surface containing tea tree oil.

S. aureus *E. coli*

Figure 2. Antibacterial activity test results of the tea tree loaded nanofibers

4. CONCLUSION

In this study, tea tree oil loaded nanofibers were produced by electrospinning method. Based on the SEM analyses, it was evaluated that bead free and uniform nanofibers were obtained. it was observed that smooth nanofibers could be obtained, these nanofibrous surfaces had antibacterial properties and did not show cytotoxicity. Thus, it is thought that tea tree oil loaded nanofibrous surfaces may have a potential to be used in wound dressing applications.

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5. REFERENCES

[1] AKDUMAN, Ç., AKÇAKOCA KUMBASAR, E.P. Chapter 2: Electrospun polyurethane nanofibers. In Aspects of Polyurethanes, Edited by F. Yılmaz. London: IntechOpen, 2017, pp. 17-52.
[2] GANESAN, A., JAIGANESH, R. A review on fabrication methods of nanofibers and a special focus on application of cellulose nanofibers. Carbohydrate Polymer Technologies and Applications, 2022, vol. 4, no. pp 1-14.
[3] TORRES-GINER, S., PÉREZ-MASIÁ, R., LAGARON, J. M. A review on electrospun polymer nanostructures as advanced bioactive platforms. Polymer Engineering & Science, 2016, vol. 56, no. 5, pp 500-527.
[4] LEE, J. Y., LEE, J., KO, S. W., SON, B. C., LEE, J. H., KIM, C. S., PARK, C. H. Fabrication of antibacterial nanofibrous membrane infused with essential oil extracted from tea tree for packaging applications. Polymers, 2020, vol. 12, no. 1, pp. 1-9.
[5] UPADHYAY, P., MALIK, P., UPADHYAY, S. Tea tree (Melaleuca alternifolia) essential oil concentration in microemulsion with antibacterial and antifungal activity: An overview. Current Drug Therapy, 2023, vol. 18, no. 4, pp. 298-311.

THE PRESSURE CHARACTERISTICS OF ELASTIC WARP KNITTED FABRICS

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ABSTRACT

Elastic textile materials such as corsets, bandages, posture correctors, wristbands, etc. are widely used for the treatment of some medical problems. These elastic textile products must have various physical and mechanical properties in order not to restrict freedom of movement, to provide comfort to the user, and to provide the required level of compression. In this study, the compressive performances of elastic warp knitted fabrics used for medical purposes were investigated. In this context, elastic warp knitted samples suitable for medical use were produced with different guide bar yarn arrangements and weft yarn materials. According to the obtained results, elastic fabrics produced from natural fibers exert higher pressure than those produced with polyester fibers, and the pressure values also increase with the increase in the amount of elastomer in the structure. Also, for all weft yarn materials, the pressure values applied by the fabric samples decrease as the elongation of the fabric increases. Additionally, various equations with high accuracy were calculated between the pressure and studied parameters.

Key Words: Warp knitting, medical textiles, laid-in yarn, elastomer threading, compression

1. INTRODUCTION

Medical textiles are an essential sub-group of technical textiles. With the use of textile products for medicinal purposes, diseases could be prevented or healed. As the life expectancy of humans extends and individuals become less active, medical conditions regarding the musculoskeletal system have become prevalent. For the treatment of these medical problems, elastic textile materials, such as corsets, bandages, posture correctors, wristbands, etc., are suggested by physicians. Elastic knitted fabrics are widely used in tight-fitting garments and supportive medical products because of their high elastic recovery, shape retention, and conformity with the shape of the body [1].

The main feature of medical fixing and compression devices is the use of elastic textile material, in particular knitted fabric. The product does not restrict movement freedom and provides the required compression level [2]. Elastic bandages, produced on crochet machines, are stretchable textile surfaces used to create localized pressure. They must have different levels of elasticity up to the usage area.

Compression, either active or passive, mainly aims to reduce or control venous reflux and peripheral oedema, by applying bandages or stockings [3]. The success of a bandage depends on the appropriate selection and use of four properties of compression bandages, namely, pressure, layers, components, and elastic properties (P-LA-C-E) [4]. The tension level of bandages depends on the type of construction, yarn material, and/or elastomer yarn amount in the fabric [5]. These products are expected to fulfill three criteria given below. They should have proper elongation and elasticity characteristics [2], apply a suitable amount of pressure onto the body, and provide comfort. The effectiveness of compression bandaging depends on the degree of pressure provided

[6]. The pressure created by a bandage is determined by the tension in the fabric that is exerted when the bandage is applied, the radius of curvature of the limb, and the width and number of layers applied. In a recent consensus meeting, a new classification system for compression bandages with four pressure ranges was recommended. The compression pressure of<20 mmHg has been categorized as mild, 20 to <40 mmHg as medium, 40 to <60 mmHg as strong, and ≥60 mmHg as very strong [4]. It was shown that high compression is more effective than low.

According to Keller et al [7], self-assessment and self-control without an objective device to measure the pressure are not sufficient to evaluate bandaging skills. Karafa and Karafova [8] investigated the healing time of a venous leg ulcer that underwent routine pressure control with the Kikuhime device at each bandage renewal. They found that the healing time of a wound with an area of approximately 20 cm^2 could be reduced to four weeks by applying bandages twice a day during the first week of treatment. They suggested that bandage pressure plays an important role in treatment and that some reliable tools such as the Kikuhime device should be used to determine the pressure value.

Laplace's Law is widely used to predict the pressure created by a compression product immediately after application. The mechanics can be described by the following equation:

$$P = T/R \tag{1}$$

where P – pressure, Pa;
T – tension of material, N;
R – radius of surface (cylinder), m.

Over the past decades, this equation has undergone several revisions and refinements for use in predicting static contact pressure [9], but the tension of the material and the curvature`s radius remain the most influential factors. Therefore, an important step in the investigation of elastic materials is the study of the stress-strain system [10].

This study aims to determine the pressure performances of elastic warp-knitted fabrics used for medical purposes. In this context, the effect of weft yarn material and threading of elastomer on the pressure performances of the elastic warp knitted fabrics. Thus, by determining the least set of elastomers and the appropriate knit structure to provide the expected pressure level after experiments, the elastic fabric that has the best performance properties and the lowest cost will be produced.

2. MATERIALS AND METHODS

2.1. Materials

Totally 13 fabric specimens were produced on a 15-gauge crochet knitting machine with 4 guide bars using 4 different threading orders for elastomer yarn and 4 different yarn materials for in-lay transverse weft yarns. Yarn feeding tension, fabric takedown load, and the number of used needles were kept constant for all specimens.

The closed pillar stitches (Figure 1.a) were knitted using 16.7 tex polyester threads which were fed from a fully threaded guide bar for the ground. Pillar stitches are used mainly as a ground for structures, connected by weft yarns [11, 12]. The 0.8 mm diameter polyurethane elastomer thread was longitudinally fed into the knitting zone with a preliminary elongation of 270 % to provide the functional properties of fabrics (Figure 1.b). To determine the influence of the guide bar threading arrangement on the fabric structure and parameters, four different polyurethane threading options were used as given in Table 1. The set of elastomer was calculated by dividing the number of elastomer by the total number of threads in a repeat. The other two guide bars (Figure 1.c and 1.d) were used to insert weft yarns in the transverse direction on both sides of the polyurethane threads. Polyester, cotton, and linen yarns were used as weft yarns to create elastic fabrics with various raw material compositions.

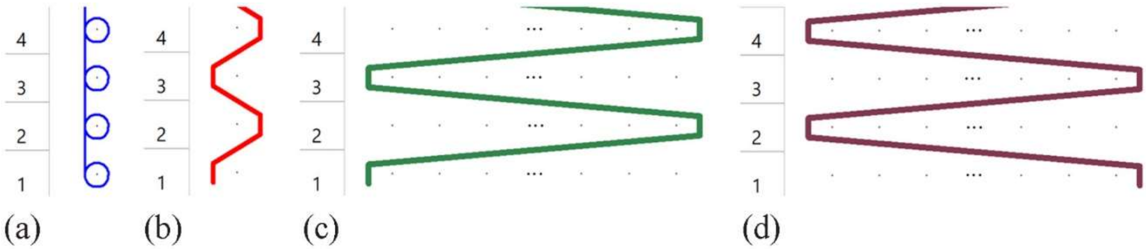

Figure 1. Lapping diagram: (a) first guide bar (pillar stitch), (b) third guide bar (elastomer thread), and (c) and (d) second and fourth guide bars (weft yarns).

Table 1. Threading of elastomer yarn and type of weft yarn materials

Variant	Threading	Set of Elastomer (%)	Type of materials
I PET 2	1 in, 1 out	50	33.4 tex polyester (96 filaments) 2 ply
II PET 2	2 in, 1 out	67	33.4 tex polyester (96 filaments) 2 ply
III PET 2	3 in, 1 out	75	33.4 tex polyester (96 filaments) 2 ply
IV PET 2	Full	100	33.4 tex polyester (96 filaments) 2 ply
I PET 4	1 in, 1 out	50	33.4 tex polyester (96 filaments) 4 ply
II PET 4	2 in, 1 out	67	33.4 tex polyester (96 filaments) 4 ply
III PET 4	3 in, 1 out	75	33.4 tex polyester (96 filaments) 4 ply
IV PET 4	Full	100	33.4 tex polyester (96 filaments) 4 ply
I COT	1 in, 1 out	50	29.0 tex cotton yarn 4 ply
II COT	2 in, 1 out	67	29.0 tex cotton yarn 4 ply
III COT	3 in, 1 out	75	29.0 tex cotton yarn 4 ply
IV COT	Full	100	29.0 tex cotton yarn 4 ply
II LIN	2 in, 1 out	67	29.0 tex linen yarn 4 ply

2.2. Methods

In our previous studies, the structural properties (mass per unit area, stitch density, and thickness), elastic behavior, and thermal comfort properties of the specimens (fabric density, air permeability, thermal conductivity, thermal resistance, and water vapour resistance) were determined [11, 13]. Investigating the effect of elastomer threading arrangement and weft yarn material on compression characteristics of the specimens was aimed in this research. The pressure exerted by elastic textile materials depends on their structural properties such as raw material, fabric structure, elongation, elasticity, and additionally the diameter of the usage area. For the pressure measurement, the fabric specimens were cut to the size of 26x5.5 cm and each specimen was sewn at the short edges to give a ring form. The fabric ring was stretched and placed on a metal disk. The pressure exerted by the fabric on the metal disk was measured with the help of a Kikuhime pressure monitor (Figure 2). To ensure the different pressure levels, three measurement disks with varied diameters (8, 9, and 10 cm) were used. With these disks, the fabric extension values were measured as 8%, 20%, and 32%, respectively.

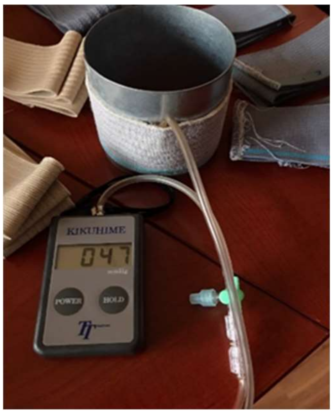

Figure 2. Measurements on Kikuhime pressure monitor

In our previous research [11], the elastic behaviours of fabrics were studied using Zwick Roell Z010 instrument according to BS EN ISO 20932-1. The fabric`s specimens were subjected to five cycles of 35 N loading. Four parameters were obtained: elongation S, permanent deformation C, recovered elongation D, and elastic recovery R. In this study, the force-elongation graphs in Figure 3 for the first loading cycle were used to determine the force values that should be applied to the fabrics to obtain 8%, 20%, and 32% extensions.

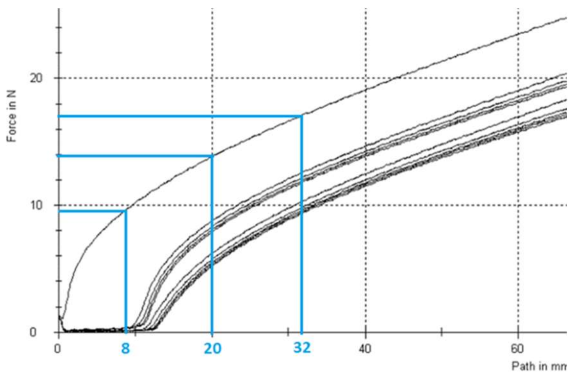

Figure 3. Force determination at different extensions according to the first cycle on Zwick Roell Z010 test

3. RESULTS

The results of pressure measurements are given in Table 2. Elongation and elastic recovery (BS EN ISO 20932-1) values for the specimens found in the previous study [11] were given in the same Table 2.

Table 2. Properties of elastic warp knitted fabric.

Variant	Set of Elastomer (%)	Pressure at different extension values P (mmHg)			Force at different extension values F (N)			Elongation at 5th cycle of 35 N loading S (%)	Elastic recovery R (%)
		8%	20%	32%	8%	20%	32%		
PET 2	50	13	24	32	3.33	6.33	8.17	206 ± 1	97.1
PET 2	67	17	32	41	4.84	8.44	10.63	192 ± 3	97.4
PET 2	75	19	37	48	5.16	9.35	12.10	182 ± 1	98.0
PET 2	100	24	45	59	6.67	12.17	15.50	147 ± 2	98.4
PET 4	50	21	30	35	4.00	6.17	8.00	175 ± 2	97.3
PET 4	67	24	39	44	5.24	7.94	10.16	168 ± 1	98.4
PET 4	75	26	42	46	6.13	9.03	11.13	160 ± 2	99.2
PET 4	100	38	56	63	8.23	12.42	15.16	142 ± 3	99.8
COT	50	23	33	37	5.00	7.34	9.06	161 ± 2	98.5
COT	67	31	43	49	6.29	9.35	11.61	154 ± 2	98.9
COT	75	30	46	51	7.30	10.95	13.33	145 ± 1	99.3
COT	100	42	57	72	9.35	13.87	17.26	122 ± 2	100.0
LIN	67	32	39	51	5.63	8.75	11.25	166 ± 4	98.8

The pressure results were evaluated according to the weft yarn type threading arrangement of elastomer threading, and extension levels.

3.1 Effect of weft yarn type

To ascertain how the weft yarn's composition affects the pressure values, the PET2, PET4, COT, and LIN specimens were compared with each other, in which the elastomer yarn has a 2 in, 1 out (67%) threading pattern.

As expected, pressure values applied by elastic materials increase with the increase of the extension values applied to the specimens during measurements. (Figure 4). The results revealed that the material type of weft yarn influences the pressure values of elastic fabrics. According to the results, the elastic fabrics from natural fibers apply higher pressure than the elastic fabrics produced with polyester fibers. Additionally, the fabrics produced by using 2-ply of polyester yarn as weft have the lowest pressure value for whole fabric extension values. According to this result, as the transverse weft yarn's diameter increases, so does the fabric's pressure.

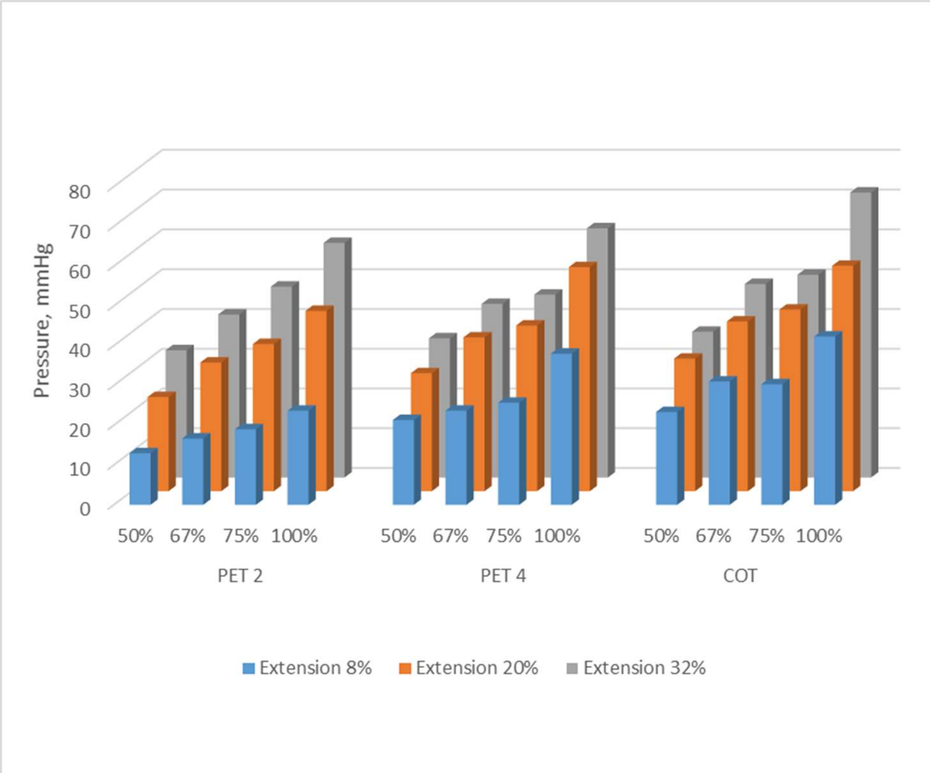

Figure 4. Effect of weft yarn type on pressure values for different extension levels

3.2 Effect of threading arrangement

The effect of the threading arrangement of elastomer on the pressure characteristic for each extension level was determined by comparing the measured values for different elastomer sets of elastomer for the specimens that have PET2, PET4, and COT weft yarns.

The results showed that the threading arrangement of elastomer had a significant effect on the pressure level of whole elastic fabrics. As is seen from Figure 5, the pressure values increase with the increase of elastomers in the structure. Because all types of weft yarn materials noticed an increase in pressure value when the amount of elastomer yarn increased in the structure and the elongation value decreased.

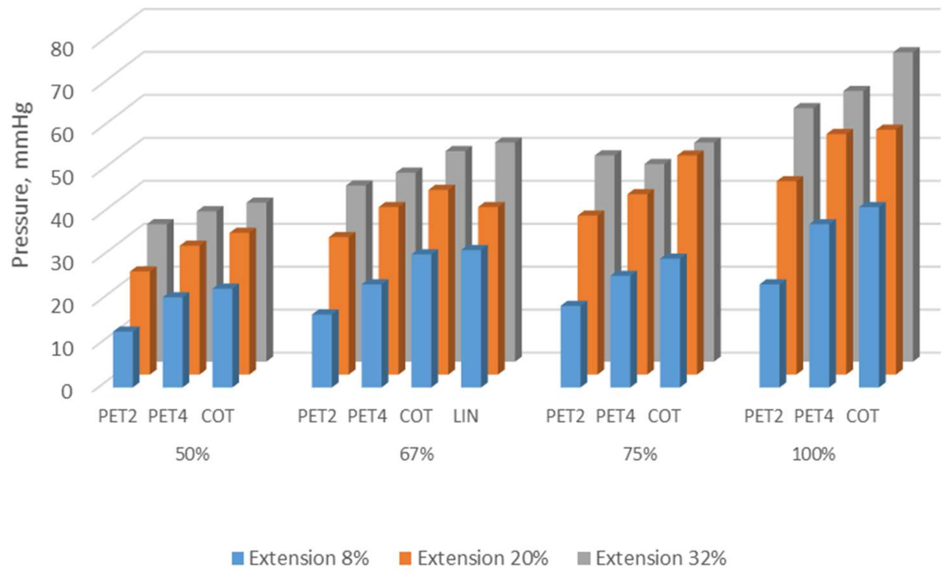

Figure 5. Effect of elastomer threading arrangement on pressure values for different extension levels

3.3 Effect of elongation value

The relation between the pressure at different levels of extension and elongation at the 5th cycle of 35 N loading for whole weft yarn materials is given in Figures 6, 7, and 8. As can be seen from the results and graphs, the pressure value applied by the fabric specimens decreases as the fabric`s elongation (S,%) increases for all weft yarn materials.

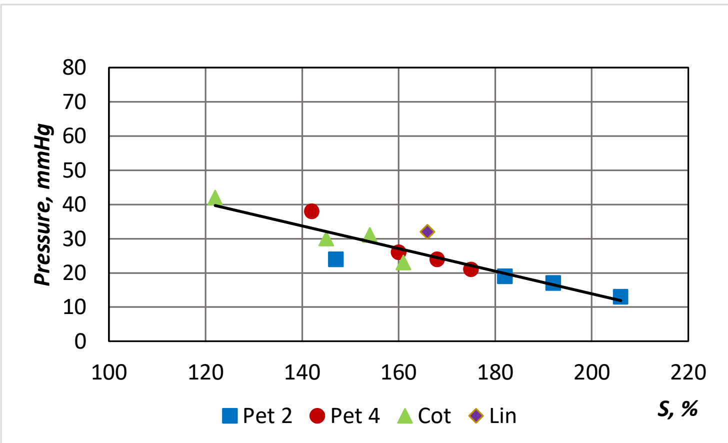

Figure 6. Dependence of pressure at 8% extension on elongation at 5th cycle of 35 N loading

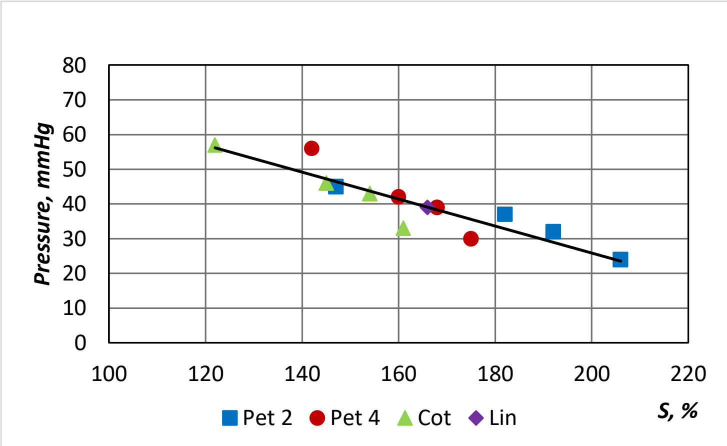

Figure 7. Dependence of pressure at 20% extension on elongation at 5th cycle of 35 N loading

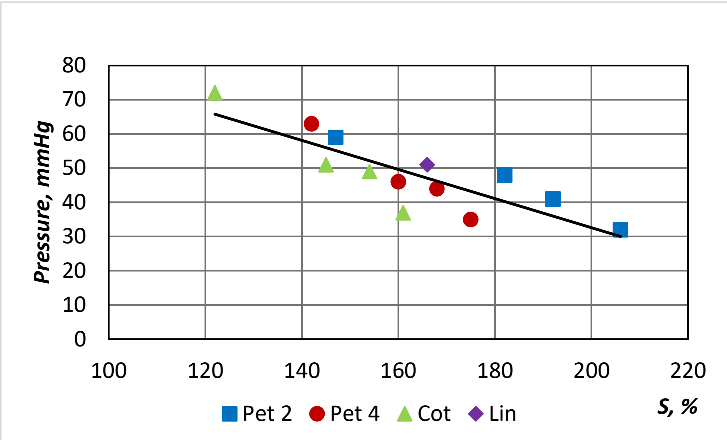

Figure 8. Dependence of pressure at 32% extension on elongation at 5th cycle of 35 N loading

Mathematically processing the experimental data, the following equations were obtained between the elongation at the 5th cycle of 35 N loading (S) and pressure at different extension levels (Table 3) for all material types and all elastomer set values. These equations allow us to determine the pressure of elastic warp knitted fabrics with high accuracy in case of changing elongation values.

Table 3. Equations between the pressure and elongation (S) values.

Elongation	Equations (mmHG)	R^2
8%	P =80.1 - 0.33 S	0.81
20%	P =103.7 - 0.39 S	0.83
32%	P =117.8 - 0.43 S	0.71

3.4 Dependences of pressure value on the load at different extension levels

The relation between the pressure at different extensions and the force applied to the specimens loading for the first loading cycle is given in Figure 9. In this graph, all pressure values obtained for all weft yarn types and elastomer layouts are used. According to the results, it is seen that as the applied force value increases for all specimens, the pressure values applied by the specimens increase as expected. It is completely correlated to the Laplace Law.

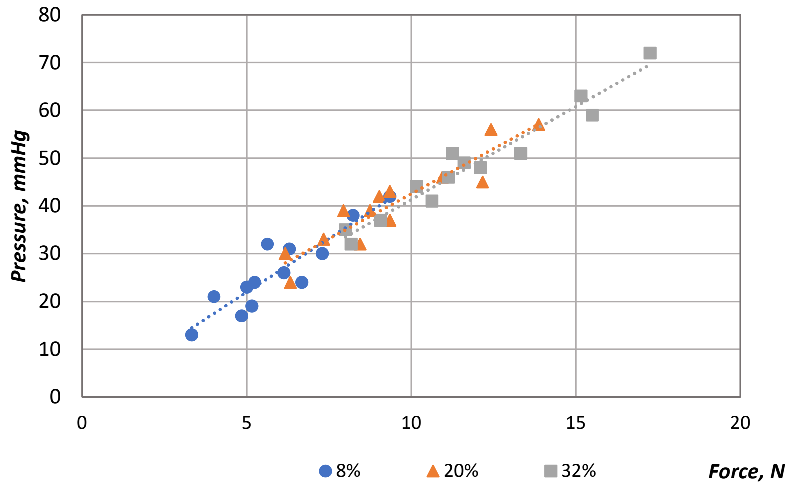

Figure 9. Dependence of the pressure at different extension levels on the force applied to the specimens

At the end of the mathematical processing of the experimental data, the following equations were obtained between the pressure and the force (F) applied to the specimens (Table 4) for whole material types and elastomer set values. Using these equations, it is possible to determine the pressure of elastic warp-knitted fabrics with high accuracy in case of changing force values applied to the specimens.

Table 4. Equations between the pressure and force (F) values.

Elongation	Equations (mmHg)	R^2
8%	P = - 0.45 + 4.48 F	0.82
20%	P = 4.79 + 3.77 F	0.87
32%	P = 2.35 + 3.90 F	0.95
For all specimens	P = 3.22 + 3.87 F	0.94

4. CONCLUSION

The elastic warp knitted materials due to their higher extensibility and elasticity have been widely used in the production of medical and preventive products. Characteristics required to provide the necessary compression usually go against the properties related to comfort. Therefore, an optimum balance between pressure (compression) and comfort should be maintained. The pressure results were evaluated according to weft yarn type, threading arrangement of elastane threading, extension, and load at different extension levels. At the end of the study, the following results were found:

- the type of raw material used as weft yarn affects the pressure values and when natural yarns are used instead of polyester yarn, the elastic bandages apply higher pressure;
- pressure values increase with the increase of elastomers in the structure;
- the elongation of elastic fabrics significantly affects the value of the pressure exerted on the disk;
- the pressure values applied by the specimens increase when the applied force value increases;
- various equations with high accuracy were calculated between the pressure and studied parameters.

By altering the threading arrangement of elastomer thread and weft yarn type, the developed mathematical equations enable a highly accurate determination of the expected pressure level in elastic warp knitted fabrics. According to the classification system for compression bandages, our specimens can be evaluated as strong (between 40-60 mmHg) at 32 % level for all weft yarn materials.

5. REFERENCES

[1] YU ZC, ZHANG JF, LOU CW, et al. Wicking behavior and dynamic elastic recovery properties of multifunction elastic warp-knitted fabrics. Text Res J 2015; 85(14): 1486–1496.
[2] KYZYMCHUK O and MELNYK L. Stretch properties of elastic knitted fabric with pillar stitch. J Eng Fibers Fabr 2018; 13(4): 1–10.
[3] RAMELET AA. Compression Therapy. Dermatologic Surgery 2002; 28(1):6-10
[4] PARTSCH H, CLARK M, MOSTİ G, et al. Classification of Compression Bandages: Practical Aspects. Dermatologic Surgery 2007; 34(5); 600-609.
[5] BASAL G and DEVECİ SS. Elastic bandages with improved comfort properties. Text Appar 2016; 6(2): 172–179.
[6] THOMAS S. Laboratory-based evaluation of a compression-bandaging system. Nursing Times 2003; 99(40); 24.
[7] KELLER A, MÜLLER ML, CALOW T, et al. Bandage pressure measurement and training: simple interventions to improve efficacy in compression bandaging. International Wound Journal 2009; 6(5): 313-404.
[8] KARAFA M and KARAFOVA A. Kikuhime Device in the Management of Venous Leg Ulcers. Clinical Interventions in Aging 2020; 15: 1533-1539.
[9] THOMAS S. The production and measurement of sub-bandage pressure: Laplace's Law revisited. Journal of Wound Care. 2014. 23, 5: 234-6, 238-41, 244.
[10] JARİYAPUNYA N. and MUSİLOVÁ B. Analysis of Stress and Strain to Determine the Pressure Changes in Tight-Fitting Garment. Autex Research Journal, 2020; 20, 1: 49-55. DOI: 10.2478/aut-2019-0006.
[11] KYZYMCHUK O, MELNYK L, MARMARALI A, et al. The effect of weft yarn type and elastomer yarn threading on the properties of elastic warp knitted fabrics. Part 1: Structure and elasticity. J Eng Fibers Fabr 2023; 18: 1–14. DOI: 10.1177/15589250231167405.
[12] KYOSEV Y. Warp Knitted Fabrics Construction. CRC Press, Taylor & Francis Group, UK, 2019.
[13] KYZYMCHUK O, MARMARALI A, MELNYK L, et al. The effect of weft yarn type and elastomer yarn threading on the properties of elastic warp knitted fabrics. Part II: Thermal comfort properties. J Eng Fibers Fabr 2023; 18: 1–9. DOI: 10.1177/15589250231171582.

BRINGING SUSTAINABLE FIBER FROM STEM, LEAF AND FOOD PRODUCT WASTE TO RING SPINNING TECHNOLOGY

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ABSTRACT

In the textile industry, the increasing number of consumers and the trend of fast fashion, which causes the demand to be always high, put the consumption of resources in our world in great danger due to the consumption of non-renewable raw materials and the pressure of natural fiber production. In recent years, this industry, like many other industrial areas, has been in search of solutions that support sustainability in raw material selection and production methods. During the production of natural vegetable fibers, tons of agricultural wastes such as roots, stems and leaves are generated. These wastes need to be disposed of in a beneficial way as the ecosystem cycle. In this sense, it is important in terms of fashion, product diversity and environment to bring the sustainable fiber obtained by converting crop wastes such as banana stems and pineapple leaves into a sustainable biodegradable fiber by a mechanical process into ring short fiber spinning technology. For this reason, within the scope of the study, yarns will be obtained from the blends of this new and environmentally friendly fiber with cotton and tencel, and yarn and fabric performance values will be evaluated by developing knitted fabrics from these yarns.

Key Words: Sustainable Raw Material, Ring Spinning Technology, Agricultural Waste

1. INTRODUCTION

With the rapid factorization and the emergence of mass production in textile industry, the use of traditional production methods has decreased, and besides, natural raw materials could not meet the need, and the use of synthetic fibers and mass production in the textile and fashion industries had devastating effects on the environment and ecosystem. Global annual fiber production in 2017 was over 105 million tons (Mt), with polyester (53.7 Mt) and cotton (25.8 Mt) accounting for 76% of the total; regenerated cellulosics (eg lyocell, viscose; 6.7 Mt), other plant fibers (eg flax, hemp; 5.6 Mt), polyamides (5.7 Mt), polypropylene (6 Mt), wool (1.2 Mt) Mt) and other natural fibers (0.4 Mt) appear to make up the rest[1]. According to these data, it is known that the use of synthetic raw materials in the textile sector is high and therefore the environmental burden of the sector increases. According to the data of the European Union Commission, when the textile sector can move to sustainability improvements and a circular economy and become carbon-neutral, it is considered to be the 3rd largest sector by volume in reducing global carbon emissions[2]. From this point of view, in order to reduce the use of synthetic raw materials, not only natural fiber production is sufficient, but also environmentally friendly alternative raw materials that serve zero carbon footprint targets should be brought to the textile industry by adding the wastes generated in the production processes to the cycle. Sustainable fiber is a biodegradable textile fiber produced from low-value agricultural waste, including oilseed hemp, oilseed flax, wheat, rice, corn, pineapple leaves, banana stems and more. This fiber is obtained by purifying residues from various food and pharmaceutical plants, including oilseed hemp/flax, CBD hemp, banana and pineapple, into soft fiber bundles ready to be spun using a special wet processing technique. With this study, it is aimed to bring this sustainable fiber into the ring short fiber spinning technology by developing yarns from the blends of cotton and tencel and obtaining knitted fabrics from these yarns with an environmentally friendly approach.

2. MATERIAL and METHOD

2.1.Material

Within the scope of the study, yarns of Ne 24/1 fineness were obtained by ring spinning technology by using 15% Sustainable Fiber 85% Cotton and 15% Sustainable Fiber 85% Tencel blends. The characteristic features of the raw materials used are given in Table 1 and the longitudinal section view of the sustainable fiber used within the scope of the study, taken with a light microscope, is given in Figure 1.

Table 1. Characteristics of Raw Materials Used in the Study

	Sustainable Fiber	Cotton	Tencel
Fiber fineness	17-22 micron	4,4 micron	1,33 dtex
Fiber length	25-40 mm	30 mm	38 mm

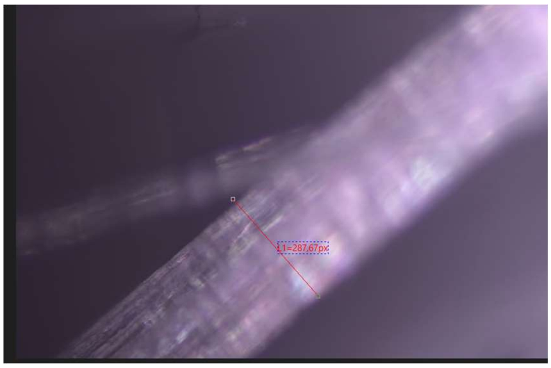

Figure 1: Longitudinal section view of sustainable fiber (20x)

2.1.Method

These yarns obtained within the scope of the study were conditioned for 24 hours under 20+/-2 0C temperature 65+/-50C humidity laboratory conditions, and their yarn strength values were determined in Uster Tensojet-4 device in accordance with TS 245 EN ISO 2062 standards, unevenness (%Cvm) and yarn defects such as thin places (-50%/km), thick places (+50%/km) and neps (+200%/km) were measured in Uster Tester-6 device using TS 628 standard. Then, knitted fabrics with a weight of 170 gr/m^2 were obtained from these yarns in a 30 pus 28 fine circular knitting machine. Knitted fabrics developed within the scope of the study were subjected to pilling tests according to EN ISO 12945-2 standard, air permeability according to TS 391 EN ISO 9237 standard and moisture transmission tests according to AATCC 195 standard.

3. RESULTS and DISCUSSION

In the study, the quality test values of sustainable fiber blended yarns are given in Table 2. Pilling test results are given in Table 3, air permeability results are given in Table 4, and moisture transmission test results are given in Table 5.

Table 2. Unevenness and Strength Test Results of 24/1 Sustainable Fiber /Cotton 15/85 and 24/1 Sustainable Fiber /Tencel 15/85 Yarns

Quality Parameters	24/1 Sustainable Fiber /Cotton %15/85	24/1 Sustainable Fiber /Tencel %15/85
Unevenness (%CVm)	24,71	21,39
Thin places (-50%)	287	14
Thick places (+50%)	2436	1822
Neps (+200%)	3319	3047
Strength RKm (kgf.Ne)	14,37	28,99
Breaking elongation (%)	6,15	9,63
B-Work (N.cm)	5,67	20,49

As can be seen from the table, the unevenness value of the yarns produced on the ring line from the mixture of 24/1 Ne Cotton/ Sustainable fiber 85/15% and 24/1 Ne Tencel/ Sustainable fiber 85/15% were measured as 24.71, 21.39% CV%, respectively. Its strength is 14.37, 28.99 Rkm, respectively; Elongation 6.15%, 9.63%; The B-Work value was measured as 5.67 N.cm, 20.49 N.cm.

Table 3. Pilling Test Results of 24/1 Sustainable Fiber/Cotton 15/85% and 24/1 Sustainable Fiber/Tencel 15/85% Fabrics

Cycle	24/1 Sustainable Fiber /Cotton %15/85	24/1 Sustainable Fiber /Tencel %15/85
125	5	5
500	5	5
1000	5	4
2000	4	4
3000	4	4
4000	4	3
5000	4	3

As can be seen from the table, according to the pilling test results performed in the martindale device with the EN ISO 12945-2 standard, no hairiness or pilling was observed on the surface of the circular knitted fabric samples using a mixture of Cotton/Sustainable fiber 85/15% and Tencel/Sustainable fiber 85/15% up to 1000 cycles while light pilling continues up to 3000 cycles in Cotton/Sustainable fiber 85/15% fabric, this situation continues up to 2000 cycles in Tencel/Sustainable fiber 85/15% fabric, while slight hairiness and pilling were observed on the Cotton/Sustainable fiber 85/15% fabric surface up to 5000 cycles, moderate hairiness and pilling was observed in the Tencel/Sustainable fiber 85/15% fabric from 3000 cycles to 5000 cycles.

Table 4. Air Permeability Test Results of 24/1 Sustainable Fiber/Cotton 15/85% and 24/1 Sustainable Fiber/Tencel 15/85% Fabrics

Yarn Type	24/1 Sustainable Fiber /Cotton %15/85	24/1 Sustainable Fiber /Tencel %15/85
Air Permeability Value (dm^3)	767	2351

According to the air permeability test results made according to the TS 391 EN ISO 9237 standard, it is seen that the Tencel / Sustainable fiber blended fabric has higher air permeability.

Table 5. Moisture Transmission Test Results of 24/1 Sustainable Fiber/Cotton 15/85% and 24/1 Sustainable Fiber/Tencel 15/85% Fabrics

Yarn Type	24/1 Sustainable Fiber /Cotton %15/85	24/1 Sustainable Fiber /Tencel %15/85
OMMC	0,341	0,520

According to the moisture transmission test results made according to the AATCC 195 standard, it is seen that the fabric of the sustainable fiber blended with regenerated cellulosic tencel fiber has a better moisture transmission value than the cotton blend.

4. CONCLUSION

In this study, when the unevenness values of sustainable yarns obtained by mixing the fiber obtained from stem, leaf and food waste with cotton and tencel fiber are examined, it is seen that the tencel blended yarn has better values than cotton yarn. This can be explained by the fact that tencel has a fiber length of 38 mm and is more uniform than cotton with a fiber length of 30 mm and a short fiber content. Considering the yarn strength results, it is seen that the strength of the tencel/sustainable fiber blended yarn is higher than the cotton/sustainable fiber blended yarn. This is due to the strength of tencel fiber being 40 cN/tex. However, when the B-Work values of these two yarns are examined, it is seen that it will not pose a problem for circular knitting machine performances. Among the knitted fabrics obtained from these yarns, it was observed that cotton/sustainable fiber blended fabric had better pilling performance and no pilling on the fabric surface. The reason why the piling of the sustainable fiber tencel blended fabric is higher than the sustainable fiber cotton blended fabric is that the pilling cannot be easily separated from the surface due to the high fiber strength of the tencel fiber. It was concluded that the fabric obtained from the mixture of tencel and sustainable fiber, which has a more breathable structure and good moisture absorption ability than cotton fiber, has a higher air permeability and moisture transmission value. It is predicted that by bringing the sustainable fiber used within the scope of the study into short fiber spinning, it will contribute to the prevention of climate changes that negatively affect the vital functions of all living things by reducing the carbon footprint. In this context, it is foreseen that the study will make significant contributions to the 3 titles of supporting the green transformation of the Green Deal Action Plan, which is prepared in terms of harmonization with the European Green Consensus (AYM); (1) border carbon regulations, (2) a green and circular economy and (7) combating climate change. At the same time, it is predicted that the study shared on this platform in order to contribute to the literature has a high potential to initiate new R&D activities.

5. REFERENCES

[1] STENTON, M., HOUGHTON, J. A., KAPSALI, V., & BLACKBURN, R. S. The Potential for Regenerated Protein Fibres within a Circular Economy: Lessons from the Past Can Inform Sustainable Innovation in the Textiles Industry. 2021. Sustainability, 13(4), 2328. https://doi.org/10.3390/su13042328

[2] https://www.ithib.org.tr/tr/surdurulebilirlik-tekstil-sektoru-etkileri.html, Date of access 17-07-2023

MICROWAVE ENERGY-BASED APPROACH TO PREPARATION AND CHARACTERIZATION OF FUNCTIONAL TEXTILES FOR FIBER REINFORCED POLYMERIC COMPOSITES

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ABSTRACT

Hierarchically structured functional textiles made up of multi-walled carbon nanotube (MWCNT) forest decorated carbon fiber (CF) and glass fiber (GF) fabrics are obtained through a microwave (MW) energy-based approach, i.e. Poptube. Both the morphological and elemental properties of these samples are characterized in detail by using electron microscopy, and elemental analysis techniques. The as-obtained test results, and the versatile and easily controllable working principle of the Poptube approach strongly supports its promising success for the preparation of such functional textiles that could be effectively used as fibrous reinforcing agents for the manufacturing of fiber reinforced polymeric composite structures (FRPCSs).

Key Words: carbon/glass fiber, carbon nanotube, conducting polymer, functional textile, microwave energy

1. INTRODUCTION

The excellent mechanical strength, thermal and electrical conductivity, light weight, and the processability of CF have made it a valuable building material for a wide range of advanced engineering systems, including aerospace ships, communication satellites, planes, hybrid vehicles, wind turbine blades, sports equipment, prosthetic limbs, and so forth [1]. Except for the thermal and electrical conductivity properties, GF has been also considered as a perfect alternative for CF in most of these applications. In many bulk composite materials that are made up of either thermoset/thermoplastic polymers or metals and concrete, CF and GF are often used as reinforcing components because of their fibrous nature [2, 3]. So far, research efforts in enhancing the reinforcing performance of both CFs and GFs are aimed at addressing phase separation issues, improving shear resistance, increasing strength, reducing weight, enhancing durability, achieving high performance, and enabling the use of C/GF reinforced composites in diverse engineering applications [4-7]. These efforts contribute to the development of advanced materials that offer a balance of strength, weight savings, and durability for various real-life applications. The growth of carbon nanotubes (CNTs) on the surface of C/GFs has indeed gained significant attention in recent years since this offers a promising solution to address the challenges and requirements in production of FRPCSs [8-10]. The as-grown CNTs on fibers enhance polymeric matrix material's adhesion, increase both the overall surface area and the number of anchoring points, improve strength and durability of the composite and maintain its lightweight profile, and enable high-performance engineering application possibilities [11-16]. As research in this area continues to advance, it is more likely to see the widespread adoption of CNT-decorated C/GF-reinforced composites in a variety of real-life engineering applications. CNTs' extraordinary mechanical, thermal, and electrical properties are indeed making them exceptional candidates for use in a FRPCS that typically consist of reinforcing fibers or textiles, a polymeric matrix, and the interface constituents [17]. Thus, CNT reinforcement possesses promising potential to provide much stronger and tougher materials than other traditional reinforcing materials [2, 3, 18]. Moreover, such novel properties of CNTs provide functional advantages, including self-sensing ability, flame retardancy, long-term wear resistance, electrical and thermal conductivity, electromagnetic interference (EMI) shielding, and improved thermal stability, to the added structure [19]. Enhanced transverse and shear resistance values are other positive outcomes of the as-produced CNT decorated C/GF hierarchical composites, due to the intense interfacial interactions that would exist between the as-grown CNTs and fibers [11-14]. Generally, the CNT growth on any engineering material can be achieved via either bottom-up method like CVD or top-down method like lithography [14-16, 20, 21]. Each method has its own set of advantages and limitations, and the choice depends on factors such as desired CNT properties, cost considerations, and application requirements. Although these methods can provide highly precise and uniform CNTs, they usually suffer from their complex production process and from their need of harsh process conditions, i.e. high vacuum/pressure, high temperature, and hazardous chemicals' use. Additionally, these methods' fabrication processes are not easily scalable and are, usually, very time consuming [14-16, 20, 21]. Thus, the as-obtained CNT amounts can be limited, and this restricts the common uses of such methods for the applications at industrial level. To tackle these common obstacles and to realize a practical application for the CNT decorated C/GF reinforced composites' preparation, in this study, a well-established MW energy-based fabrication approach, i.e. Poptube, through which forest-like MWCNT decoration on C/GFs' surface can be rapidly grown, is proposed [22, 23]. It is important to note that the specific details and characteristics of this approach would depend on its proprietary or research-based methodology [18, 24]. This approach seems to leverage the above-mentioned properties of CNTs and the efficiency of MW energy-based growth to produce CNT decorated textiles in a quick and cost-effective manner. However, the application of CNTs into a FRPCS is hampered by three common problems about; (i) the non-homogeneous dispersion of such nanoscale additives within the structure, (ii) the inconsistency in the implementation of laboratory results up to industrial scale, and (iii) the failure in lowering the cost/benefit ratio [22-24]. This study aims to address all these problems through Poptube approach. Unlike any other similar existing methods, such as chemical vapor deposition (CVD), Poptube approach utilizes MW energy as the heating source, a metallocene precursor chemical, e.g. ferrocene, as the carbon and metal catalyst source, and conducting polymer (CP), e.g. polypyrrole (PPy), coating as the effective MW energy absorption layer on the fibrous textile material surface [22-24]. However, it is noteworthy that the success of this approach would depend on the specific details of the process, including the choice of materials, the precise conditions used, and the desired outcome [18-24]. Furthermore, the field of CNT synthesis is continually evolving, and new methods and variations, i.e. Poptube, are developed regularly to address specific applications and their needs. With that, it becomes possible to grow forest-like CNT decoration on the fibrous textile substrates' surface, such as CF and/or GF fabric, which would be used as a reinforcing agent in a FRPCS. Thus, the major objective of this study is to explore a novel MW energy-based nano-engineering technique, i.e. Poptube approach, which not only can be considered as one of the fastest methods to grow CNTs with high energy and cost efficiency, but also as a readily scalable approach for high-volume industrial manufacturing of FRPCSs that have been extensively implemented in various high-tech industries.

2. EXPERIMENTAL

2.1 Materials

Plain weave CF and GF fabric, acetone (JT Baker), toluene (JT Baker), pyrrole, ammonium peroxy disulfate (APS), hydrochloric acid (HCl) and ferrocene (AlfaAesar) were all used as purchased without further purification, unless otherwise specified.

2.2 MW Pretreatment and Preparation of CF Fabric Samples

Prior to application of Poptube approach, several 1"×1" prepreg CF fabric samples are continuously heated in a conventional kitchen MW oven (Panasonic Inverter) at full power (1250 W) for 60 s to; (i) remove the protective thin sizing layer, and (ii) to reveal as much reactive sites as possible on CFs' surface for the following process steps (Figure 1).

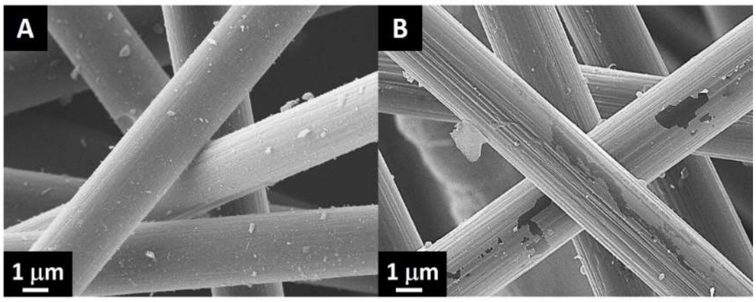

Figure 1. Scanning electron microscopy (SEM) images of CFs; A. before and B. after MW pre-treatment

2.3 CP Coating and Preparation of GF Fabric Samples

Since GF fabric is insulating, first, thin CP layer coating is applied on the sample surface through the in-situ polymerization reaction of PPy. Here, 1"×1" GF fabric sample is taped inside the beaker's wall and then it is filled with 50 mL of 1 M aq. HCl. Next, 1 mL of pyrrole monomer is gently added into the beaker under magnetic stirring to obtain its homogenous dispersion and better interaction with GF fabric sample. After 10 min. magnetic stirring at ambient conditions 1.15 g of APS is eventually added into the beaker, as the oxidative agent, to initiate the polymerization reaction. Meanwhile, a rapid color change is observed into the beaker from cloudy to black indicating the conversion of pyrrole monomers into PPy. After 4 h of polymerization reaction the dark slurry in the beaker is filtered, and then washed and rinsed with copious HCl and acetone, respectively together with the as-coated GF fabric sample.

2.4 Preparation of MW-treated CF and PPy/GF Fabric Samples for Poptube Approach

Here, initially, 0.2 M ferrocene solution is prepared by dissolving 0.11 moles of ferrocene in 550 mL of toluene, for the homogenous deposition of the carbon and catalyst source precursor chemical on both the as-treated CF, and PPy/GF fabric samples. After that, all the samples are individually submerged into this solution for 10 min. under continuous gentle shaking. Eventually, the fabric samples were drip dried on a Nylon string before the application of Poptube approach (Figures 2 and 3).

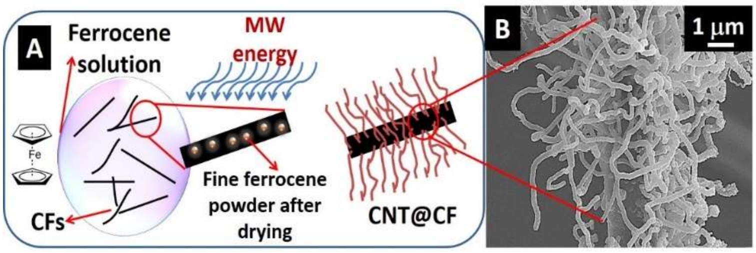

Figure 2. A. Schematic representation of the preparation and MW energy-based Poptube approach application on CF fabric samples, B. SEM image of a single CF covered by the as-grown CNTs on its surface

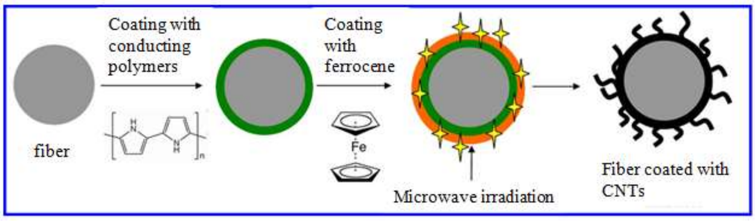

Figure 3. Schematic representation of the preparation and MW energy-based Poptube approach application on GF fabric samples

2.5 Application of MW Energy-based Poptube Approach on Fabric Samples

The as-prepared C/GF fabric sample is tightened vertically between a pair of glass rods on a handmade PVC stand, and then it is placed on the glass MW tray. Here, the evenly deposited thin ferrocene layer can be clearly observed on the fabrics with an orange tint. The glass tray is then placed into the MW oven chamber. The fabric on the PVC stand is irradiated at the maximum power level, while intensive reactions are observed inside, as indicated by sparking, flames, and dense chemical vapor emission. After 30 s MW energy exposure, the fabric sample with the as-grown CNT decoration on its surface is taken out, and then gently rinsed with acetone to remove any impurities and unreacted chemicals (Figures 4 and 5).

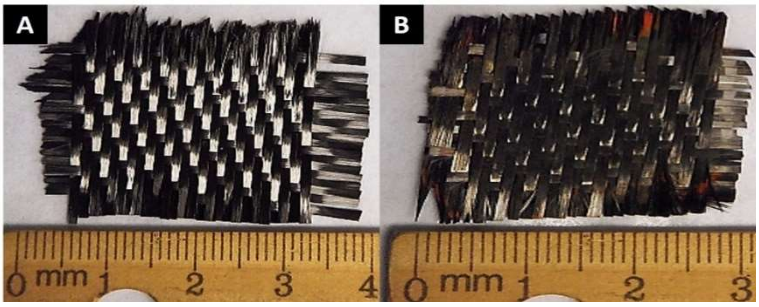

Figure 4. Digital images of a CF fabric sample; A. before, and B. after the MW energy-based Poptube approach application

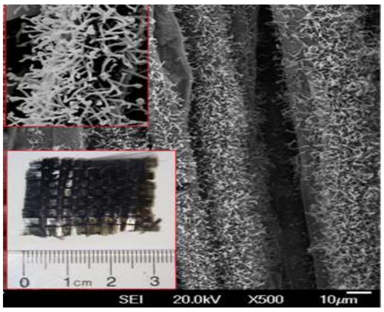

Figure 5. SEM image of the GFs decorated by the as-grown CNTs (Insets: (top) zoomed-in view of the as-grown CNTs, (bottom) digital image of 1"×1" PPy/GF fabric after the MW energy-based Poptube approach application)

During the application of Poptube approach, firstly, either the CP surface coating on the GF fabric or the CF fabric itself effectively absorbs the MW energy, gets quickly carbonized, and simultaneously produces tremendous amount of heat. The temperature on the fabric surface then rapidly raises high enough to decompose ferrocene to into its iron (Fe) and cyclopentadienyl fragments. Here, Fe serves as the catalyst while the cyclopentadienyl groups provide the required carbon to accomplish the bottom-up CNT growth [18-24]. Schematic representations of the above-mentioned process is shown in both Figures 2 and 3.

2.6 Characterization of the As-prepared Functional Textiles

Morphological and elemental analyses of the as-prepared functional textiles are conducted by using a JEOL JSM-7000F SEM equipped with an energy dispersive X-ray (EDX) detector. An EMS 550X auto sputter coating device is also utilized for surface Au sputter coating of the fabric samples, which were readily fixed on carbon tape mounted sample holders, prior to their analysis. The in-depth morphological property analysis of the as-prepared composites is performed on a JEOL 2100F transmission electron microscope (TEM), operated at 200 kV. Here, CF strands from the as-treated fabric sample were carefully removed and dispersed in ethyl alcohol by ultrasonication for 10 min. to separate the as-grown CNTs from the CFs. Next, droplets (~5 µL) from the supernatant surface are sucked with a pipette, and then transferred onto a carbon coated copper Formvar grid and left to dry at ambient conditions before TEM imaging.

3. RESULTS AND DISCUSSION

Upon the application of Poptube approach, forest-like CNTs are grown on both the PPy/GF and CF fabric surfaces, and covered majority of the fiber surfaces with a radially aligned and entangled assembly look, as can be seen from the images shown in Figures 5 and 6.

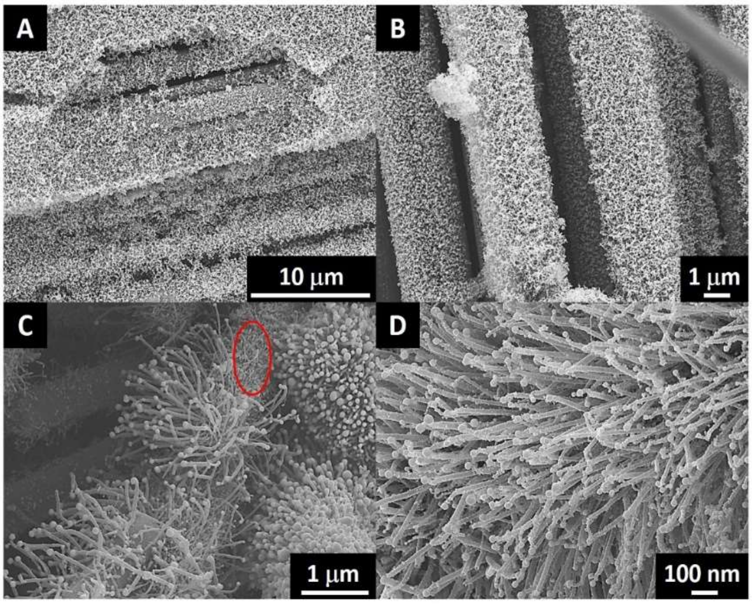

Figure 6. SEM images of; A.-B. hierarchically structured CNT/CF fabric samples, C. CFs covered by the as-grown CNTs on their surfaces, D. zoomed-in view of the as-grown CNTs

The as-grown CNTs' coverage on both fabric surfaces is high, as the growth can be observed to span along the full fiber axis length. Here, both long-winding and short-rigid CNTs are grown on the fabrics, indicating the heterogeneous nature of the catalytic growth process induced by MW energy [11-16, 18-24]. Based on the measurements taken from these images the average diameter of these CNTs is ~50 nm while their length can extend up to couple of µm. The high aspect ratio of these CNTs thus provide an ultra-high surface area, which enables enhanced interfacial interactions and multi-scale functions in the FRPCS, through the formation of new interfaces [11-16]. In good agreement with the previous literature data, bottom up tip-growth mechanism is also effective on the as-grown CNTs [18-24]. This phenomenon is also supported by the characteristic

matchstick-like morphology, which is composed of hollow and multi-walled stem with oxidized Fe nanoparticle (NP) tip, of these CNTs (Figure 6D), as well.
After proving the Poptube approach's success on generating CNT/C-GF hierarchical structures via SEM imaging, the in-depth morphological and elemental features of such CNTs are further characterized by using TEM microscopy and EDX analysis. Collected results from these analyses are shown in Figure 7.

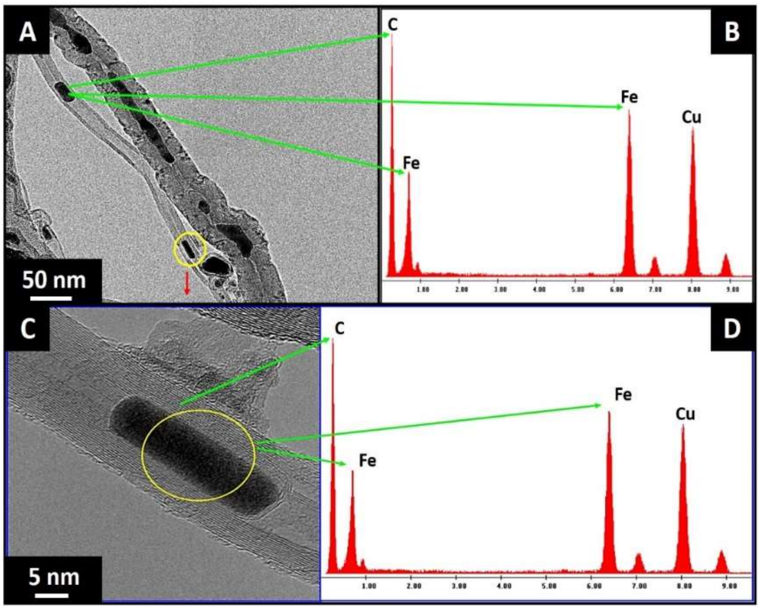

Figure 7. A. TEM image of the catalyst Fe NPs encapsulated within the as-grown CNTs, B. EDX diffractogram of the catalyst Fe NP and the as-grown MWCNT, C. HR-TEM image of the marked area in Figure 7A, and D. EDX diffractogram of the marked area in Figure 7C

The TEM image in Figure 7A provides more detailed information about the as-grown CNTs by showing their hollow stems that encapsulate catalyst Fe NPs. This morphological structure is obtained during the above-mentioned tip-growth process. As it also can be seen from the HR-TEM image in Figure 7C, a single ~25 nm×5 nm catalyst Fe NP is encapsulated within the as-grown MWCNT's walls that is composed of ultrathin graphene layers [18-24]. The EDX analysis results of both the as-grown MWCNTs and the encapsulated catalyst iron NPs are shown in Figures 7B and 7D, respectively. These diffractograms clearly proves the presence of both the as-grown MWCNTs and Fe NPs (made up of C and Fe elements) within them. Additionally, two sharp peaks with Cu indicators in these diffractograms are caused by the Cu grid used for the TEM imaging process as the sample holder.

4. CONCLUSION

Hierarchically structured functional textiles with vertically aligned nano/micro interface are prepared within very short time frames by applying MW energy-based Poptube approach. Homogenously grown, forest-like CNTs are obtained on both CF and PPy/GF fabric surface with high yield, high aspect ratio, and high coverage density. The as-produced functional textiles offer promising potential for FRPCSs preparation. The as-proposed highly efficient and cost-effective Poptube approach is also envisioned to secure the industrial scale production of such composites with high quality, as well.

REFERENCES

[1] CHAND, S. Carbon fibers for composites. Journal of Materials Science, 2000, 35(6), 1303-1313.

[2] MONIRUZZAMAN, M., WINEY, K. I. Polymer nanocomposites containing carbon nanotubes, Macromolecules, 2006, 39, 5194-5205.

[3] THOSTENSON, E., REN, Z., CHOU, T. Advances in the science and technology of carbon nanotubes and their composites: a review. 2001, Composites Science and Technology, 61(13), 1899-1912.

[4] DELAMAR, M., DESARMOT, G., FAGEBAUME, O., HITMI, R., PINSONC, J., SAVEANT, J. M. Modification of carbon fiber surfaces by electrochemical reduction of aryl diazonium salts: Application to carbon epoxy composites. 1997, Carbon, 35(6), 801-807.

[5] XU, B., WANG, X., LU, Y. Surface modification of polyacrylonitrile-based carbon fiber and its interaction with imide. 2006, Applied Surface Science, 253(5), 2695-2701.

[6] YU, B., JIANG, Z., TANG, X. Z., YUE, C. Y., YANG, J. Enhanced interphase between epoxy matrix and carbon fiber with carbon nanotube-modified silane coating. 2014, Composites Science and Technology, 99, 131-140.

[7] YUAN, H., WANG, C., ZHANG, S., LIN, X. Effect of surface modification on carbon fiber and its reinforced phenolic matrix composite. 2012, Applied Surface Science, 259, 288-293.

[8] CHEN, H., ROY, A., BAEK, J. B., ZHU, L., QU, J., DAI, L. Controlled growth and modification of vertically-aligned carbon nanotubes for multifunctional applications. 2010, Materials Science & Engineering R-Reports, 70, 63-91.

[9] GOJNY, F. H., WICHMANN, M. H. G., FIEDLER, B., BAUHOFER, W., SCHULTE, K. Influence of nano-modification on the mechanical and electrical properties of conventional fibre-reinforced composites, Composites Part a-Applied Science and Manufacturing, 2005, 36, 1525-1535.

[10] LIN, Y. R., EHLERT, G., SODANO, H. A. Increased Interface Strength in Carbon Fiber Composites through a ZnO Nanowire Interphase, Advanced Functional Materials, 2009, 19, 2654-2660.

[11] GARCIA, E. J., WARDLE, B. L., HART, A. J., YAMAMOTO, N. Fabrication and multifunctional properties of a hybrid laminate with aligned carbon nanotubes grown In Situ, Composites Science and Technology, 2008, 68, 2034-2041.

[12] SAMSUR, R., RANGARI, V. K., JEELANI, S., ZHANG, L., CHENG, Z. Y. Fabrication of carbon nanotubes grown woven carbon fiber/epoxy composites and their electrical and mechanical properties. 2013, Journal of Applied Physics, 113(21), 214903-214908.

[13] THOSTENSON, E. T., LI, W. Z., WANG, D. Z., REN, Z. F., CHOU, T. W. Carbon nanotube/carbon fiber hybrid multiscale composites. 2002, Journal of Applied Physics, 91(9), 6034-6037.

[14] ZHANG, Q. H., LIU, J. W., SAGER, R., DAI, L. M., BAUR, J. Hierarchical composites of carbon nanotubes on carbon fiber: influence of growth condition on fiber tensile properties, 2009, Composites Science and Technology, 69, 594-601.

[15] ZHAO, Z. G., CI, L. J., CHENG, H. M., BAI, J. B. The growth of multi-walled carbon nanotubes with different morphologies on carbon fibers, 2005, Carbon, 43, 651-673.

[16] ZHU, S., SU, C. H., LEHOCZKY, S. L., MUNTELE, I., ILA, D. Carbon nanotube growth on carbon fibers, 2003, Diamond and Related Materials, 12, 1825-1828.

[17] PHILLIPS, J., LESEMAN, Z. C., CORDARO, J., LUHRS, C., AL-HAIK, M. Novel graphitic structures by design, In: Proceedings of ASME IMECE, 2007, Seattle, WA, USA: 42977-42979.

[18] POYRAZ, S., ZHANG, L., SCHRODER, A., ZHANG, X. Y. Ultrafast microwave welding/reinforcing approach at the interface of thermoplastic materials, 2015, ACS Applied Materials and Interfaces, 7, 22469-22477.
[19] XIE, H., POYRAZ, S., THU, M., LIU, Y., SNYDER, E. Y., SMITH, J. W., ZHANG, X. Y. Microwave-assisted fabrication of carbon nanotubes decorated polymeric nano-medical platforms for simultaneous drug delivery and magnetic resonance imaging, 2014, Rsc Advances, 4, 5649-5652.
[20] ZHANG, X. Y., LIU, Z. Recent advances in microwave-initiated synthesis of nanocarbon materials, 2012, Nanoscale, 4, 707-714.
[21] ZHANG, X. Y., MANOHAR, S. K. Microwave synthesis of nanocarbons from conducting polymers, 2006, Chemical Communications, 23, 2477-2479.
[22] LIU, Z., WANG, J. L., KUSHVAHA, V., POYRAZ, S., TIPPUR, H., PARK, S., KIM, M., LIU, Y., BAR, J., CHEN, H., ZHANG, X. Y. Poptube approach for ultrafast carbon nanotube growth, 2011, Chemical Communications, 47, 9912-9914.
[23] LIU, Z., ZHANG, L., POYRAZ, S., SMITH, J., KUSHVAHA, V., TIPPUR, H., ZHANG, X. Y. An ultrafast microwave approach towards multicomponent and multi-dimensional nanomaterials, 2014, Rsc Advances, 4, 9308-9313.
[24] POYRAZ, S., LIU, Z., LIU, Y., ZHANG, X. Y. Devulcanization of scrap ground tire rubber and successive carbon nanotube growth by microwave irradiation, 2013, Current Organic Chemistry, 17, 2243-2248.

UTILIZING PTFE FILAMENT TO ACHIEVE EFFICIENCY AND AESTHETICS IN WEARABLE TRIBOELECTRIC GENERATORS

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ABSTRACT

Numerous research articles refer to the use of PTFE material in triboelectric generators, but they lack the rich aesthetic and mechanical properties of a pure textile structure. Hereby a PTFE filament was used to knit a fabric sample. This was repeatedly brought in contact, sliding and separation with a knitted cotton or modal fabric sample, providing a V_{pp} from 98 to 188 mV. A comparison was also made with a PTFE coated glass fabric which reached 284 mV. This work aims to emphasize that textile technology can overpass its traditional applications and contribute to other technological areas such as sustainable energy.

Key Words: Textile, knitting, PTFE, triboelectricity, triboelectric generator

1. INTRODUCTION

One of the most interesting and unexplored physical phenomena which are met in the physical environment is that of triboelectricity. This describes the electrical energy that is produced when two material surfaces are brought in contact and separated. Most people might remember it from their childhood when rubbing a balloon on their head and then sticking it on the wall. However, triboelectricity today has been more than a game for many academic research teams worldwide. Over the last decade, big efforts have been applied to exploit it and produce sustainable electric energy through structures which are called triboelectric generators (TEGs) [1].

The suitable choice of the participating materials is very important in the direction of achieving the best electrical outputs of a TEG. One of the most popular materials met very often in studies and reports is Polytetrafluoroethylene (PTFE). A look at the various triboelectric series tables which classify materials according to their tendency to become positively or negatively charged after a contact, can quickly show that PTFE is always positioned at the very end of the tables, considered mainly the most negative one [2]. Considering that the higher the charge tendencies the more intense the phenomenon and the more efficient the TEGs, it becomes easily understood that PTFE is a big player in TEGs.

Apart from its outstanding triboelectric properties, PTFE has also a set of excellent physical properties which can cover the demanding conditions of clothing. It is characterized by flexibility, excellent chemical resistance, easiness to clean its surface and satisfactory dimensional stability. Moreover, it has resistance to ultraviolet radiation (UV) and high temperatures, while it is also non-toxic under regular ambient conditions of clothing usage.

This paper presents the first steps which have been taken in an attempt to combine PTFE material and textile design. Until today, PTFE has been used in textile-based TEGs in the form of a film [3], [4] or coating [5], [6], on either flexible or solid surfaces, using various methods. Hereby, thanks to the big opportunities of the textile technology, PTFE is used to build a knitted fabric which is after added in a testing TEG device to get examined.

2. EXPERIMENTAL

2.1 Materials

Three samples were produced for the experimental part. These include the under-examined PTFE textile sample and two regular textile samples: one made of cotton fibres (natural cellulosic material) and one made of modal fibres (regenerated cellulosic material). It must be mentioned that cotton and modal have light tendency to become positively charged under the triboelectric phenomenon, while the PTFE material has a very intense tendency to become negatively charged. This is a reason for using often in the construction of TEGs the combination of cotton fabrics with PTFE [7].

Thus a cotton and a modal yarn were produced, with a yarn English count of 20 Ne (30 Tex) and an English twist factor $a_e = 3.8$ (metric twist factor $a_m = 115$). Each yarn was knitted at Ege University by applying a single jersey knitting pattern. Their course and wale densities were 8.0 /cm and 8.0 /cm respectively. A detailed view of the front and back sides of the cotton sample's pattern is presented in Figure 10 and Figure 11.

Additionally, a PTFE filament (1250D) was supplied by Marmara Boyahanesi company and used in a hand-knitting machine at Ege University. The Milano-rib pattern was set and used for the production of a 5 x 5 cm knitted sample. Its course and wale densities were 3.6 /cm and 4.8 /cm respectively. A detailed view of the loops of the front and back sides of the PTFE knitted structure is presented in Figure 12 and Figure 13.

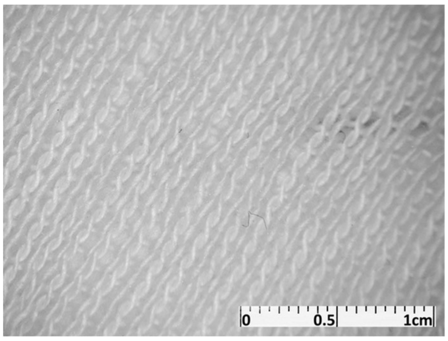

Figure 10. The front side of the cotton sample.

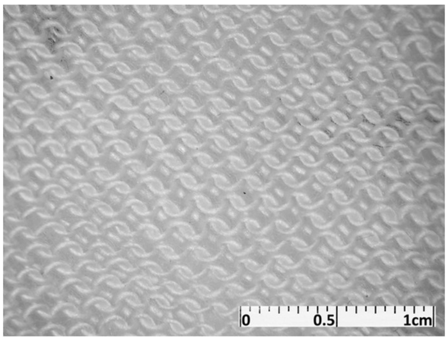

Figure 11. The front side of the cotton sample

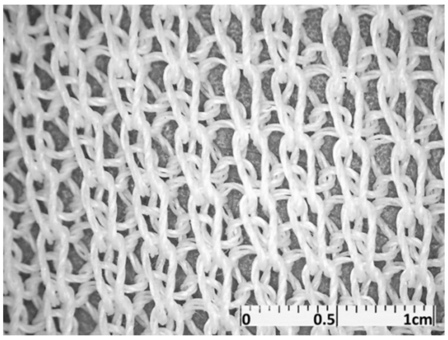

Figure 12. The front side of the knitted PTFE fabric.

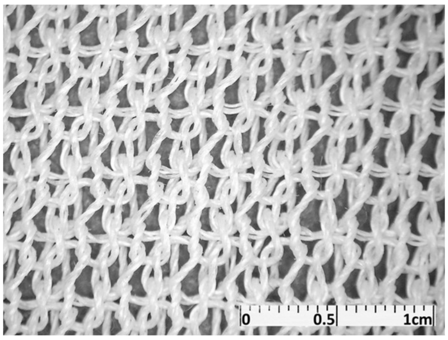

Figure 13. The back side of the knitted PTFE fabric.

Finally, a PTFE coated glass fabric was bought from Fiberflon, in order to collate it with the knitted PTFE fabric. This is composed of woven glass fibers coated with PTFE as can be seen in Figure 14 and Figure 15.

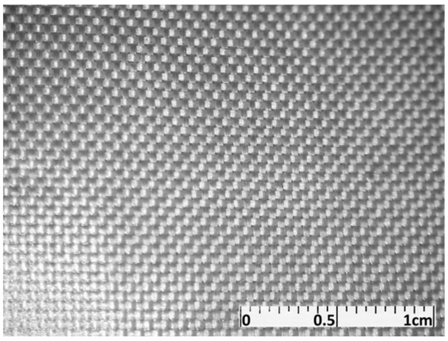

Figure 14. The front side of the PTFE coated glass fabric.

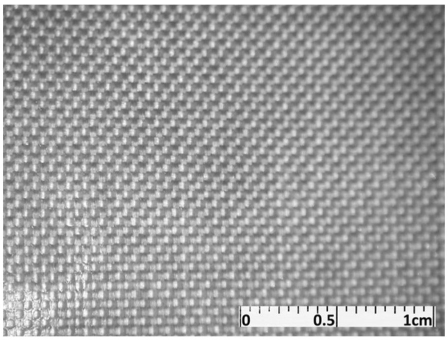

Figure 15. The back side of the PTFE coated glass fabric.

2.1 Method

After its production, a specimen (5 x 5 cm) from the knitted PTFE fabric sample was positioned on a prototype TEG measuring device which has been designed and built at the University of West Attica (Figure 16). This device has been presented in previous studies and it can repeatedly bring in contact and rub the two under testing triboelectric surfaces [8]. The testing conditions are such that the TEG measuring device can simulate a motion as if the two triboelectric surfaces were positioned on a garment (e.g. on the inner side of the sleeve and aside from the body while walking) as previewed in Figure 17.

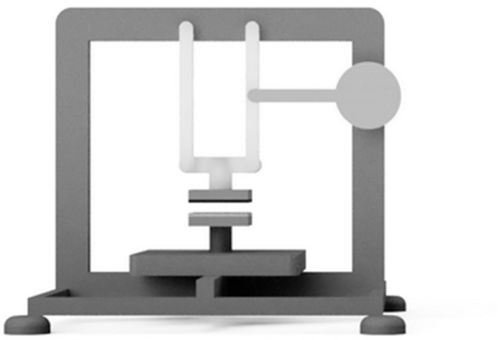

Figure 16. Sketch of the prototype TEG measuring device which was used for the measurements. It simulates the motion as if the two triboelectric surfaces were positioned on a garment **[9]**.

Figure 17. Sketch of the contact, friction and separation motion executed by two triboelectric surfaces on the inner side of the sleeve (black strip) and aside from the body (grey clothing) while walking **[9]**.

Additionally, one specimen (5 x 5 cm) was cut from the cotton sample and was also positioned on the TEG measuring device. In the continue, 500 repeats of contact, sliding and separation were applied under a load of 50 grf. The coming electrical outcome due to the phenomenon of triboelectricity was detected using an oscilloscope which was connected to the two samples using two appropriate electrodes to collect the electrical charge. The peak-to-peak open circuit voltage (V_{pp}) was measured on the connected oscilloscope. This procedure was repeated for each of the 10 specimens which were cut from the cotton and modal samples respectively. After the completion of the previous measuring procedures, the knitted PTFE fabric was replaced by a PTFE-coated glass fabric. Thus a PTFE material of a different form was examined as before and compared to the initial knitted PTFE fabric.

3. RESULTS AND DISCUSSION

Unlike using PTFE in the form of a film or coating, hereby PTFE in textile form was proposed. The use of a PTFE filament to knit the fabric provided by definition significant textile advantages like flexibility, elasticity and breathability thanks to the presence of the knitting loops, tailorability as it can be cut or knitted in a desired size, and most importantly the textile appearance which covers the need for better aesthetic than that of a film. Thanks to the uncountable knitting pattern choices the PTFE knitted fabric may obtain a desired attractive design. Thus the produced PTFE knitted fabric achieved a relatively nicer look, making it suitable to embed it directly on clothing, while at the same time it combines PTFE's robust characteristics in resistance to wear and tear.

After the cotton and knitted PTFE fabrics executed the required contacts, slidings and separations, the resulting V_{pp} was measured in the range of 124 mV and 188 mV. For the pair of modal and the knitted PTFE fabrics, the resulting V_{pp} was in the range of 98 mV to 186 mV. The distributions of the V_{pp} measurements are graphically presented in Figure 18.

To compare the efficiency of the knitted PTFE fabric with another form of PTFE, the sample of PTFE-coated glass fabric was paired with the modal and cotton samples respectively, and the measuring procedure was repeated. When using the knitted cotton fabric with the PTFE-coated glass fabric instead, the resulting V_{pp} ranged from 166 mV to 240 mV, while in the case of the knitted modal fabric and the PTFE-coated glass fabric, the resulting V_{pp} was in the range of 192 mV to 284 mV (Figure 18).

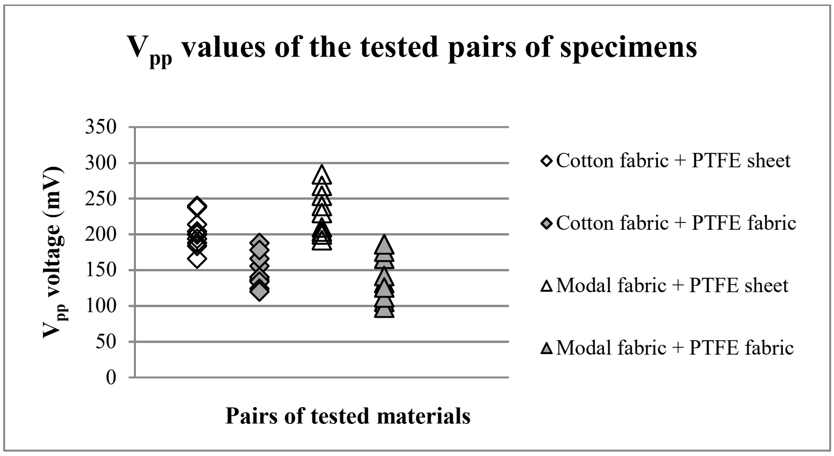

Figure 18. Distribution of the open circuit V_{pp} final values for each pair of the tested specimens after 500 repeats of contact, sliding and separation (weight load 20 grf, 23±1 oC, RH 40±2%).

By processing the measurements in the form of box plots to display their quartiles, it can be seen that the median values a significant difference between the values of PTFE-coated glass fabric and the knitted PTFE fabric when they are paired with cotton (Figure 19). The same applies to the modal sample.

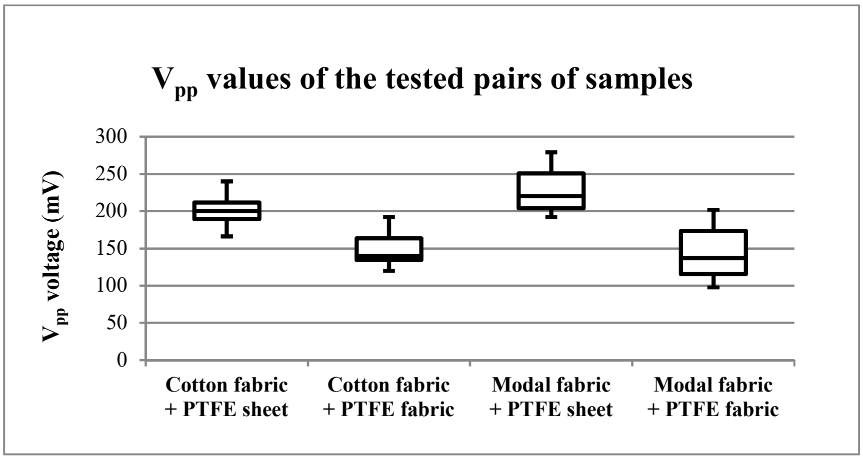

Figure 19. Median and quartile values of the open circuit V_{pp} final values for each pair of the tested specimens after 500 repeats of contact, sliding and separation (weight load 20 grf, 23±1 oC, RH 40±2%).

As it can comes from the results, the PTFE knitted fabric provided lower V_{pp} values in comparison with the PTFE coated glass fabric. This is most probably due to the low knitting density of the PTFE knitted fabric, which means a lower surface to participate in contact and rubbing than that one of the PTFE-coated glass fabric.

However, the lower values of the PTFE knitted fabric are significant amounts of voltage taking into account the small participating fabric area (25 cm^2) and the considerably low load which was applied between the two surfaces (50 grf). At this point it is very important to mention that the cotton and modal samples have not undergone any chemical treatment, so the electrical outcomes concern their raw condition. Apart from the knitting density, the voltage values may improve by increasing the TEG's participating surface areas [10]. This demand can be easily achieved as garments, trousers and other clothing provide adequately available areas to position greater TEG surfaces, which will be brought in contact and rubbed upon walking, running etc.

4. CONCLUSIONS

Numerous research articles refer to the use of PTFE material in TEGs thanks to its excellent triboelectric potentials. However, these are mostly limited to the use of PTFE as a film or a coating. Thus the excellent properties of PTFE material in the resistance to wear and tear make urge to examine its triboelectric behavior in a textile structure. This study exploits textile technology to build a knitted fabric made of PTFE filament. This sample is paired with each of two regular cellulosic textile samples, and examined as if it was a TEG embedded on the arm side of a garment. To achieve this, a prototype measuring TEG was used to simulate the arm's motion under a load of 50grf. The results of the proposed scheme depict significant electrical outcomes considering the small size of the samples (25 cm^2). The cotton and modal knitted fabrics reached a maximum V_{pp} of 188 mV and 186 mV respectively with the knitted PTFE fabric. Additionally, the cotton and modal knitted fabrics reached a maximum V_{pp} of 240 mV and 284 mV respectively when paired with a PTFE-coated glass fabric. The results show that the use of a knitted PTFE filament can provide both the option of an aesthetic knitted fabric and a considerable electric outcome thanks to triboelectricity. It must be noticed that the hereby used PTFE knitted fabric provided lower V_{pp} values than the PTFE-coated glass fabric, which is most possibly due to its lower participating surface area, while only one knitting pattern was examined keeping constant the course and wale densities. The application of more research in the direction of finding more optimal knitting patterns and structures is consequential to exploit the advantages which a PTFE knitted fabric can provide, achieving both efficiency and aesthetics in wearable TEGs. This work is summarized in the overall conclusion that textile technology must not stay limited to traditional applications but give significant solutions and contribute to other technological areas such as sustainable energy.

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5. REFERENCES

[1] LUO, J., WANG, Z. L., Recent progress of triboelectric nanogenerators: From fundamental theory to practical applications. EcoMat, 2020, vol. 2, no. 4, *doi: 10.1002/eom2.12059*.
[2] GOKHOOL, S., BAİRAGİ, S., KUMAR, C., MULVİHİLL, D. M. Reflections on boosting wearable triboelectric nanogenerator performance via interface optimisation. Results in Engineering, 2023, vol. 17, p. 100808, *doi: 10.1016/j.rineng.2022.100808*.
[3] NİU, L., MİAO, X., Lİ, Y., XİE, X., WEN, Z., JİANG, G. Surface Morphology Analysis of Knit Structure-Based Triboelectric Nanogenerator for Enhancing the Transfer Charge. Nanoscale Research Letters, 2020, vol. 15, no. 1, *doi: 10.1186/s11671-020-03401-1*.
[4] HAQUE, R. I., FARİNE, P.-A., BRİAND, D. Electrically conductive fabric based stretchable triboelectric energy harvester. Journal of Physics: Conference Series, 2016, vol. 773, p. 012005, *doi: 10.1088/1742-6596/773/1/012005*.
[5] PAOSANGTHONG, W., WAGİH, M., TORAH, R., BEEBY, S. Textile-based triboelectric nanogenerator with alternating positive and negative freestanding woven structure for harvesting sliding energy in all directions. Nano Energy, 2022, vol. 92, p. 106739, *doi: 10.1016/j.nanoen.2021.106739*.
[6] PHARİNO, U., AUSAMAN, K., PHONİMDANG, K., PONGAMPAİ, S., VİTTAYAKORN, W., MUANGHUA, R., ATİWONGSANGTHONG, N., CHAROONSUK, T., VİTTAYAKORN, N., “Water Repellent Modified Polyester Fabric Based Triboelectric Nanogenerator for Harvesting Human Mechanical Energies, 2022, Integrated Ferroelectrics, vol. 223, no. 1, pp. 127–136, doi: 10.1080/10584587.2021.1964292.
[7] TANG, Y., ZHOU, H., SUN, X., FENG, T., ZHAO, X., WANG, Z., LİANG, E., MAO, Y., Cotton-based naturally wearable power source for self-powered personal electronics, Journal of Materials Science, 2020, vol. 55, no. 6, pp. 2462–2470, doi: 10.1007/s10853-019-04095-2.
[8] REPOULİAS, A., ERTEKİN, M., GALATA, S. F., PESEZ, J., ANİCAUX, C., VASSİLİADİS, S., MARMARALİ A. The Effect of Ambient Humidity on the Performance of a Wearable Textile Triboelectric Generator, Energy Tech, 2023, p. ente.202201433, doi: 10.1002/ente.202201433.
[9] REPOULİAS, A., GALATA, S. F., KALLİVRETAKİ, A., MARMARALİ A., VASSİLİADİS, S. Performance investigation of textile triboelectric generators. In XVth International Izmir Textile and Apparel Symposium 2021, doi: https://doi.org/10.32710/tekstilvekonfeksiyon.1065348.
[10] GOMES, A., RODRİGUES, C., PEREİRA, A., VENTURA, J. Influence of thickness and contact area on the performance of PDMS-based triboelectric nanogenerators, 2018, doi: https://doi.org/10.48550/arXiv.1803.10070.

THE EFFECT OF USING GRAPHENE IN DENIM FABRICS ON THERMAL PERFORMANCE CHARACTERISTICS

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ABSTRACT

Graphene is well known with its light-weight and excellent thermal and electrical conducting properties. It has potential in using clothing industry for not only advanced technical properties but also comfort-related wearing properties due to thermal characteristics. This study investigates various thermal properties of graphene enriched denim fabric. The results pointed to thermoregulation performance of graphene like a phase change material.

Keywords: Graphene, denim, thermal diffusivity

1. INTRODUCTION

The use of graphene in textile surfaces resulted with advanced properties like enhanced electrical resistivity [1], hydrophobicity [2], thermal conductivity [3] and UV protection [4] which enabled to produce wearable e-textiles [5], adaptive optical textiles [6], textile-based temperature and pressure sensors [7,8]. Also, there are various studies on graphene utilization in clothing design for protective clothing, intelligent medical garments and adaptive clothing through IR emissivity. Thus, it is possible to produce graphene enriched garments that regulate the body temperature.

Denim, generally cotton woven fabric, is one of the most popular fabric type for clothing and has large global market share. Since it is known for advanced weight, abrasion resistance and tensile properties there are many studies in denim to add functionality and increased mechanical / thermal properties by utilizing chemicals and different fiber types [9-11]. This study investigates the thermoregulation performance of denim fabrics and to run objective measurements pointing it. For this purpose, commercially available graphene / PET blend yarns were used as weft in denim fabric (graphene denim) and thermal performance assessments comparing with conventional %100 cotton denim fabric (conventional denim) were completed by an in-house method based on thermal camera imaging along with objective thermal diffusivity, thermal absorptivity and maximum heat flux measurements. Graphene denim sample was found to have lower thermal capacity which is correlated with better thermo-response or thermoregulation.

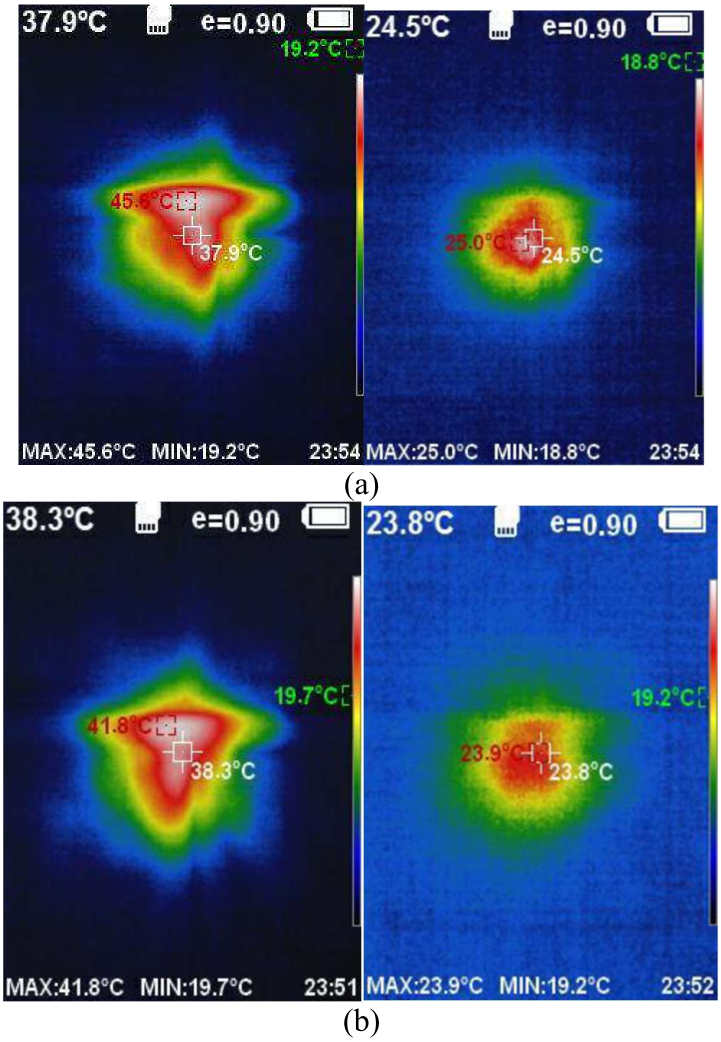
2. MATERIAL AND METHOD

Denim fabric sample was produced with Ne 14/1 cotton yarn as warp and 150/40 Denier polyester / graphene yarn as weft in 26 x 24 sett and 6.20 onz weight construction (graphene denim). The identical sample with %100 cotton (conventional denim) was also produced to use in comparison. The samples were subjected to rinsing before testing.

For the analysis, an in-house thermal camera imaging was applied to observe heat dissipation and calculate so-called “dissipation delta value. The testing is based on thermal camera monitoring of denim sample which placed at 4 cm distance with a heat source and after 1 minute of irradiation and repeating the procedure after 1 minute of cooling down by the removal of the heat source. Also thermal diffusivity, thermal absorptivity and maximum heat flux measurements were completed by the Alambeta Sensora device in accordance with device standard.

3. RESULTS AND DISCUSSIONS

Figure 1 shows thermal camera imaging of graphene denim and conventional denim samples. The hottest point after the irradiation phase for graphene denim was 45.6^{0}C and 41.8^{0}C for conventional sample. The same was recorded after cooling down. Thus, thermal dissipation from hot to cold was 20.6^{0}C (45,6^{0}C - 25^{0}C) for graphene denim and 17,9^{0}C (41,8^{0}C – 23.9^{0}C) for conventional denim sample.



(a)

(b)

Figure 1. Thermal camera imaging of a) grapheme denim b) conventional denim sample

Dissipation delta value was calculated through the thermal dissipation values of the samples as in Eq. 1:

$$\text{Dissipation Delta \%} = \frac{(45{,}6\text{-}25)}{(41.8\text{-}23{,}9)} \tag{1}$$

The dissipation delta difference in % was 1, 15 which points to increase of 15% on behalf of graphene denim.

Table 1 shows the results of the Alambeta measurements. The results are the average of five measurements. The results in Table 1 showed that graphene denim exhibited higher maximum heat flux as expected due to increased thermal conductivity, however it gave lower thermal absorptivity and increased thermal diffusivity. This finding agrees with some earlier studies on graphene [12] and calculated dissipation delta value.

Table 1. Thermal measurements of the samples

Sample	Thermal diffusivity (m^2/s)	Thermal absorptivity ($W/m^2s^{1/2}K$)	Maximum heat flux (W/m2)
Conventional denim	0,104	157,2	0,435
Graphene denim	0,191	122,8	0,565

4. CONCLUSIONS

The study is a comparison of thermal characteristics of graphene enriched denim and conventional denim samples. The results showed that graphene denim exhibited increased thermal diffusivity and heat flux which points reduced thermal capacity. The findings also revealed increased heat dissipation performance which corresponds better thermoregulation property.

5. REFERENCES

[1] KONGAHGE, D. et al. Fabrication of a graphene coated nonwoven textile for industrial applications. RSC Advances, 2016, vol.77, no.6, pp 73203-73209.
[2] TISSERA, N.D. et al. Hydrophobic cotton textile surfaces using an amphiphilic graphene oxide (GO) coating. Applied Surface Science, 2015, vol.324, pp 455-463.
[3] MANASOGLU, G. et al. Electrical resistivity and thermal conductivity properties of graphene-coated woven fabrics. Journal of Applied Polymer Science, 2019, vol.136, no.40, pp 48024-48032.
[4] OUADIL, B. et al. Surface modification of knit polyester fabric for mechanical, electrical and UV protection properties by coating with graphene oxide, graphene and graphene/silver nanocomposites. Applied Surface Science, 2017, vol. 414, pp 292-302.
[5] KARIM, N. et al. Scalable production of graphene-based wearable e-textiles. ACS Nano, 2017, vol.11, no.12, pp 12266-12275.
[6] ALONSO T. et al. Graphene electronic fibres with touch-sensing and light-emitting functionalities for smart textiles. NPJ Flexible Electronics 2018, volç2, no.25, pp 1-8.
[7] SADASIVUNI, K.K. et al. Reduced graphene oxide filled cellulose films for flexible temperature sensor application. Synthetic Metals, 2015, vol.206, pp 154-161.
[8] ZHU S.E. et al. Graphene based piezoresistive pressure sensor. Applied Physics Letters, 2013, vol.102, pp 161904-161912.
[9] VIJAYALAKSHMI, D., RAMACHANDRAN, T, Application of natural oil on light weight denim garment and analysis of its multi-functional performances. IJFTR, 2013, vol.38, no.3, pp 309-312.
[10] VIJAYALAKSHMI, D. et al. An experimental study on the multi-functional efficacy of nano TiO2 treated denim fabrics. Journal of Textile and Apparel Technology and Management, 2012, vol. 7, no. 4, pp. 1-12

[11] IBRAHIM, N.A. et al. Eco-friendly surface modification and multifunctionalization of cotton denim fabric. Egyptian Journal of Chemistry, 2022, vol. 65, no. 13, pp. 39 5 1
[12] EL-BROLOSSY, T.A., ALMUTAWA, A., Thermal diffusivity and thermal effusivity enhancement of graphene based polyvinyl chloride nanocomposites. IOP Conference Series: Materials Science and Engineering, 2020, vol.762, pp 0122006-0122017.

IMPLEMENTATION OF MODERN DYNAMIC APPROACH IN GARMENT PATTERN DESIGN FOR DEAF PEOPLE

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ABSTRACT

The analysis of the specific needs of the deaf community shows that during the motion of the hands, sign language speaking people require significantly more freedom in their clothing compared to hearing people. Therefore, our topic relates to the development an adaptive clothing with high wearing comfort for sign language speaking people based on the latest technical solutions in the field of clothing design. Typical sign language gestures were scanned with a high-performance MOVE4D scanner and the obtained data was automatically processed to investigate changes in the sizes of body parts during motion. The resulting dynamic measurements were used to create an ergonomic pattern construction, which was evaluated using virtual modeling. Moreover, based on the newest developed methodology, the impact of style and material parameters on the garment pressure was investigated. After analysis, the optimization of an pattern construction was carried out in the selected garment piece.

Key Words: 3D simulation, ergonomic, virtual fit, sign language

1. INTRODUCTION

Hearing loss is the fourth highest cause of disability globally. According to the World Health Organisation (WHO) over 5% of the world's population – or 430 million people – require rehabilitation to address their 'disabling' hearing loss (432 million adults and 34 million children). It is estimated that by 2050 over 700 million people – or one in every ten people – will have disabling hearing loss [1]. 'Disabling' hearing loss refers to hearing loss greater than 35 decibels (dB) in the better hearing ear. The following types of disease are defined:

1) Hearing loss - a person who is not able to hear as well as someone with normal hearing – hearing thresholds of 20 dB or better in both ears;
2) 'Hard of hearing' refers to people with hearing loss ranging from mild to severe;
3) 'Deaf' people mostly have profound hearing loss, which implies very little or no hearing. They often use sign language for communication [2].

We will focus on the last group, as due to the lack of "hearing-speech" communication, this group requires the greatest efforts in terms of social adaptation or rehabilitation.

The word Deaf with a capital D is used to refer to a group of people with similar medical conditions, which are hearing loss or deafness. Deaf people tend to communicate in sign language as their first language [3]. Signed languages (also known as sign languages) are languages that use the visual-gestural modality to convey meaning through manual articulations in combination with non-manual elements like the face and body. Similar to spoken languages, signed languages are natural languages governed by a set of linguistic rules [4]. One of the challenging aspects regarding the translation of signed languages compared to spoken languages is that while spoken languages usually have agreed-upon written forms, signed languages do not. Current data from the World

Federation of the Deaf suggest, there are more than 70 million deaf people worldwide. Totally, they use more than 300 different sign languages.

According to these trends, it is obvious why the deaf community is winning more and more attention in modern society. A significant number of scientists are working in various research fields on problems related to the social adaptation of Deafs. Millions of dollars are invested in research related to disease prevention and the development of tools for psychological and social adaptation. At the same time, the apparel industry is lowly involved in this trend. The main reason is the widely held belief, that hearing loss people have no special requirements in clothing, as they do not physiologically differ from hearing people. But there is another reason still presented in our daily lives is social discrimination against deaf people, also known as audism. Audism understands the world from the perspective of a hearing person, and how they face the situations and environments around them. Being a hearing person became a synonym of being normal. This pattern we have in society today, results in many people with hearing disabilities being denied of perceiving and affirming themselves as part of the deaf community. This sociocultural construct creates a very hard environment of exclusion, rejection and invisibility for deaf people [5]. However, both statements caused by external and internal impacts are false or only partially correct.

In the first case, it was not taken into account that the preferred method of communication for such people is sign language. Active manual articulation involves stress on the hands, which is significantly increased by the use of uncomfortable clothing. This is especially true for sign language interpreters. Interpreters from/to sign language play an important role to allow hearing, deaf, and hard of hearing people equal access to information and interactions. However, the complexities of the task, the types of visual interpreting, and the enormous range of qualifications brought by the interpreter make it anything but simple. Since the duration of one simultaneous interpretation cycle is up to 4 hours, clothing comfort is of particular importance for this group [6].

As for the tendency to conceal their affiliation with the deaf community, with changing the social acceptance vector towards inclusion it becomes irrelevant. Deaf organizations, associations, clubs, schools, events, and much more promote social interaction for deaf people. It may play an integral role in boosting one’s confidence with interactions that they may have found hard before, or rather find themselves overcoming obstacles that impede them on their path to be treated with equity.

The fashion product for deaf people are coming up as response to these trends. Some brands offer customisation of clothing for hearing impaired people through colour design or printed information images [7-9]. Another trend is the use of built-in electronic elements that can reinforce sound or simulate acoustic recording [10-11]. At the same time, any research on improving the wear comfort of garments for sign language speaking persons was not found in the available sources.

Since the use of sign language to communicate is the major functional environment for such people, clothing products in this category must be developed with the optimal ergonomic solution. While also keeping in mind that the product must allow the wearer to perform repetitive movements of relatively constant amplitude for a certain time without any stress to provide the wearer with a necessary comfort. For this reason, clothing for the Deafs should be defined as functional clothing and an ergonomic approach should be used for its design that accounts the peculiarities of the functional environment formed by communication in sign language.

Ergonomic considerations dictate that the mechanical characteristics of clothing match the motion, degree of freedom, range of motion and force, and moment of human joints. The working postures, materials handling, movements, workplace layout, safety and health considerations should be given due consideration while developing the style, cut and features of a functional garment [12]. For products belonging to the functional clothing, these factors are ensured by design (using optimal amounts of constructive additions according to the dynamic effects of the dimensions of the body), constructive elements (vents or folds), and by combining materials with different mechanical properties appropriate to the final purpose of the product.

Since the technological evolution from 3D to 4D scanning systems enabled scanning in motion, significant advances in the development of functional clothing have occurred. In this case, more attention is paid to determining the typical positions for a particular field of functional activity, on which basis kinematic models for further virtual clothing design are developed. The popularization of such new technologies is an important factor in helping speed up the development chain and save resources within the clothing industry [13]. Therefore, our topic relates to improving the ergonomics of a formal jacket for sign language speakers by integrating data on human body dynamics obtained through 4D scanning for further use in clothing design.

Clothing design and fitting have been moving into the 2D and 3D virtual space for a long time. Currently, in the apparel industry, 2D CAD is being used for designing made-to-measure (MTM) patterns, while 3D CAD programs are available to meet the requirements of virtual prototyping. This technology includes V stitcher™ by Browzwear (Browzwear® Solutions Pte. Ltd, Singapore; 3D Runway from OptiTex, Ltd, Israel; AccuMark 3D from Gerber Technology, Tolland, USA; TUKA3D (Tukatech Inc., USA); Modaris 3D Fit from Lectra Modaris, France; and Vidya from Assyst, Germany. More recently, two other solutions were added with similar capabilities, namely, CLO 3D (CLO Virtual Fashion LLC, Korea), and Marvelous Designer (CLO Virtual Fashion Inc.) [14]. Some 3D software programs, like Lectra Modaris, offer for example the option to fit the garment on an avatar in a static position, with the sole option to lower the arms for a more “relaxed” pose. Others like Clo3D and Browzwear offer the option to add animations to your avatar in simulation mode. The last option is commonly used to improve the ergonomics of the garment. Using this software can not only greatly reduce the duration of the design process, but also save the cost and time of production, making it a very convenient and practical clothing design software. At the same time, a certain evaluation of the designed virtual clothing can be also made through this software [15].

The availability of fit analysis tools and the ability to animate the developed designs ensures that Clo3D is widely used in scientific research related to ergonomic clothing design. So, in the paper [16], the authors propose an ergonomic and personalised approach for designing the patterns for a men’s jacket model with a fitted silhouette (business casual outfit) using digital tools while integrating data regarding the dynamics of the human body to improve functionality and comfort. They use Clo3D to analyse the balance and fit of the product on the avatar in static and dynamic positions to determine how well the product fit on the different parts of the body, whether the constructive, stylistic details of the model were preserved, and whether there were areas of the product with possible constructive defects. The aim of the study [17] was to improve garment pattern design for cycling sports from the aspect of clothing pressure to provide support and enhance comfort to the user. This paper investigated the suitability of pressure maps from 3D fashion design software CLO 3D for design. Moreover, the impact of the mechanical properties of fabric was analyzed. In particular, the virtual prototyping tool CLO 3D and pressure mapping were employed to achieve the required compression while ensuring fit and comfort in static and dynamic cycling positions. The impact of fabric types on garment fit has been shown by generating the stress, strain, and pressure maps with a virtual simulation. The output was found to be sufficiently accurate to optimize the garments based on material and cycling posture.

Although research and development of virtual fitting systems have attracted a large number of researchers, the key technologies for virtual fit evaluation are still immature, and some problems have not been well solved. Eg. there is no clear protocol for garment fit testing of the 3D simulation programs. However, they offer a comprehensive set of tools for checking the digital fit. These tools allow us to analyse the structural changes of the textile through the material parameters and impact of the avatar. So far, the evaluation of clothing fit and its characteristics is performed visually [16, 17]. Quantitative assessment is only possible at certain predetermined points and not over the entire surface of the product [18-20]. Both ways do not provide the necessary accuracy and reproducibility of research and do not allow the use of these data for analysis and prognosis.

With these aspects in mind, this study aims to improve the ergonomics of a formal jacket for people who use sign language in everyday life by matching the motion with mechanical characteristics of clothing and by using a new approach to clothing fit assessment in virtual simulation systems.

2. MATERIAL AND METHOD

2.1 Material

Since the objectives of this work involve the creation of formal clothing for people who use sign language, including sign language interpreters, we have chosen linen outerwear fabric. Virtual fabric prototypes from the Clo3D database were used to simulate the designed product. However, the real values of the mechanical properties of fabric determined by common testing instruments cannot be uploaded to the library of CLO 3D simulation software directly. The software provides relative values of the mechanical properties of fabric automatically for the fabric chosen. The selected materials are characterised by the following properties:

Construction		Woven
Composition		55 Linen, 45 Cotton
Weight		186 g/m^2
Thickness		0,4 mm
Stretch[5]	weft	58
	warp	59
Bending[1]	weft	47
	warp	53

2.2 Method

Study of the typical movements of sign language

Since the main objective of our research was to develop an ergonomic construction, it was important to study the product's behavior on the body shape during movement. In this case, the movements should correspond to the typical ones for the investigated functional environment.

In order to analyze typical motions and develop their virtual prototypes, modern high-speed 4D-scanning technology is used. The scanning is performed with the MOVE4D scanner, installed in

[5] The fabric's tensile properties don't follow existing standards. They were obtained through a testing instrument composed as part of the software for creating a digital fabric library in CLO 3D software. The units of measurement are virtual units, v.u.). To refer to the fabric elasticity, the term "stretch" will be used in further discussion, according to the CLO 3D manual.

the scan lab of the Chair of development and assembly of textile products, ITM, TU Dresden, Germany. The scanner consists of 12 scanning modules, which are able to record motion with a special resolution up to 1 mm and up to 180 frames per second.

MOVE4D software generates automatically homologous meshes during the processing of scanned data. All approximate 50k vertices are moving with the body between the frames while remaining associated with the same body parts. It means that these vertices can be considered as landmarks and can be used for analysis of the motion. This special feature is used in the current work.

After the scanning and data processing, a large list of files with the body geometry, associated textures and light data are available. To simplify the data processing, at the Institute of Textile Machinery and High-Performance Material the TU Dresden was developed a Matlab workflow to automatically estimate the distances between selected points within each frame based on the mesh vertex IDS data. Using this program, we calculated the changes in the distances of the body surface measurements during selected typical movements.

Development of the basic pattern construction

The basic pattern construction of a women's jacket for a typical female figure was designed in Graphis CAD. Graphis CAD is a reputed system for parametric garment design. The pattern construction can be created in two ways: using integrated interactive modules or by computational and graphical generating. The construction is based on a flexible system of measurements, and the design process is recorded in the form of an algorithm. An additional advantage is automatic grading. These capabilities of Graphis CAD allow you to quickly adapt finished constructions to new requirements while ensuring high fit quality.

Virtual simulation of the product and fit quality assessment

The developed basic pattern construction was imported into the virtual simulation program Clo3D. The process of simulating a garment in Clo3D involves the virtual stitching of parts and their placement on a virtual mannequin. The software's functionality allows you to assess the quality of the product's fit not only visually, but also based on the specially developed tools. Clo3D offers three different tools for analysis, the stress map, the strain map, the pressure point map and the fit map (Table 1). These maps are calculated within the simulation and displayed in a colour gradient over a specific range. The Strain Map calculates the deformation of the textile by external influences. The stress map indicates the stretching of the textile. The pressure points show where the textile is in direct contact with the avatar's surface. The fit map calculates the three previous values and indicates where the clothing fits tightly or cannot be worn at all.

Table1. Garment Fit Maps in the 3D window to check 3D Gament's fit*

Stress Map	External stress causing garment distortion per area of the fabric appears in the range of color and numbers. Stress Map appears in a total of eight colours: Red indicates the strongest stress (100kPa) while blue indicates zero distortion (0.00kPa). Other numbers in between are expressed as the gradation of two colours.
Strain Map	Garment's distortion rate due to external stress appears in percentage. Stain Map appears in a total of eight colours: Red indicates 120% of

	distortion rate while blue indicates 100% (no distortion). Numbers in between are expressed as the gradation of two colours.
Fit Map	Fip Map shows the tightness of the 3D Garment. Can't Wear appears in red indicating not wearable area. Very Tight appears in orange indicating a very tight area. Tight appears in yellow indicating a slightly tight area. Show Pressure Points Show or hide contact points between 3D Garment and Avatar.

*[Garment Fit Maps Copyright © 2023 CLO Virtual Fashion LLC. All Rights Reserved. https://support.clo3d.com/hc/en-us/articles/360000436368-Garment-Fit-Maps]

3. RESULTS AND DISCUSSION

Ensuring the dynamic fit of clothing is based on the study of movements that are typical for a given functional environment. In our case, the task relates to the study and classification of sign language movements in order to take them into account when providing dynamic compliance. For this purpose, an interpreter with 30 years of experience in sign language communication and sign language interpreting was also consulted. In addition, methodological guidance for sign language interpreters was examined and several sign language videos were watched. On this basis, the typical shoulder and forearm movements were determined, which represent the basis for the vast majority of the signs. A kinematical model from the field of modern biomechanics was used to schematically represent and record the results. In modern biomechanics, the human body is viewed as a biocinematic chain in which each limb has its numbering and can perform three types of movement, which can be recorded in vector or coordinate form [21]. Using the described procedure typified patterns of basic sign language movements were developed to be adopted in the following research phases.

In order to bring the study conditions closer to the real usage environment, we scanned typical sign language movements with a 4D scanner. The procedure of scanning and processing the data obtained is explained in detail in [22]. To simplify of the received data analysis, a new script in the programming environment Matlab of the company MathWorks was created. To analyze the lengths of the selected measurements, these curves were defined and saved as a list of vertex indices. After processing all files, the discrete described curves from all selected frames were plotted and their length were computed and visualized (Figure 1). The workflow for this processing in detail and open issues were reported in [23]. This methodology allowed us to extract particular frames from the obtained dataset that are critical for providing ergonomics during sign language communication, further called extreme postures. In addition, the values of the maximum dynamic effect of body dimensions affecting the pattern construction were determined (Table 2).

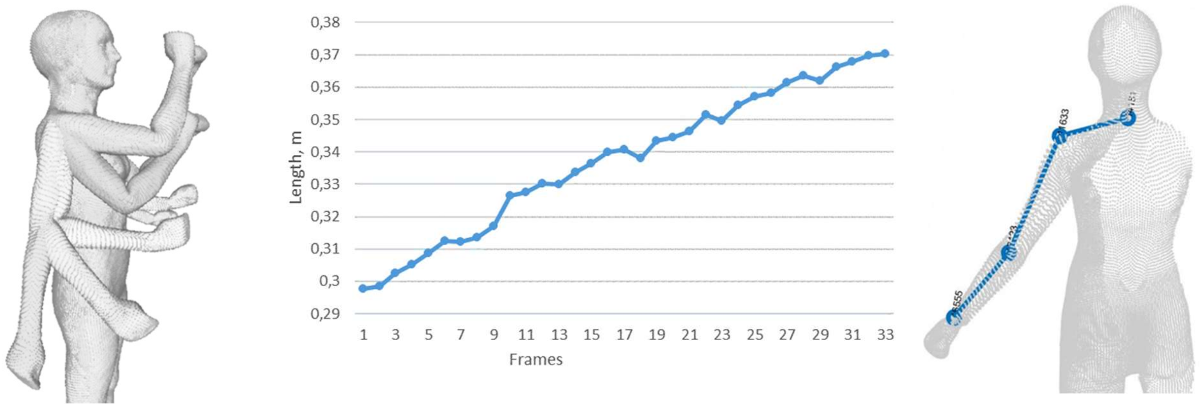
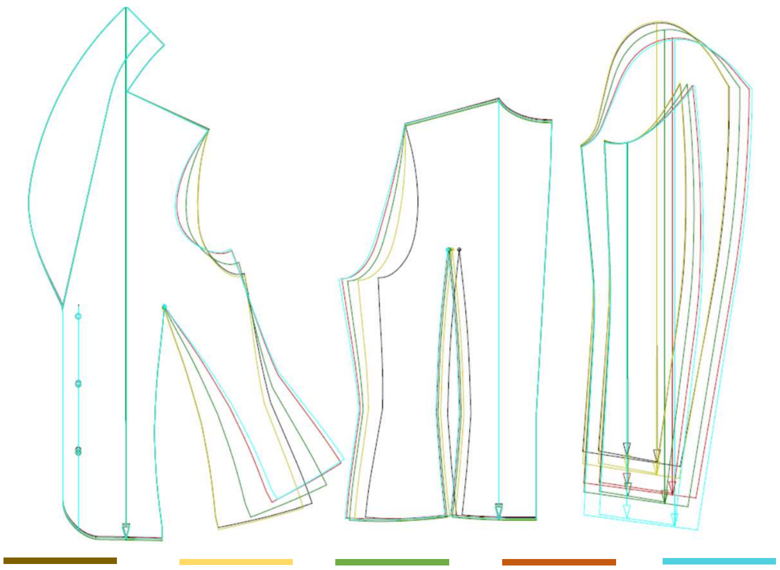


Figure 1. Change the position and length of selected segments in motion

Table 2. Calculation of measurements for deaf people's clothing design

Measurement	Body dimension in static, mm	Body dimension in dynamic, mm	Dynamic effect absolute, mm	Dynamic effect relative, %
7CV to waist	396	415	19	5
Arm length	519	567	48	9
Arm girth	239	255	16	7
Back armpits	300	374	74	25
Front armpits	287	242	-45	15

The measurements shown in Table 2 were determined on a sample of a female size 36 according to the European size system. These measurements were taken for each separate captured frame during the scanning of a series of sign language movements. After that, the data was statistically analysed. The values of the following statistical parameters were determined by the confidence level of 95.0%: mean value, standard error, median, mode, standard deviation, minimum, and maximum. The maximum value from the entire series of captured frames was adopted as the body dimension in dynamic. The largest dynamic effect was observed in the arm length and back width. The increase in the Back armpits measurement is up to 25%.



At the next stage of our research, the basic pattern construction of the women's formal jacket was developed. Since the ergonomic approach involves the integration of dynamic measurement into the design parameters, it was necessary to develop a flexible system. This became possible due to the mentioned advantages of the GRAFIS software. The main

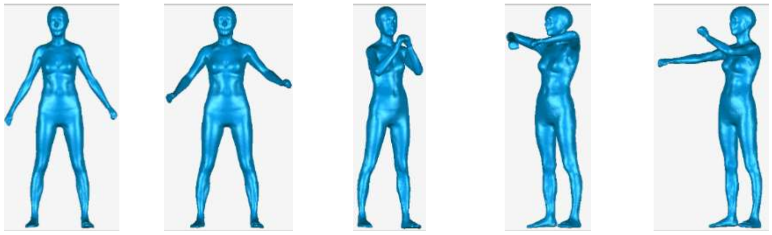


Figure 2. Comparative analysis of the motion-oriented design geometry

constructive ease allowances in the construction process were set in the form of variable values (X-Werte). Varying these values made it possible to track how the configuration and arrangement of certain parts of the construction changes while adapting to a particular sign language movement.

Most of the parametric changes concern the width of the back and front parts, the width and length of the sleeves, and the dimensions of the dart, which causes further deformations of the armhole and the sleeve cap (Figure 2). It is obvious that ensuring ergonomics in a constructive way will lead to a complete deformation of the product shape and occurs planty fitting defects in the product. This option is unacceptable, as the jacket is a formal casual garment supposed to have a good appearance in static positions and retain it during typical movements.

Therefore, it was decided to use another approach, which involves compensating for dynamic growth by combining the ease allowances and elasticity of the material. For this purpose, it was necessary to investigate the impact of these factors on the ergonomics of the construction and the quality of the product's fit. The research was performed according to the following workflow:
⇒ Importing 2D flat pattern
⇒ Fabric properties adjustment
⇒ Importing 3D human body model in a motion corresponded to critical sign language postures
⇒ Arrangement and simulation of the product in Clo3D
⇒ StressMap recording while varying the ease allowances and fabric elasticity
⇒ Picture cluster generation based on the obtained images
⇒ Colour extraction and plotting graphs
⇒ Calculating and graphical analysis of the data obtained
⇒ Optimum determination for the studied variables
⇒ Validation of the results

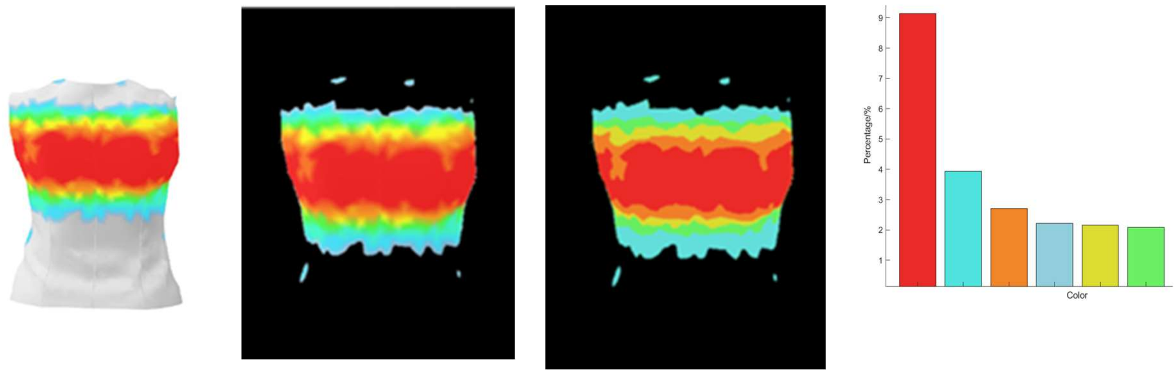
The virtual prototyping process covers several work steps, starting with a 2D pattern preparation and ending with the development of a final virtual prototype. To simulate the product, the details of a women's jacket designed in Graphis CAD with typical for this product range ease allowances were imported into the 2D area of the Clo3D software and assembled. The linen fabric from the virtual Clo 3D database was selected as the top fabric and then the properties were adjusted and processed (Table 1). Once the virtual garment has been assembled and placed roughly on the avatar, the real process is simulated in the avatar window using the CLO 3D interface. Analysis of garment fitting has been done through optical assessment, stress, and fit maps, created during the simulation process for the garment prototype. So, Figure 3a shows a defect in the back width caused by an increase in the back width ease by the amount of dynamic effect. At the next stage, the static mannequin in the static A-pose was replaced by a dynamic mannequin, whose pose corresponds to the extreme postures of sign language movements (Figure 3b). The Stress Map was evaluated for the chosen conditions (Figure 3c). The Stress Map shows the external stress causing garment pressure and appears in an arrangement of colors with the number where the red color indicates the highest stress while the blue color indicates zero distortion. As we can see, moving the hands forward and to the top, which is the dominant hand position when communicating in sign language, is accompanied by a significant effort for the consumer due to increased pressure in the middle back and elbows.

a b c

Figure 3. Dynamic fit analysis through virtual simulation

In order to avoid these defects, the virtual garment's behavior on the avatar was studied by changing the "stretch" of the fabric in the range from 40 to 70 virtual units, and by varying the back width ease in increments of ±1cm.

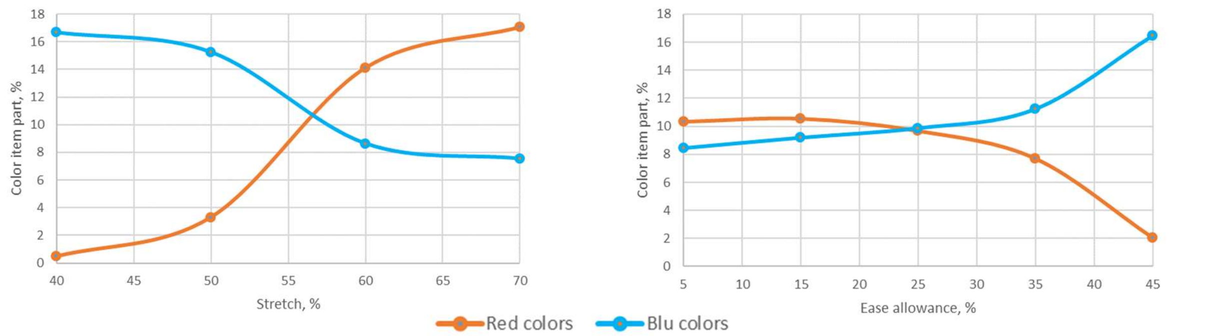
The images generated in Clo3d had to be quantified to trace the interaction between these factors. For this purpose, the following methodology was proposed. Using the Matlab software environment the obtained images have been clustered and the main colours reflected in the Stress Map images have been identified (Figure 4).



a b c d

Figure 4. Stress map image color analysis in Matlab:
(a) Clo3d image; (b) original image; (c) cluster stress map image; (d) color histogram

The program also allows exporting of numerical data describing the percentage of a particular colour in the image to be analysed. In our case, black was excluded as a background colour. The resulting colour palette was divided into two groups. The first group consisted of red and yellow colour spectrum characterised areas with high pressure (58-100 kPa[6]), the presence of which is interpreted by the system as unacceptable. The second group of colours consisted of the green and blue colour spectrum (0-42 kPa[2]), which characterise acceptable pressure values not significantly affecting the ergonomics of the product. It is obvious that the trend of changes in the values for these two groups is inversely proportional. The results of the graphical analysis of the impact of material elasticity (Stretch) and the back width ease on the stress value are shown below.



a b

Figure 4. Graphs of the impact of material elasticity (Stretch) (a) and the back width ease (b) on the stress value

As we can see, the percentage of red colours rises rapidly with increasing "stretch"-properties of the materials, especially in the range from 50 to 60 v.u. Most suit fabrics belong to this "stretch" range. At the same time, the growth trend in the red colour ratio with increasing ease allowances values is much less. This indicates that the most effective way to ensure ergonomics in the pattern construction is to use elastic materials. An increase in the value of the ease allowances leads to the occurrence of fit defects and has a much smaller impact on the high-pressure area in the garment. Thus, by varying the amount of eases and selecting materials with appropriate elasticity properties, the existing conflict between ergonomic design and a good fit can be resolved. By integrating the

[6] kPa are pressure units used in the Clo3D simulation software to characterise external stress causing garment distortion per fabric surface in the Stress Map. Their correlation with standard pressure values has not been investigated

obtained results into the design process of fitted fashionable garments, the resulting garment product will better meet the customer's requirements and will significantly increase their confidence and satisfaction degree.

4. CONCLUSION

An important aspect of designing ergonomic functional clothing is to take into account the typical movements of the usage environment. In the case of deaf people, these are movements of sign language. The use of modern scanning and data processing methods made it possible to obtain detailed information about the kinetics of the studied sign language movements and create virtual animated prototypes for further export to virtual 3D clothing design systems. By integrating dynamic data into the design process of fitted fashionable garments, the resulting garment product will better meet the customer's freedom of movement and will increase their well-being.

Changes in the shape of body parts during communication in sign language, which significantly affect the parameters of clothing design, have been studied. Based on the obtained dynamic measurements, an ergonomic pattern construction was created. It was shown that ensuring ergonomics by dynamic measurement will lead to a complete distortion of the product shape and cause planty fitting defects in the product. This option is unacceptable, as the jacket is a formal casual garment supposed to have a good appearance in static positions and retain it during typical movements. Therefore, a new procedure has been proposed to ensure the ergonomics combined with a good fit.

The 3D visualization of the model on the animated avatar enabled the identification of design solutions based on the ergonomic criteria of functional clothing models. The ability to visualize the level of pressure provided useful information for the optimization of material and style parameters while considering the requirements for wearing comfort. Since the problematic point of all previous studies was the quantitative assessment of Garment Fit Maps in Clo3D, we proposed a methodology for solving this issue by applying colour extraction. Based on the developed methodology, the impact of ease allowances and material elasticity on garment pressure were investigated. The resulting data were used to develop recommendations for the design of an ergonomic construction with a good fit for people who communicate in sign language. The application of the developed approach can be extended to other functional clothing ranges.

Future research will deal with sleeve parameters because the sleeves have the second largest areas of high garment pressure after the back part caused by the design's non-compliance with ergonomic requirements. The next step will be the automation of the developed approach, which will help reduce the time required for data processing and analysis. Of course, the selected clothing range is a multi-layered construction and the presence of additional layers may change the results obtained.

The presented study can be applied for future analyses and operational validations regarding the optimal values for ease allowances, multilayered structures that are typical for a jacket, and other types of materials. The results provided a theoretical basis and practical guidance for clothing designers, and engineers involved in functional clothing design, and assisted in evaluating the garment fit while using a virtual simulation system.

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5. REFERENCES

[1] WORLD HEALTH ORGANISATION. 2023, February 27. Deafness and hearing loss. Retrieved from https://www.who.int/news-room/fact-sheets/detail/deafness-and-hearing-loss

[2] UNIVERSITY OF WASHINGTON. 2022, Mai 05. How are the terms deaf, deafened, hard of hearing, and hearing impaired typically used? Retrieved from https://www.washington.edu/doit/how-are-terms-deaf-deafened-hard-hearing-and-hearing-impaired-typically-used

[3] FERNANDA FOGGETTI. 2023, March 23. The Deaf Community: What it is, Characteristics and Who is part of it. Retrieved from https://www.handtalk.me/en/blog/deaf-community/

[4] SANDLER, WENDY, AND DIANE LILLO-MARTIN, Sign Language and Linguistic Universals, Cambridge University Press, 2006

[5] ANA SOFIA GALA, 2022, Juli 28. Audism and the discrimination against deaf people. Retrieved from https://www.handtalk.me/en/blog/audism/

[6] ADAM, R., ARO, M., DRUETTA, J. C., DUNNE, S., & AF KLINTBERG, J. (2014). Deaf interpreters: An introduction. Deaf interpreters at work. *International insights*, 1, 18.

[7] https://www.deafapparel.com

[8] https://deafclothing.com

[9] ELLIE PARFITT. 2019, October 21. Introducing a new Fashion Brand: DEAF IDENTITY. Retrieved from https://www.hearinglikeme.com/introducing-a-new-fashion-brand-deaf-identity

[10] URSIN CADERAS. 2020, September 7. Vibrating suit allows deaf people to 'feel' music By, CNN Retrieved from https://edition.cnn.com/style/article/chase-burton-vibrating-suit-spc-intl/index.html

[11] MICHELLA MAIORANA-BASAS , CLAUDIA M. (2014) Pagliaro, Technology Use Among Adults Who Are Deaf and Hard of Hearing: A National Survey. *The Journal of Deaf Studies and Deaf Education*, 19(3), 400–410, https://doi.org/10.1093/deafed/enu005

[12] GUPTA, DEEPTI. (2011). Design and engineering of functional clothing. *Indian Journal of Fibre and Textile Research*, 36, 327-335.

[13] KLEPSER, A., & MORLOCK, S. (2020). 4D Scanning - Dynamic View on Body Measurements. *Communications in Development and Assembling of Textile Products*, 1(1), 30-38. https://doi.org/10.25367/cdatp.2020.1.p30-38

[14] CHAUDHARY S, KUMAR P, JOHRI P. (2020) Maximizing performance of apparel manufacturing industry through CAD adoption. *International Journal of Engineering Business Management.* 12. doi:10.1177/1847979020975528

[15] YAN-XUE WANG & ZHENG-DONG LIU . (2020). Virtual Clothing Display Platform Based on CLO3D and Evaluation of Fit. *Journal of Fiber Bioengineering and Informatics*, 13 (1), 37-49. doi:10.3993/jfbim00338

[16] AVADANEI, M.L. , OLARU, S. , DULGHERIU, I. , IONESI, S.D. , LOGHIN, E.C. , IONESCU, I. A (2022) New Approach to Dynamic Anthropometry for the Ergonomic Design of a Fashionable Personalised Garment. *Sustainability*, 14, 7602. https://doi.org/ 10.3390/su14137602

[17] TEYEME, YETANAWORK & MALENGIER, B. & TESFAYE, TAMRAT & VASILE, SIMONA & VAN LANGENHOVE, LIEVA. (2023). Fit and pressure comfort evaluation on a virtual prototype of a tight-fit cycling shirt. *Autex Research Journal*. 23. 10.2478/aut-2021-0057.

[18] R. WU AND Z. LIU. (2022) Research on Improving Garment Fit through CLO 3D Modeling. International Seminar on Computer Science and Engineering Technology (SCSET), Indianapolis, IN, USA, 2022, pp. 204-207, doi: 10.1109/SCSET55041.2022.00055.

[19] SHUXIAN HUANG, LI HUANG. (2022) CLO3D-Based 3D Virtual Fitting Technology of Down Jacket and Simulation Research on Dynamic Effect of Cloth. *Wireless Communications and Mobile Computing*, 2022, Article ID 5835026, 11 pages. https://doi.org/10.1155/2022/5835026

[20] LIU, WEIYI & YAO, TONG & YAO, CHONG & LIU, PEI. (2021). Research on Pressure Comfort of Yoga Suit and Optimization Scheme of Pattern Based on CLO 3D Software. *Journal of Physics: Conference Series*. 1790. 012016. 10.1088/1742-6596/1790/1/012016.

[21] ROUPA, I., DA SILVA, M.R., MARQUES, F. ET AL. (2022) On the Modeling of Biomechanical Systems for Human Movement Analysis: A Narrative Review. *Arch Computat Methods Eng*. 29, 4915–4958 . https://doi.org/10.1007/s11831-022-09757-0

[22] SADRETDINOVA, N., KYOSEV, Y. 2022, 25-26 Oct. Method for Evaluation of the Motion Comfort of the Clothing for Deaf People Using of High Speed (4D) Scanning. In: Proc. of 3DBODY.TECH 2022 - 13th Int. Conf. and Exh. on 3D Body Scanning and Processing Technologies. Lugano, Switzerland. https://doi.org/10.15221/22.60.

[23] KYOSEV, Y. ET AL. 2022, 25-26 Oct. Method for Automatic Analysis of the Clothing Related Body Dimension Changes During Motion Using High-Speed (4D) Body Scanning. In: Proc. of 3DBODY.TECH 2022 - 13th Int. Conf. and Exh. on 3D Body Scanning and Processing Technologies. Lugano, Switzerland. https://doi.org/10.15221/22.24

DEVELOPMENT OF A PRODUCTION SYSTEM FOR BLEACHING MACHINES INDEPENDENT OF HUMAN CONTROL AND AIMING THE RIGHT PRODUCTION AT ONCE

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ABSTRACT

This study delves into the integration of Industry 4.0 principles within the textile industry, with a particular emphasis on automating machine parameter adjustments during the bleaching process. Industry 4.0, characterized by its hallmark features of automation, data-driven decision-making, and heightened efficiency, stands as a pivotal transformation across various industrial sectors. In the context of the textile industry, historically pivotal in the realm of industrialization, the adoption of Industry 4.0 is poised to deliver substantial advantages. These include heightened operational efficiency, reduced operational costs, elevated product quality, and enhanced customer satisfaction. This study primarily revolves around the automation of machine settings within a bleaching machine, with the overarching goal of diminishing human intervention while ensuring standardized production protocols. The cornerstone of this research is the development of a system adapt at seamlessly transmitting vital parameters contingent on the fabric type. This pivotal system not only fosters error reduction but also optimizes resource utilization. By achieving this, the study contributes significantly to the establishment of smart factories of Industry 4.0. The implementation strategy encompasses robust industrial communication systems, prominently featuring SCADA (Supervisory Control and Data Acquisition) and RFID (Radio-Frequency Identification) technology. These systems are instrumental in monitoring and governing the intricacies of the production process.

The outcomes of this research exemplify the successful blend of Industry 4.0 concepts into the textile sector. This integration dramatically curtails human involvement in the fine-tuning of machine parameters, ultimately elevating production efficiency to new heights. At last, this research emphasizes the transformative potential of Industry 4.0 within the textile industry, especially in error-prone processes like bleaching, offering a glimpse into a future where manufacturing operations are revolutionized.

Keywords: Industry 4.0, Digitalizing, Home Textile Production Steps

1. INTRODUCTION

Industry 4.0, which is stated with terminologies such as Digital Transformation, Digitizing Industry, Fourth Industry Evolution, is a collective term that encompasses automation system, data interchange and production technologies, where business activities are handled with data-based scientific methodologies. Industry 4.0 generally starts with the purchase of raw materials, producing products, delivering them to the consumer, and then recycling, deterioration, etc. It alludes to the continued use of emerging technologies to improve processes at all points along the supply chain, including the recall of reasons[1]. Industry 4.0 applications offer considerable improvements in terms of production efficiency, product quality, resource, time, and energy savings and are now widely used across a variety of industries. Speed, width-depth, and system effect are three of Industry 4.0's most significant defining characteristics. The competition between businesses and nations is made up of these three defining characteristics. As a result of this conflict, it is expected that enterprises and countries that do not comply with these three aspects would suffer large losses in the coming periods[2]. It becomes clear that the textile industry was the primary sector at the outset of the industrialization revolution in many developed nations. As a consequence of the studies, it is determined that integrating business 4.0 into the textile business has numerous advantages, including improved efficiency, decreased operating costs, improved quality, transparency, sped-up order delivery, and enhanced customer satisfaction[3]. Due to the challenges faced in the production of the textile industry, it is expected in a different study done in Germany that Industry 4.0 would be in a better position thanks to the manufacturers of system software and current machinery in the textile sector[4].

Yosumaz et al. in their study, they make sure that various parameters, including employee performance information, machine capacity information, machine fault conditions information, machine temperature and vibration information, and machine usability status are tracked with Industry 4.0 applications integrated into the production processes of the ready-made clothing company [5]. In a different study by Gökalp et al., studies were done into the development of a smart clothing factory in the ready-made clothes sector, and Industry 4.0 applications were recommended for the process from the acquisition of raw materials through the packing and delivery of the product to the customer [3].

As a result of these researches, it is predicted that many processes in the textile industry can be included in Industry 4.0 applications. There are many error-prone processes in the textile industry. One of these is bleaching, which is the removal of the color of raw textiles by removing natural pigments. Thanks to the bleaching process, a constant whiteness value is obtained in the fabrics and thus color problems that may be encountered in the subsequent processes are avoided. There are multiple dependent and independent variables in this process. Making these variables manually by the operator makes this process an error-prone process.

This study's goal is to develop a smart factory based on preventing human-induced errors in the machine parameter settings for the fabric type in the bleaching machine. The goal of integrating Industry 4.0 into the production system is to move the decision-making process to the system by focusing on machine adjustment. The system will become error-proof in this way, and potential issues will be resolved. As a result, it aims to standardize production, prevent quality-related issues by producing the proper amount at once, and utilize resources as efficiently as possible.

2. MATERIALS AND METHODS

2.1. Machinery

In cotton textile production processes, bleaching machine used in the pre-treatment process as a crucial step. The bleaching stage plays a critical role in ensuring the precise whiteness of next processes, including printing, dyeing, and final finishing. In this study, automatization technologies were applied on the Küsters 1996 bleaching machine. The primary purpose of the bleaching process is to remove the natural ecru color derived from the cotton's natural structure in order to obtain white fabrics. Additionally, it is crucial for removing the inherent oils, impurities, and natural dyes present in cotton, aiming to achieve a consistent canvas with uniform properties before dyeing. Hydrogen peroxide serves as the key chemical agent in the bleaching process, functioning as an oxidizer. Caustic, stabilizer, wetting agent, and ion binder constitute the other chemicals in the bleaching recipe. Figure 1 represents the relevant bleaching machine.

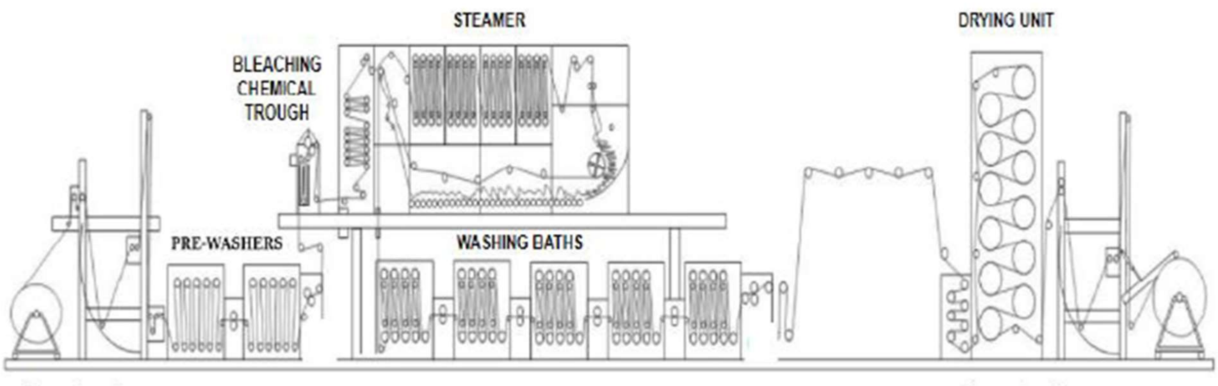

Figure 1. Bleaching Machine

In general, the machine parameters on the bleaching machine are manually adjusted by operators through the PLC interface. The operator-set parameters are segregated into two distinct categories: variable parameters and fixed parameters. Variable parameters encompass those that fluctuate in response to factors like fabric quality, width, and the specific process in use. In contrast, fixed parameters encompass those that remain constant and are essential for the machine to function optimally, such as steam pressure, bath temperature, and the status of the vacuum system. The primary aim of this study is to devise a system that eradicates the need for operator intervention in handling variable parameters, and subsequently integrate this system seamlessly into the machine's PLC interface. This effectively eliminates human involvement and ensures that production consistently adheres to the same critical machine settings. As a result, fabrics emerging from the bleaching process consistently exhibit specific characteristics tailored to their fabric type. By implementing a system that enables accurate production in a single cycle, we can proactively avoid inefficiencies such as repairs, additional processing steps, and quality issues. Furthermore, this approach contributes to a reduction in resource consumption, including energy and water, while simultaneously boosting machine capacity. Ultimately, this paves the way for increased production output, aligning with our goal of enhancing efficiency and productivity.

2.2. Industrial Communication

The SCADA system plays a crucial role in managing various procedures, including monitoring raw materials, production processes, and final products. It operates in a virtual environment, collecting data from sensors installed on machines during their physical operations. These sensors convert real-world events into electrical data (analog signals), which are then converted into digital information using D/A (digital/analog) converters before being transmitted to the computer. For on-off actions, such as the presence or absence of an object, direct communication with the computer is possible without D/A conversion. The SCADA system also relies on PLCs to gather process data, such as production quantity, temperature, pressure, and processing times, to efficiently monitor and control manufacturing processes. Individual RFID cards are created for each product to determine and track the processes a product (finished fabric) goes through during its production process. Raw fabrics are equipped with RFID cards before the production process begins, allowing the machine to record product-specific information. Machine settings are configured manually by operators. The primary aim of the study is to prevent errors that may occur due to human intervention in configuring machine parameters based on fabric type in production machines and to establish the foundation for a smart factory. In this regard, when the RFID card is scanned into the machine, the goal is to seamlessly transfer critical machine parameters defined in the existing ERP system directly to the machines and automate the settings. A system is designed through the development of software and connectivity technologies for the study, which can be integrated into all the machines used in the factory. This system creates a microservice capable of retrieving production or any required information from management, analysis, and reporting programs such as ERP, CRM, and MES, and sends it to the machines. The microservice aims to be able to retrieve data from WebServices or API connections, determine data types, and convert the transmitted data into data sets that the machine can understand, with tags being integrated into the data set before being sent to the machine. A new service is being developed for the connection types of the machines. This new service enables communication with independent industrial protocols from the entire system, and new protocols can be added to this service when needed. For example, for a PLC (Siemens S71500) in the bleaching machine with an RS422 connection type and another one with MODBUS TCP, separate tags are created using this service for each protocol. Continuous data analysis is conducted while the machine is in operation. The software and connection systems developed retrieve production or any required information from management, analysis, and reporting programs such as ERP, CRM, and MES. This information is matched, any alterations are transmitted to the machine, and a machine information card is generated. This card contains the necessary parameters for production, and it lists the tags generated within the system that match these parameters. To ensure the study's success, an environment is established to test the software and hardware in real working conditions during the initial phases. After completing MVP and PoC studies, a test environment within Zorluteks ensures the stability of products emerging from this study before they are deployed. This enables the seamless integration of all changes and requests made by Zorluteks. The study's roadmap aims to meet most of the customer demands, even in the initial product versions. Regarding connections with smart devices, considerations include compatibility with modern technology, cost-effectiveness, precision, suitability for industrial environments, and continuity. The primary goal is to establish connections using Wi-Fi, Ethernet, and USB. For Authorization and Security, factors like security measures, response time, user-friendliness, international compliance, and reliability are all carefully considered. A dual-layered protection approach is implemented, including User Name/Password - 2FA - HTTP Basic Authentication. In Mobile Platform Software development, considerations include device compatibility, optimal utilization of device resources, speed, and alignment with selected technologies/methods. Programming languages like Java, Node JS, React JS, Hybrid, HTML 5, and more are employed. In Web Software Development, factors like speed, technology compatibility, development efficiency, and security are taken into account. Programming languages such as Node.JS, Java, React JS, HTML 5, and others are used. For Database selection, considerations include speed, supply cost, reliability, and backup/restore time. Consequently, No SQL and PostgreSQL databases are chosen. The study incorporates risk analyses and testing at each stage using the spiral method to ensure that outputs align with the Postgre and No SQL study proposal. These practices are upheld throughout the study's duration.

3. RESULTS AND DISCUSSION

Within the scope of this study, a system has been developed within Zorluteks to automatically configure machine parameters for production processes for the first time, eliminating the need for human intervention and laying the groundwork for the establishment of a smart factory. In this context, the existing production system was initially examined, and both fixed and variable parameters were identified. A data library containing variable parameters that require human intervention in the system was created. To enable the process to be conducted using IoT, analyses of the company's ERP infrastructure system and Local Network were conducted. Additionally, detailed examinations of the industrial communication protocols between the operator panel of the existing machine system and the PLC system were carried out, and it was determined that communication was taking place through the Profibus network.

In the course of the study, the goal was to automatically set machine settings based on fabric characteristics without operator intervention when an RFID card is scanned into the machine. Special APIs were developed to enable these adjustments to be made automatically, and an application was created that could write values to the TAGs, thereby establishing a DevOps infrastructure. To facilitate communication, data reading, and external intervention in the machine's PLC, a specialized device was developed by the study's industrial partner. In the final step of the study, the integration of the acquired device with the machine was tested, and tests were conducted for communication between the PLC and Operator Panel over the industrial protocol, data transmission, and addressing any potential errors. After conducting tests with real data, the developed system was put into use within the production process. As a result, the bleaching machine became the first machine within Zorluteks Textile to fully embody Industry 4.0 features. The developed Industry 4.0 application was integrated into the production system, transferring the decision-making mechanism for machine settings from human to the system. In the study, the efficiency of the machine-operated production process, along with losses in energy, reprocess, and chemical usage, were compared between the production process following the integration of Industry 4.0 into the production system and the process under operator control. Initiated with the aim of achieving accurate production in a single attempt, the study resulted in a 26% improvement in reprocess rates upon implementation of the system. Additionally, there was a 21% reduction in the amount of chemicals consumed.

In summary, the study aimed to eliminate human-related errors in making machine parameter adjustments based on fabric type, thereby establishing the foundation for a smart factory. The integration of Industry 4.0 practices was intended to reduce human influence and improve the efficiency and accuracy of production processes.

ACKNOWLEDGEMENT
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4. REFERENCES

[1] MUTLU, M., Perceptions of Industry 4.0 applications: A research on the automotive and textile sectors, Bursa Uludag Unıversity Institute of Social Sciences, Master’s degree Thesis, 2019.
[2] ÖZSOYLU, A., F., Industry 4.0. Journal of Cukurova University Faculty of Economics and Administrative Sciences, Volume: 21, Issue: 1, 41-64.
[3] GÖKALP, E., GÖKALP, M., O., EREN, P., E., Industry 4.0 Revolution In the Apparel Sector: Smart Apparel Factory AHIT-e: Academic Journal of Information Technology, 10(37), 73-96. Doi: 10.5824/1309-1581.2019.2.005.x
[4] İLHAN, İ., Concept of industry 4.0 in textile manufacturing processes, Pamukkale University Journal of Engineering Sciences, 25(7), 810-823,2019. Doi: 10.5505/pages.2018.69851
[5] YOSUMAZ, B., ÖZKARA, B., Effects of Industry 4.0 Process on Garment Businesses: The Case Study of Hugo Boss Turkey, Journal of Business Research- Turk, 2019, 11(4), 2587-2600. http://doi.org/10.20491/isarder.2019.760

SUSTAINABLE DYEING PROCESS OF PET FABRICS BY USING IONIC LIQUIDS

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ABSTRACT

PET fiber needs to be dyed about 130ºC or dyed with carrier method because of the characteristics features such as high crystallinity, lack of active groups and highly hydrophobic nature. Therefore, PET fibers dyeing methods have been consumed excessive amount of energy and chemicals. In this regard, our study is aimed at reducing energy and chemical consumption in the PET dyeing process by the utilization of mono and dicationic ionic liquids. In our sustainable dyeing process at 95ºC, usage of 10 g/l 1,4-Bis(3-methyl imidazolium)butane dibromide (IL3) increases colour strength (K/S) %117 compared to blind dyeing.

Key Words: Sustainable dyeing, ionic liquids, monocationic ionic liquids, dicationic ionic liquids.

1. INTRODUCTION

PET fiber is most widely used synthetic fiber because of the fact that good elastic recovery, ease of care, long life, excellent dimensional stability, resistance to many chemicals and high tensile strength. However, the high degree of crystallinity, lack of active groups and hydrophobic characteristic lead to difficulties in the penetration of dye molecules into the fiber [1]. Therefore, PET fabric needs to be dyed with the carrier method or high temperature (HT) dyeing method at around 130°C. These methods provide better disperse dye penetration into the fiber matrix and can be achieved higher colour yield [2, 3]. However, HT dyeing method comes up with two drawbacks, high energy consumption and long dyeing duration. In recent years, researches on alternative PET dyeing method at low temperature has increasingly drawn attention the context of sustainable production goals [1]. Research on the use of auxiliary chemicals like ethanol and glycerol, which have less ecotoxic and polluting features, and also on manufacturing methods that utilize fewer natural resources for sustainable production, has been carried out in the textile sector. [4, 5, 6, 7]. In this regard, one of the most effective alternative approaches that may be used in the PET dyeing process is the utilization of ionic liquid as an auxiliary chemical or solvent under atmospheric dyeing conditions. [3, 8, 9].

Ionic liquids are novel green solvents with melting points below 100°C that may be made up of millions of different cation and anion combinations (about 10^{18}). The selection of cation and anion influences the key features of ionic liquids for dyeing, such as density and viscosity. This liquid class also has numerous properties that allow them to be considered sustainable chemicals, including high thermal stability, good recycling, mild reaction conditions, non-volatility, non-flammability, reusable, waste prevention and low toxicity [9, 10].

Ionic liquids are used in many kinds of textile processes, including spinning, textile preparation, colouring, and finishing [9]. Studies on eco-friendly applications of ionic liquids in dyeing are very new, with just a few publications to date. In the literature, it has been utilized as an auxiliary chemical, surface modification chemical, or solvent in the dyeing processes of wool, cotton, PET, silk, cotton/PET, nylon, and meta-aramid textiles [3, 4, 8, 11, 12, 13, 14, 15].

This research is mainly focused on minimizing energy and chemical demand in PET dyeing with the utilization of mono and dicationic ionic liquids in the textile dyeing process.

2. MATERIALS AND METHODS

In this work, 100% PET knitted fabric (120 g/m^2, single jersey) and C.I. Disperse Red 167 were used. 1-butyl-3-methylimidazolium chloride (IL1), 1-butyl-3-methylimidazolium bromide (IL2), 1,4 bis(3-methylimidazolium) butane dibromide (IL3) and 1,4 bis(3-methylimidazolium) butane dichloride (IL 4) have been synthesized by Dokuz Eylül University Department of Chemistry for IL dyeing processes. Dyestuff is shown in Figure 1 and ionic liquids are shown in Figure 2.

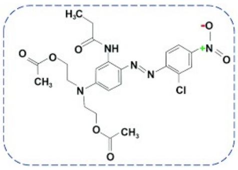
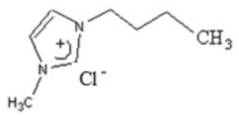
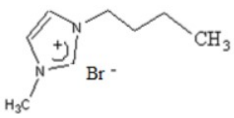


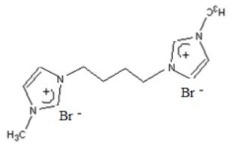
Figure 1. Chemical structure of C.I. Disperse Red 167 [16]



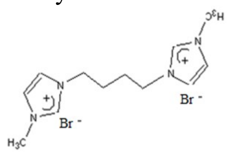
(a)1-Butyl-3-methyl imidazolium chloride (IL1)



(b)1-Butyl-3-methyl imidazolium bromide (IL2)



(c)1,4-Bis(3-methyl imidazolium)butane dibromide (IL3)



(d) 1,4-Bis(3-methyl imidazolium)butane dichloride (IL4)

Figure 2. Chemical structure of ionic liquids

0.5% C.I.Disperse Red 167 (o.w.f) was utilized in all dyeing experiments. In addition, 2% C.I. Disperse Red 167 (o.w.f) was attempted according to the best results obtained with 0.5% dyestuff. In comparison, HT dyeing processes were performed at 130ºC, whereas our ionic liquid dyeing methods were performed at 95ºC. All experiments were conducted with a 1:20 liquor ratio at pH 4.

In the conventional HT dyeing process, an alkali pretreated (5% NaOH, 1:50 liquor ratio,100ºC, 60 min.) PET fabric was used. Furthermore, unlike ionic liquid dyebaths, conventional HT dyebaths contain a dispersion agent. In the blind dyeing process, PET fabrics dyed with dyestuff and water were used to observe the effects of ionic liquids at 95 ºC. IL has been utilized as a solvent and an auxiliary chemical in our dyeing processes. When ionic liquid has been used as an auxiliary chemical, 2g/l- 5g/l- 10g/l and 20g/l (ionic liquid/water- (w/v)) solutions are prepared, and the dyestuff dissolves in these solutions. In the case of IL usage as a dyeing medium, the dyestuff is dissolved directly in the ionic liquid All dyeing curves were shown in Figure 3. After the dyeing processes, all samples were rinsed with distilled water until the water was clear, then dried in an oven.

(a) Conventional HT dyeing (b)Blind dyeing-ionic liquid dyeing

Figure 3. Dyeing Curves

After dyeing processes, the colour strength (K/S values) of PET fabrics were determined by using spectrophotometer and calculated K/S values by the Kubelka-Munk equation, at Eq (1):

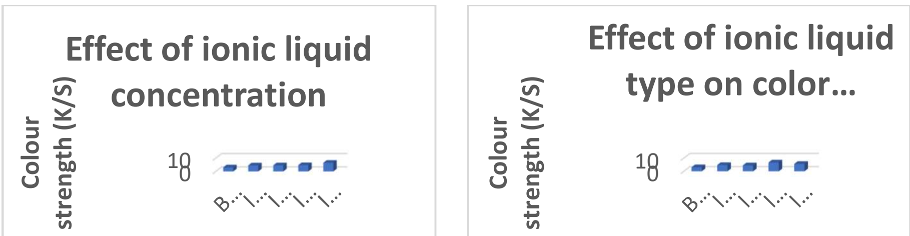
$$K/S = \frac{(1\text{-}R^2)}{2R} \tag{1}$$

Where K is the absorption coefficient, S is the scattering coefficient and R is the reflectance of dyed samples at the wavelength of maximum dye absorption [13].

UV–visible spectrophotometer has been used to determine the dye uptake differences of the samples by measuring the absorbance values of the remaining dyebath. Washing and rubbing fastness tests, as well as XRD and FTIR analyses, has been performed of dyed samples.

3. RESULTS AND DISCUSSION

Figure 4a illustrates that increasing the IL1 concentration from 2g/l to 20g/l has an influence on color strength, with blind dyeing samples having a lower colour strength than IL 1 dyeing samples. The highest color strength value has been achieved at concentration of 20 g/l IL 1.



(a) (b)

Figure 4. Effects of different amounts of IL 1 usage on colour strength (0.5% dyestuff) (a), Effects of four different ionic liquids on colour strength for 10 g/l IL concentration (0.5% dyestuff) (b)

Figure 4b shows the effect of ionic liquid types (monocationic or dicationic) on colour strength at 10 g/l IL concentration. The colour strength of the blind dyeing sample is significantly lower than the colour strength of all IL dyeing samples. Furthermore, the colour strength of dicationic IL3 and IL4 dyed samples was greater than that of monocationic IL1 and IL2 dyed samples at 10 g/l IL concentration. Figure 5 shows photographs of various dyeing samples.

(a) (b) (c)

Figure 5. Photographs of HT dyeing sample (a), 95ºC blind dyeing sample(b), 95ºC 20 g/l IL1 dyeing sample(c), 95ºC IL1 dyeing as a dyeing medium

Figure 6 shows the UV-Vis absorption spectra of the remaining IL3 dyebath after the dyeing process. The dye uptake of IL 3 dyed fabrics was found to be higher than that of blind dyeing samples. The maximum dye uptake was observed when 10 g/l IL3 was utilized for IL 3 dyeing.

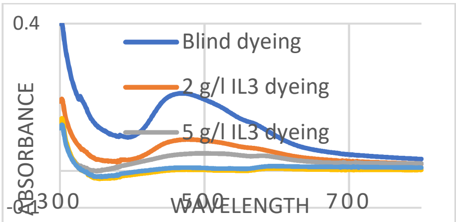


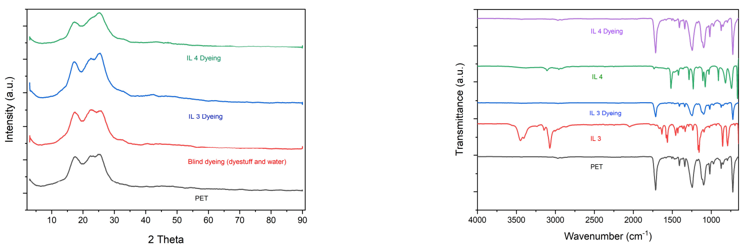
Figure 6. Absorbance spectra of remaining dyebath of IL3 dyeing

Dyeability has been correlated with crystallinity because reducing crystallinity enhances diffusion of the dye into the fiber, resulting in increased dye uptake [17, 18].

X-ray diffraction analysis was used to examine the influence of ionic liquids (IL3 and IL4) and blind dyeing on the physical structure of polyester fabric, as shown in Fig. 7a and FTIR spectra of PET, IL3, IL3 dyed PET The degree of crystallinity was estimated using the following formula [19]:

$$\text{Crystallinity}=\frac{(\text{Intensity of crystalline region})}{(\text{Intensity of crystalline region+Intensity of amorphous region})}\times 100$$

$$\frac{(\text{Intensityofcrystallineregion})}{(\text{Intensityofcrystallineregion+Intensityofamorphousregi}\quad)}\times 100 \qquad (2)$$



(a) **(b)**

Figure 7. X-ray diffractograms of PET, Blind dyeing, IL3 dyeing and IL 4 dyeing samples (a), FTIR spectra of PET, IL 3, IL3 dyeing sample, IL 4 and IL 4 dyeing sample.

According to the Figure 7a undyed polyester fabric shows higher crystallinity than blind dyed and ionic liquids dyed polyester fabrics. The crystallinity degrees of undyed, blind dyed, IL3 dyed and IL4 dyed polyester fabrics are 48.22 %, 47.00 %, 33.12 % and 41.69 %, respectively. Because of dye and fibre interaction, the crystallinity degree of dyed PET fabric decreases as compared with undyed polyester fabric [19].

According to the Figure 7b the peaks at 2969 cm^{-1} and 2931 cm^{-1} in the dicationic chloride dyed fabric show the aliphatic and asymmetric -C-H stretching vibrations in the fabric and IL4. The peak at 1713 cm^{-1} represents the carbonyl (C=O) vibration peak of the fabric, whereas the peaks at 1408 cm^{-1}, 1471 cm^{-1}, 1505 cm^{-1}, and 1578 cm^{-1} indicate C=C and C=N stretching vibrations of the ionic liquid and the fabric, respectively Peaks between 1339 and 1244 cm^{-1} indicate -C-H bending vibrations, and peaks at 1077 cm^{-1} and 1108 cm^{-1} correspond to -C-C stretching vibrations. The aromatic =C-H out-of-plane bending vibrations are seen in the peaks between 792 cm^{-1} and 970 cm^{-1} [20, 21, 22].

The peak at 2971cm^{-1} of the IL 3 dyed PET fabric demonstrates the =C-H stretching vibrations of the ionic liquid and the fabric. The peaks at 2356 cm^{-1}, 2318 cm^{-1}, 2110 cm^{-1}, and 1949 cm^{-1} show the aliphatic symmetric and asymmetric C-H stretching vibrations of the fabric and IL 3. The carbonyl (C=O) vibration peak of the fabric is shown by the peak at 1713 cm^{-1}, and the C=C and C=N stretching vibrations of the ionic liquid and the fabric are represented by the peaks at 1408 cm^{-1}, 1471 cm^{-1}, and 1578 cm^{-1}. Peaks at 1340 cm^{-1}, 1245 cm^{-1} are -C-H bending vibrations, whereas peaks between 1097 cm^{-1} -1018 cm^{-1} are -C-C stretching vibrations. The aromatic =C-H out-of-plane bending vibrations are seen in the peaks between 827cm^{-1}-971 cm^{-1} [20, 23, 24].

Furthermore, IL dyeing samples demonstrated the same dry and wet rubbing fastness as HT dyeing samples, but their washing fastness was one or two degrees lower, according to the fastness test results.

4. CONCLUSIONS

In this study, monocationic and dicationic ionic liquids were utilized as a dyeing medium and auxiliary chemical in the dyeing process. The usage of ionic liquids as an auxiliary chemical in the dyeing process resulted in higher colour strength than blind dyeing at all concentrations. According to the XRD data, the swelling impact of IL reduces the crystallinity of PET fibers, increasing dye uptake. Dry and wet rubbing fastness of IL dyeing samples were equivalent to HT dyeing, whereas washing fastness was one or two degrees lower than HT dyeing results.

As expected, the ionic liquid dyeing process is a sustainable dyeing process that decreases the environmental impact of the HT dyeing process by reducing the dyeing temperature while utilizing fewer auxiliary chemicals.

ACKNOWLEDGEMENT

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5. REFERENCES

[1] WANG, X., WANG, J., HE, J., GU, X., QIN, K. A comparative study on dyeing properties of iterative polyester and ordinary polyester dyed with disperse dyes. The Journal of The Textile Institute, 2023, 114, 5, 774-781.

[2] NAKPATHOM, M., SOMBOON, B., NARUMOL, N. and MONGKHOLRATTANASIT, R. High temperature dyeing of PET fabric with natural colourants extracted from annatto seeds. Pigment & Resin Technology, 2019, 48, 2, 129-136.
[3] OPWIS, K., GUTMANN, J. S., and KNITTEL, D. Dyeing of textile materials in ionic liquids. In 5th International Congress on Ionic Liquids (COIL-5). Vilamoura, Portugal. 2013.
[4] BIANCHINI, R., CEVASCO, G., CHIAPPE, C., POMELLI, C. S. and RODRÍGUEZ DOUTON, M. J. Ionic liquids can significantly improve textile dyeing: an innovative application assuring economic and environmental benefits. ACS Sustainable Chemistry & Engineering, 2015, 3, 9, 2303-2308.
[5] FERRERO, F., PERIOLATTO, M., ROVERO, G. and GIANSETTI, M. Alcohol-assisted dyeing processes: a chemical substitution study. Journal of Cleaner Production, 2011, 19, 12, 1377-1384.
[6] FERRERO, F., PERIOLATTO, M. Glycerol in comparison with ethanol in alcohol-assisted dyeing. Journal of Cleaner Production, 2012, 33, 127-131.
[7] PASQUET, V., PERWUELZ, A., BEHARY, N. and ISAAD, J. Vanillin, a potential carrier for low temperature dyeing of polyester fabrics. Journal of Cleaner Production, 2013, 43, 20-26.
[8] OPWIS, K., BENKEN, R., KNITTEL, D. and GUTMANN, J. S. Dyeing of PET fibers in ionic liquids. International Journal of New Technology and Research, 2017, 3, 11, 101-108.
[9] MEKSI, N., MOUSSA, A. A review of progress in the ecological application of ionic liquids in textile processes. Journal of Cleaner Production, 2017, 161, 105-126.
[10] TROGER-MULLER, S., BRANDT, J., ANTONIETTI, M. and LIEDEL, C. Green Imidazolium Ionics–From Truly Sustainable Reagents to Highly Functional Ionic Liquids. Chemistry–A European Journal, 2017, 23, 49, 11810-11817.
[11] OPWİS, K., CELİK, B., BENKEN, R., KNİTTEL, D. And GUTMANN, J. S. Dyeing of m-Aramid fibers in ionic iquids. Polymers, 2020, 12, 8, 1824.
[12] ZHUANG, L., ZHENG, C., SUN, J., YUAN, A., and WANG, G. Performances of ramie fiber pretreated with dicationic imidazolium ionic liquid. Fibers and Polymers, 2014, 15, 226-233.
[13] S. ANDRADE, R., TORRES, D., RIBEIRO, F. R., CHIARI-ANDRÉO, B. G., OSHIRO JUNIOR, J. A. and IGLESIAS, M. Sustainable cotton dyeing in nonaqueous medium applying protic ionic liquids. ACS Sustainable Chemistry & Engineering, 2017, 5, 10, 8756-8765.
[14] CHENG, D. H. Application of ionic liquid in silk dyeing. Advanced Materials Research, 2011, 331, 253-256.
[15] YUAN, J., WANG, Q., AND FAN, X. Dyeing behaviors of ionic liquid treated wool. Journal of Applied Polymer Science, 2010, 117, 4, 2278-2283.
[16] HUSSAIN, N., HUSSAIN, S., MEHDI, M., KHATRI, M., ULLAH, S., KHATRI, Z. and KIM, I. S. Introducing deep eutectic solvents as a water-free dyeing medium for poly (1, 4-cYclohexane dimethylene isosorbide terephthalate) PICT nanofibers. Polymers, 2021, 13, 16, 2594.
[17] ASIABAN, S., MORADIAN, S. Investigation of tensile properties and dyeing behavior of various polypropylene/polyamide 6 blends using a mixture experimental design. Dyes and Pigments, 2012, 92, 1, 642-653.
[18] HARIFI, T., MONTAZER, M. Free carrier dyeing of polyester fabric using nano TiO2. Dyes and Pigments, 2013, 97, 3, 440-445.
[19] PAWAR, S. S., MAITI, S., BIRANJE, S., KULKARNI, K. and ADIVAREKAR, R. V. A novel green approach for dyeing polyester using glycerine based eutectic solvent as a dyeing medium. Heliyon, 2019, *5*, 5.
[20] İÇOĞLU, H. I. Comparative Analysis of PET, PTT and PBT Yarns Hydrolyzed by Alkali. Textile and Apparel, 2022, 32, 1, 57-64.

[21] DHARASKAR, S. A., VARMA, M. N., SHENDE, D. Z., YOO, C. K., and WASEWAR, K. L. Synthesis, characterization and application of 1-butyl-3 methylimidazolium chloride as green material for extractive desulfurization of liquid fuel. The Scientific World Journal, 2013, 2013.
[22] ABDUL RAHMAN, W., ABDUL WAHAB, S. A., and ZAKARIA, S. Influence of 1-butyl-3-methylimidazolium chloride ([BMIM] Cl) reaction temperatures to the toxicity and biodegradation of kapok cellulose film. Jurnal Intelek, 2015, 10, 1, 67-73.
[23] RAJKUMAR, T., RAO, G. R. Synthesis and characterization of hybrid molecular material prepared by ionic liquid and silicotungstic acid. Materials Chemistry and Physics, 2008, 112, 3, 853-857.
YUE, Q. F., WANG, C. X., ZHANG, L. N., NI, Y., and JIN, Y. X. Glycolysis of poly (ethylene terephthalate)(PET) using basic ionic liquids as catalysts. Polymer Degradation and Stability, 2011, 96, 4, 399-403.

A RESEARCH ON PROPERTIES OF KNITTED FABRICS PRODUCED WITH RING AND ROTOR-SPUN YARNS CONTAINING RECYCLED COTTON FIBER

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ABSTRACT

Recycle fibre blended yarn and fabrics are becoming more popular and important every day due to fashion marketing strategies and decreasing raw material sources. So that, every producer and customer needs to evaluate products to re-source. This study was conducted on the production of value added products like finer yarns from recycled cotton fibers obtained from pre-consumer textile products with acceptable quality and high recycled fiber ratios.

Key Words: Recycled cotton, spinning, knitted fabric, sustainability, virgin cotton.

1. INTRODUCTION

Like other industries, textile industry needs to be flexible and suitable for all human demands due to decreasing resources and increasing human population and desires. Therefore, textile has found internal source as "recycling materials" or "waste management". Since the raw material sources decreasing and human demands are increasing all producers has started searching new technologies to eliminate wastes and reduce costs of production. Developments has been done with different raw materials and compositions to achieve similar quality compared to conventional qualities. Recycling is the process of converting materials from all kinds of waste to produce new products. Textile recycling implies the reuse and reprocessing of clothing scraps or any fibrous textile material. All types of consumer or industry discarded textile goods are used as textile wastes for recovery. It is obvious that recycling, which has evolved into sustainability over time and its importance has been understood even in ancient times. Recycling can be defined as re-producing all kinds of materials into similar or different products and can be classified as “open-loop” and “close-loop recycling”. It can be applied in many fields of the textiles as textile-to-textile (closed-loop) recycling or textile-to-nontextile (open-loop) recycling (1).

In this paper, pre-consumer wastes’ quality values of yarn and fabric side will be compared between each other and also current conventional productions. The textile recycling route can be classified based on the nature of the processes involved or the level of disassembly of the recovered materials. Fabric recycling consists in recovering and reusing of a fabric into new products (2). Integration of recycling may be challenging for couple of reasons such as separating wastes between each other, pre-treatment planning, sustainability concerns and rules.
Researchers focused on recycling parameters and the utilization of recycled cotton fibres for different purposes. Lu et al. (2023) compared the characteristics of waste cotton and high-value products such as yarn, composites, regenerated cellulose fibers, biofuels etc. derived from waste cotton via mechanical, chemical, and biological recycling methods. They’ve concluded that as low-cost cotton and high return values can be obtained with recycling waste cotton, industrialization and commercialization can be achieved. The spatial water footprint of a 100% cotton T-shirt was investigated and compared different recycling scenarios like no recycling, 30% recycling, and 100% recycling were compared [4]. Bogale et al. (2023), focused on acoustics

insulation properties of samples made from recycled Cotton/polyester (PET) in different blend ratios and found that recycled/PET/cotton selvedge waste showed more than 70% of the sound absorption coefficient and the recycled nonwoven mats provided the best insulation, sound absorption, moisture absorption, and fiber properties. Özdil et al. (2023), developed functional and high value-added upholstery fabrics by recycled cotton/polyester blended yarns with different ratios. They've reported that fabrics containing 15% recycled cotton showed better results among the other flame retardant, water, and stain repellent upholstery fabrics. A new type of vacuum insulation panels with recycled and economical cotton fiber core was prepared by Kan et al [7]. Ütebay et al. (2019), reported that the recycled fibre quality and the yarn properties are associated with the waste fabric properties and shredding parameters. They've showed that the yarns produced from greige fabric based recycled fibres had higher tenacity and lower hairiness. Higher quality recycled cotton fibres can be achieved by the selection of loosely knitted greige cotton fabrics shredded in 3 passages with large feeding size. In their further study, 30 tex and 20 tex, 100% cotton yarns were produced with different recycled/virgin fiber blend ratios (with a recycled fiber ratio more than 50%) by compact and open-end spinning systems without any chemicals treatment. They've found that yarn properties improved with the increase of virgin cotton fiber ratio in the yarn. The yarn hairiness and unevenness of open-end yarns were better whereas yarn tenacity is lower compared to compact-spun yarns [9].

2. EXPERIMENTAL

This study was conducted on the production of value added products like finer yarns from recycled cotton fibers obtained from pre-consumer textile products with acceptable quality and high recycled fiber ratios. Recycled cotton fiber is expressed as Re-Co and virgin cotton fiber as V-Co. The Re-Co used in the study was obtained from post-consumer textile products. Ring spun and Open end spun yarns made with different yarn counts and Re-Co blend ratios to examine the difference on yarn, knit and fiber side. Experimental plan is given in Table 1.

Table 1. Experimental plan

Blend Ratio (Re-Co/V-Co)	Spinning Method	Yarn count (Ne)
50/50	Ring	18/1
	Rotor	18/1
	Rotor	24/1
	Rotor	30/1
60/40	Ring	18/1
	Rotor	18/1

Production was made with same machines for each spinning technologies, circular knitting and dyeing to eliminate machine parameter differences. Physical tests of Uster Tester 6 and Tensojet 4 results of yarns and fabrics were analysed taking into consideration of Re-Co blend ratio differences.

3. RESULTS

Yarn tenacity and variation results are given in Figure 1 whereas yarn evenness and hairiness values are given in Table 2.

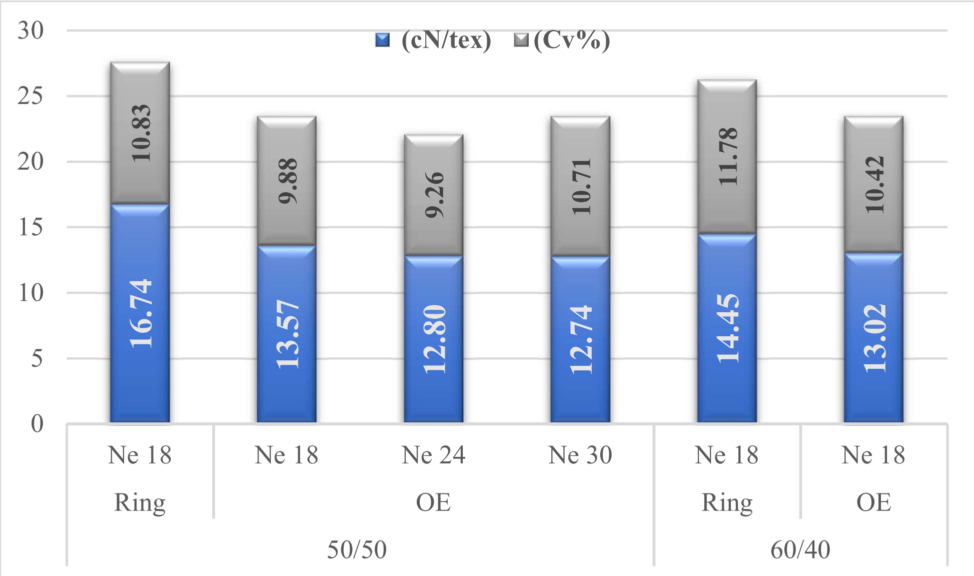

Figure 1. Yarn tenacity test results. (cN/tex).

According to Figure 1, yarn strength variation increased with the decrease of yarn count (Ne) and virgin cotton ratio in the blend. It is found that rotor spun yarns' offer a more stable structure in terms of yarn tenacity. Regarding spinning system, ring-spun yarns had higher yarn evenness, yarn hairiness and yarn tenacity values, compared to rotor-spun yarns with the same blend ratio and yarn count. Among rotor-spun yarns produced with 50/50 Re-Co /V-Co fibers, finer yarns had higher yarn evenness, lower yarn hairiness and yarn strength values.

Table 2. Yarn evenness and hairiness values.

U%	13,11	11,42	11,27	12,59	13,17	11,05
CVm	16,92	14,46	14,24	15,9	17,03	14,02
H	9,02	5,83	4,53	3,99	9,86	5,72
	Ne 18/1 RI	Ne 18/1 OE	Ne 24/1 OE	Ne 30/1 OE	Ne 18/1 RI	Ne 18/1 OE
	50/50				60/40	

Single jersey fabrics was knitted from yarns made from each blend. Machine efficiency, fabric quality, breakage and other raw fabric defects were examined. As a result of the controls, it was observed that the difference in blend ratio, yarn count or spinning technology does not affect the machine efficiency.

Table 2. Physical test results

Pilling	3,50	3,50	4,00	4,00	3,00	3,50
Bursting Strength	305 kPa	282 kPa	265 kPa	256 kPa	302 kPa	298 kPa
	Ne 18/1 RI	Ne 18/1 OE	Ne 24/1 OE	Ne 30/1 OE	Ne 18/1 RI	Ne 18/1 OE
	50/50				60/40	

Table 2 presents pilling and bursting test values for dyed finished fabrics. Pilling tests were carried out on a Martindale pilling device for 2000 rounds. Compared to the fabrics produced with conventional cotton, the test results of samples knitted with Re-Co/V-Co fibers at different blend ratios are acceptable and can be observed that the yarn count is more effective than the blend ratio. For Ne 18/1 ring yarns, when the recycle cotton ratio in the blend increases, the pilling value decreases by half a point.

4. CONCULUSION

Recycled fabrics and yarns have become the focus of current textile productions for their quality. In comparison to traditional cotton productions, shorter fibre length is a significant concern that affects finished fabric quality. Dyed fabric values impacted by fibre length are pilling and bursting, which have a notable impact on consumer comfort. In this study, we observed the impact of various blend ratios and yarn counts on finished fabric.

The data in the tables shows that yarn technology and count have a greater impact on the finished fabric than blend ratio. Additionally, we observed that increasing the recycle ratio did not result in a significant difference in physical test results.

5. REFERENCES

[1] EKOLOJIST, Tekstil Geri Dönüşümü Nasıl Yapılır? [cited 01.06.2023]. Available on https://ekolojist.net/tekstil-geri-donusumu-nasil-yapilir

[2] GERI DÖNÜŞÜM KUMAŞ REHBERI, Atilla Tekstil, [01.06.2023]. Available on https://atillatekstil.com/tekstil-bilgilendirme-atolyesi/geri-donusum-kumas/

[3] LU, LINLIN, ET AL. Current recycling strategies and high-value utilization of waste cotton. Science of The Total Environment, 2023, 856: 158798.

[4] CHEN, SHUANG, ET AL. A Spatial Water Footprint Assessment of Recycled Cotton T-Shirts: Case of Local Impacts in Selected China Provinces. *Sustainability*, 2023, 15.1: 817.

[5] BOGALE, MESERET, ET AL. Sound absorbing and thermal insulating properties of recycled cotton/polyester selvedge waste chemical bonded nonwovens. *The Journal of The Textile Institute*, 2023, 114.1: 134-141.

[6] ÖZDIL, NILGÜN, ET AL. Multifunctional Modification with TiO2, SiO2, and Flame Retardant Agent on Upholstery Fabrics Produced From Recycled Cotton Fibers. *AATCC Journal of Research*, 2023, 24723444221147976.

[7] KAN, ANKANG, ET AL. Effective thermal conductivity of vacuum insulation panels prepared with recyclable fibrous cotton core. *International Journal of Thermal Sciences*, 2023, 187: 108176.

[8] ÜTEBAY, BURÇIN ET AL. Effects of cotton textile waste properties on recycled fibre quality. Journal of Cleaner Production, 2019. 222, 29-35.
[9] UTEBAY, BURCIN ET AL. Valorization of fabric wastes through production of recycled cotton yarns by compact ring and open-end rotor spinning. Journal of Cleaner Production, 2023, 409: 137135.
[10] JOHNSON, SARA, ET AL. Supply chain of waste cotton recycling and reuse: A review. AATCC Journal of Research, 2020, 7.1_suppl: 19-31.

THE EFFECT OF DIFFERENT STRUCTURAL PARAMETERS AND WASHINGS ON THERMAL PROPERTIES OF DENIM FABRICS

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ABSTRACT

In this study, the thermal properties of 3/1 Z and 3/1 S twill directions of 100% cotton, %85 cotton %15 Tencel elastane, and %85 cotton %15 modal elastane including denim fabrics were investigated. Bleach, enzyme, rinse, and stone washing operations were performed on these fabrics. The results showed that the highest thermal resistance values were observed in rinse washed fabrics, the highest thermal conductivity values were observed in stone washed fabrics, and the highest thermal diffusion values were observed in bleach washed fabrics. In addition, the highest thermal conductivity values were observed for the cotton/modal elastane including fabrics in the Z-twill direction.

Key Words: Denim, different washings, thermal properties, Tencel, Modal.

1. INTRODUCTION

Denim fabrics are durable and abrasion resistant fabric structures that have been developed as workwear in previous times. Denim fabrics are woven using 2/1 and 3/1 Z twills, which are generally warp-faced twill types. The warp yarn is indigo blue dyed, and the weft yarn consists of raw and undyed cotton yarns. The parameters that affect thermal comfort are the thermal resistance, thermal conductivity, air permeability, and water vapour permeability. Because denim fabrics have a hard structure after weaving, the appearance and comfort properties of denim fabrics are changed by washing, such as bleach, stone, enzyme, and rinse. Vivekanadan et al. (2011) investigated the warm-cool feeling of denim fabrics and declared that the washing process creates a feeling of coolness [1]. In a study investigating the impact of fabric structural properties on the thermal and air permeability features of denim fabrics, it was found that properties such as the fiber type, yarn structure, and fabric thickness affect the thermal comfort of denim fabrics [2]. Mangat et al. (2012) investigated the effect of different weft yarn and washing treatments on moisture management properties of denim fabrics. It was found that the overall moisture management values of the denim fabrics were affected by the washing treatments and weft yarns [3]. In another study, the influence of different softeners on the thermal and comfort features of stretch denim fabrics was investigated. The results demonstrated that the water vapour permeability values were higher when non-ionic softeners were used than both enzyme and stone enzyme washings [4]. The thermophysiological comfort properties of different washed cotton denim fabrics have been investigated in a previous study. It was found that the comfort properties of denim fabrics are influenced by their weight and thickness [5]. Türksoy et al. (2021) investigated the effects of the weft yarn type, weft density, and finishing process on the elasticity, permanent elongation, thickness, thermal resistance, water vapour permeability, and air permeability properties of different denim fabrics. It was observed that the weft yarn type, weft density, and finishing process have statistically significant effects on the comfort properties of denim fabrics [6].
The aim of this study is to investigate the effects of different weft yarns, twill directions, and washing processes on the thermal comfort properties of denim fabrics.

2. EXPERIMENTAL

The warp yarn of the fabrics used in this study were kept constant and the weft yarns were changed. 100% cotton elastane, 85% cotton, 15% Tencel elastane and 85% cotton and 15% modal elastane yarns were used in the weft direction. The fabric samples were woven in 3/1 Z and 3/1 S twill directions. In addition, the fabric samples were subjected to four different washing processes: bleach, enzyme, rinse, and stone washing. The properties of the tested samples are presented in Table 1. The thermal resistance, thermal conductivity, and thermal diffusion coefficient of the denim fabrics were measured with an Alambeta test device using the EN ISO 11092 standard (EN ISO 11092 standard).

Table 1. Properties of denim fabrics

Fabric Type	Warp Yarn Count (Ne)	Weft Yarn Count (Ne)	Composition	Weight
PZB	9.97	16	%100 Cotton+ 78 Dtex Elastane	405
PZE	9.97	16	%100 Cotton+ 78 Dtex Elastane	396
PZR	9.97	16	%100 Cotton+ 78 Dtex Elastane	396
PZS	9.97	16	%100 Cotton+ 78 Dtex Elastane	408
PSB	9.97	16	%100 Cotton+ 78 Dtex Elastane	393
PSE	9.97	16	%100 Cotton+ 78 Dtex Elastane	388
PSR	9.97	16	%100 Cotton+ 78 Dtex Elastane	387
PSS	9.97	16	%100 Cotton+ 78 Dtex Elastane	396
MZB	9.97	16	%85 Cotton+ %15 Modal + 78 Dtex Elastane	415
MZE	9.97	16	%85 Cotton+ %15 Modal + 78 Dtex Elastane	412
MZR	9.97	16	%85 Cotton+ %15 Modal + 78 Dtex Elastane	411
MZS	9.97	16	%85 Cotton+ %15 Modal + 78 Dtex Elastane	419
MSB	9.97	16	%85 Cotton+ %15 Modal + 78 Dtex Elastane	401
MSE	9.97	16	%85 Cotton+ %15 Modal + 78 Dtex Elastane	407
MSR	9.97	16	%85 Cotton+ %15 Modal + 78 Dtex Elastane	402
MSS	9.97	16	%85 Cotton+ %15 Modal + 78 Dtex Elastane	406
TZB	9.97	16	%85 Cotton+ %15 Tencel + 78 Dtex Elastane	410
TZE	9.97	16	%85 Cotton+ %15 Tencel + 78 Dtex Elastane	412
TZR	9.97	16	%85 Cotton+ %15 Tencel + 78 Dtex Elastane	411
TZS	9.97	16	%85 Cotton+ %15 Tencel + 78 Dtex Elastane	418

TSB	9.97	16	%85 Cotton+ %15 Tencel + 78 Dtex Elastane	403
TSE	9.97	16	%85 Cotton+ %15 Tencel + 78 Dtex Elastane	376
TSR	9.97	16	%85 Cotton+ %15 Tencel + 78 Dtex Elastane	397
TSS	9.97	16	%85 Cotton+ %15 Tencel + 78 Dtex Elastane	403

*B= bleach washing, E=enzyme washing, R= rinse washing, S=stone washing, Z= twill direction Z and S= twill direction S.

3. RESULTS AND DISCUSSION

3.1. Thermal Resistance

The thermal resistances of the fabrics are shown in Figure 1. The highest thermal resistance was observed in the case of rinse washing for all fabrics, regardless of the weft yarn type and the lowest thermal resistances were measured under enzyme washing conditions. The thermal resistance properties of the S-twill fabrics were found to be higher than those of the Z- twill fabrics in cotton/modal elastane weft yarn woven fabrics. Similar to 100% cotton, the lowest thermal resistance was measured when enzyme washing was used in cotton/modal elastane weft woven fabrics. Unlike the other two types, the Z-twill fabrics showed higher thermal resistance values than the S-twill fabrics in the cotton/Tencel elastane woven fabrics. In a previous study, when Tencel fiber was mixed with modal, it was observed that the thermal resistance was higher than that of fabrics produced from 100% cotton fiber [7]. In this study, the thermal resistance of the Z-twill fabrics with 85% cotton and 15% Tencel elastane enzyme washing and stone washing processes was higher than that of the Z-twill fabrics with 100% cotton elastane enzyme and stone washing.

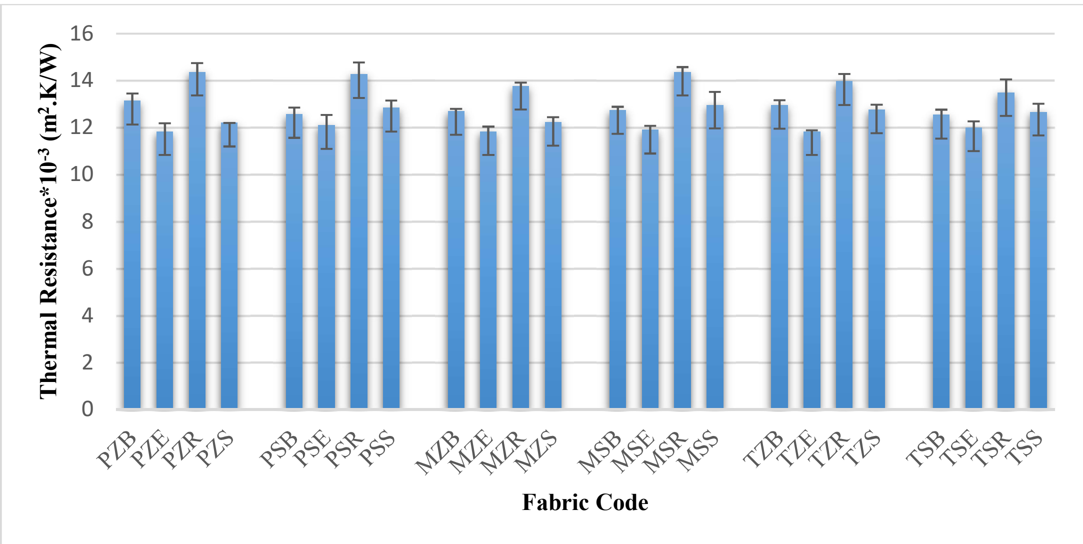

Figure 1. Thermal resistance of fabrics

3.2. Thermal Conductivity

The thermal conductivity of a textile structure is a measure of its capability to conduct heat. The thermal conductivities of the fabrics are shown in Figure 2. When the thermal conductivity values of the fabrics were compared, the highest thermal conductivity value was obtained for the MZS coded cotton/modal elastane stone washed fabric and the lowest thermal conductivity value was observed for PZR coded 100% cotton rinse washed fabric. The lowest thermal conductivity values were observed for the rinse washed fabrics, and the highest thermal conductivity values were observed for the stone washed fabrics. In a previous study, it was observed that bleaching and softening treatments decreased thermal conductivity [8]. In contrast, the lowest thermal conductivity values were observed for the rinse washed fabrics in this study. In addition, the thermal conductivity values of cotton/ modal elastane woven fabrics were higher than those of the other fabrics.

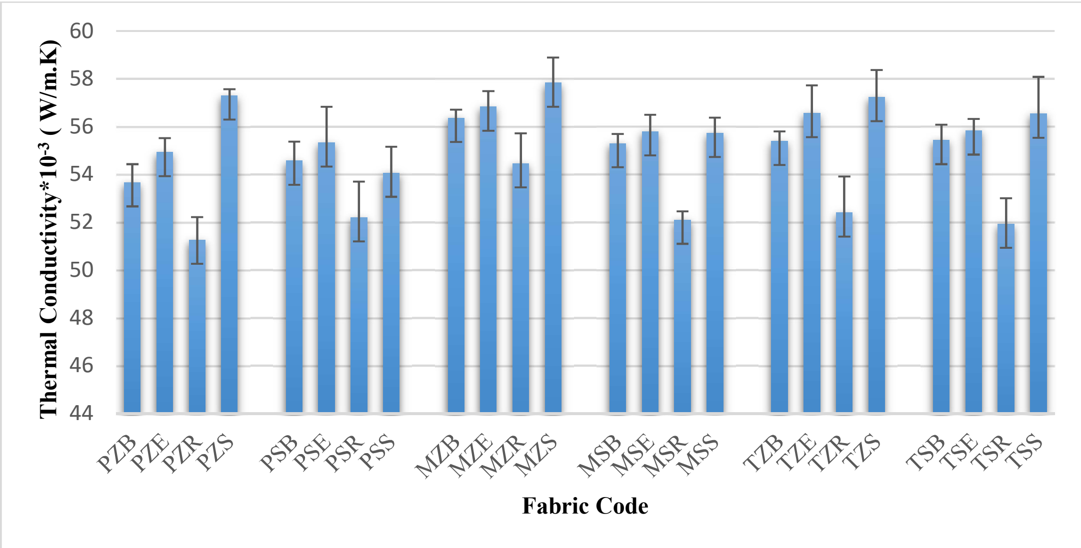

Figure 2. Thermal conductivity of fabrics

3.3. Thermal Diffusion

Thermal diffusion is a thermal property related to the heat flow from the fabric structure. The thermal diffusions of the fabrics are shown in Figure 3. In a previous study, the thermal diffusion of knitted fabrics made of Tencel yarn was higher than that of fabrics knitted with cotton yarn [9]. The highest thermal diffusion coefficient was observed for the TSB coded cotton/Tencel elastane S-twill bleach washed fabric, and the lowest thermal coefficient for the MSB coded cotton/modal elastane S-twill direction bleach washed fabric. The lowest thermal diffusion coefficient was observed for the rinsed washed fabrics, and the highest thermal diffusion coefficient was observed for the bleach washed fabrics (except for MSB). It can be concluded that rinse washing reduces the thermal diffusion value of fabrics, while bleaching increases this value.

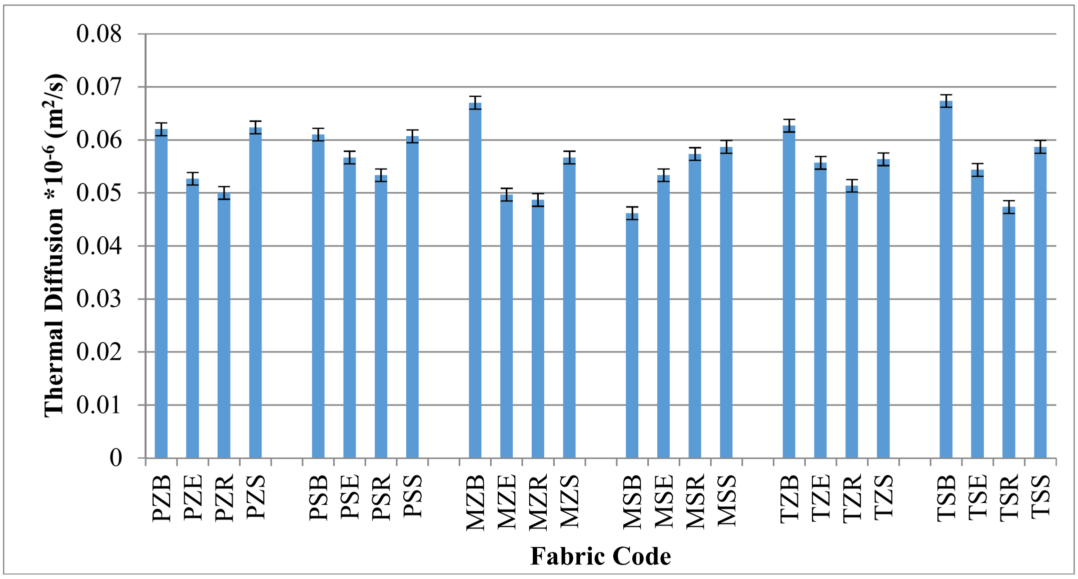

Figure 3. Thermal diffusion of fabrics

4. CONCLUSION

The results showed that the highest thermal resistance values were observed for the rinse washed fabrics, and the lowest thermal resistance values were observed for the enzyme washed fabrics. The highest thermal conductivity values were observed for fabrics in cotton/modal elastane weft yarn woven fabrics in the Z- twill direction. In addition, the twill direction only affected the thermal conductivity of the fabrics, and the Z-twill fabrics had higher thermal conductivities. The lowest thermal conductivity values were observed for the rinse washed fabrics, and the highest thermal conductivity values were observed for the stone washed fabrics. The lowest thermal diffusion coefficients were measured for rinse washed fabrics, and the highest thermal diffusion coefficients were measured in bleach washed fabrics (except MSB).

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5. REFERENCES

[1] VIVEKANADAN, M.V., RAJ, S., SREENIVASAN, S., NACHANE, R.P. Parameters affecting warm-cool feeling cotton denim fabrics. Indian Journal of Fibre & Textile Research, 2011, Vol. 36, pp 117-121.
[2] KHUSHBU, P., THAKKAR, A. Effect of Fabric Construction Parameters on Air Permeability and Thermal Resistance of Commercially Produced Denim Fabric. International Journal for Scientific Research & Development, 2015, Vol. 3, pp 767-769.
[3] MANGAT, M.M., HUSSAIN, T., BAJZIK, V. Impact of Different Weft Materials and Washing Treatments on Moisture Management Characteristics of Denim. Journal of Engineered Fibers and Fabrics, 2012, Vol. 7, No. 1, pp 38-49.

[4] HOSEN F., ASIF A.H., HASAN Z, MAHMUD S.T., ISLAM R. Evaluation of comfort and thermal properties of stretch denim fabric by applying different softeners. Indian Journal of Science and Technology, 2021, Vol. 14, pp 752–764.
[5] ERYÜRÜK, S.H. Analyzing thermophysiological comfort and moisture management behavior of cotton denim fabrics. AUTEX Research Journal, 2021, Vol. 21, No 2, pp 248-254.
[6] TÜRKSOY, H.G., YILDIRIM, N., AVCI, M.E. Comparative evaluation of some comfort properties of denim fabrics including dual-core yarns containing wool and elastane yarn. The Journal of The Textile Institute, 2021, pp 1-8.
[7] BASİT, A., LATİF, W., ASHRAF, M., REHMAN, A., IQBAL, K., MAQSOOD, H. S., JABBAR, A., BAİG, S. A.Comparison of mechanical and thermal comfort properties of tencel blended with regenerated fibers and cotton woven fabrics. Autex Research Journal, 19(1), 2019, 80-85.
[8] ERYURUK, S. H. The effects of elastane and finishing processes on the performance properties of denim fabrics. International Journal of Clothing Science and Technology, 31(2), 2019, 243-258.
[9] FRYDRYCH, I., DZİWORSKA, G., BİLSKA, J. (2002). Comparative analysis of the thermal insulation properties of fabrics made of natural and man-made cellulose fibres. FIBRES and TEXTILES in Eastern Europe, 10(4), 2002, 40-44.

THE EFFECT OF PCM ON THE SURFACE TEMPERATURE OF TIGHT GARMENTS AND SUBJECTIVE COMFORT EVALUATIONS

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ABSTRACT

Thermal comfort is defined as feeling comfortable in the environment and activity conditions of a person. In this study, wear trials of tight garments (with and without PCM) used in sports activities in outdoor conditions were conducted under three different ambient and activity conditions. The results showed that the PCM-containing tight samples measured higher temperatures in the after exercise period (except for slightly cold 16 C°). As the ambient temperature increased, the surface temperature of the tight garment increased and F5 coded tight with the highest thermal resistance value measured subjectively highest temperature and the lowest hand value.

Key Words: Tight garments, thermal imaging, PCM, subjective comfort.

1. INTRODUCTION

The thermal comfort of humans changes the metabolic rate (internal heat production), heat loss from the body, and climatic conditions. The main task of clothes is to ensure the continuity of thermal balance by balancing the heat and moisture losses on the skin surface. Phase change materials (PCM) are materials that provide storage at a constant temperature range and can be used for both heating and cooling depending on the melting temperature [1]. PCM has a very high ability to store high levels of energy during melting or solidification, and it has a structure that can release the stored energy [2]. PCMs are generally used by encapsulating very small microspheres. Thus, both ease of use and controlled release were ensured. Currently, phase change materials in textiles are mainly designed to produce temperature-regulating products in order to achieve improved thermal comfort [3]. The parameters that are important for microcapsules are the diameter of the capsule, the thinness of the capsule shell, its heat conduction property, and its adaptation to volumetric changes [4]. The microcapsule with PCM should control the heat passing through the textile material [5]. Fibers or fabrics containing PCM can be widely used in daily wear products such as coats, gloves, berets, underwear, and products with significant protective effects such as diving suits and ski suits [6]. Many factors must be taken into account when selecting the convenient PCM for protective clothing in order to reach the ideal thermal insulation and regulation effect. Pause (1995) pointed out that the choice of PCM for a particular field of application depends on the phase transition temperature, which must be equal to the temperature range in which the heat flow through the material must be delayed [7]. The heat exchange that occurs during phase change provides thermal protection by allowing users to store and dissipate heat to resist environmental thermal influences, thereby allowing users to interact with clothing [8,9]. Güler and Kut (2011) obtained microcapsules by embedding fatty acid eutectic mixtures into the natural polymeric gelatin-gum arabic shell material using the complex coacervation method in order to provide temperature regulation in curtain fabrics. It was observed that the thermal comfort of the environment improved by 0.5-1.5 ºC after the materials used in capsule production were transferred to the fabric [10].

The present study, it was aimed to improve the thermal comfort of tight garments, which have a wide range of uses from sports to daily activities, in slightly cold to slightly warm ambient conditions. Also, it was measured the subjective comfort sensations of tight garments depended on the temperature changes in the ambient conditions by applying phase change materials to these fabric structures.

2. EXPERIMENTAL

In this study, five fabric structures suitable for the production of tights, which weight values are close to each other, were supplied by a manufacturer. The fabrics' specifications were shown in Table 1. Before applying the phase change material to the fabrics, enzymatic hydrophilization, dyeing with reactive dyestuff, softener application, and drying processes were applied. In this study, a phase change material containing paraffin at a concentration of 200 g/l was used (Ruco-Therm PCM 28) and this material was transferred to the fabric according to the impregnation method in fluard. While preparing the solution, sodium bicarbonate (soda) was added to the solution to make the pH alkaline, and the pH value was kept around 10. In addition, while preparing the solution, attention was paid to ensure that the temperature of the water used did not exceed 40 C°. Alambeta test device used for thermal resistance measurements of fabrics. Tight garments were sewn from without PCM and PCM included fabrics (Table 1) and wear trials were carried out with 10 female subjects whose height (165±5 cm) and weight (60±5 kg) measurements were close to each other in a predetermined training program on a treadmill. The Ethics Committee of Uludag University approved this study. The wear trial consists of three periods: before exercise, after exercise, and post-rest. A digital infrared camera was used and thermal images of the subjects were taken during three activity conditions (Testo 882, 320x 240 pixels, thermal sensitivity < 50 mK). The infrared emissivity of the skin was adjusted to 0.98. At the start of the test, the subjects put on the tight samples and rested for 10 min under laboratory conditions to adapt themselves to the experimental environment. The participants wore the same shoes, socks, and underwear in each trial. The tripod of the thermal camera was placed 1m away from the treadmill for thermal images. Thermal photographs of the subjects were taken under three different temperature conditions (16 °C slightly cold, 20 °C room temperature, and 25 °C slightly warm) during three activity periods.

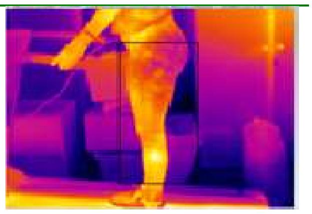
Table 1. Fabrics used in the experiments

Fabric Code	Knit	Yarn Composition	Pus/ Fein	Weight (g/m^2)	Thermal Resistance ($K.m^2/W$)	Yarn Report
F1	S. Jersey	- Ne 28/1 Compact Combed Cotton, - 60 dtex Elastane % 90 Cotton - %10 Elastane	26"28	269.4	10. 66	Cotton+ Elastan
F2	Doube Face Jersey	- Ne 40/1 Compact Combed Cotton - 75/72 Denye Textured Punted PES -78 dtex Elastane %58 Cotton -%30 PES %12 Elastane	30"20	281.54	10.12	Front Face: Cotton Back Face: Cotton/ PES+Elastane
F3		-100/96 Denier Ecru Low Punted Textured PES - Ne 40/1 Compact Combed Cotton -78 dtex Elastane	30"20	279.38	9.68	Front Face: PES Back Face: Cotton+

		%48 PES- %41 Cotton- %11 Elastane				Elastane
F4		-100/96 Denier Ecru Textured Low Punted PES - Ne 38/1 % 88/12 Ring Polyester / Wool -78 dtex Elastane %49 PES -%40 PES+Wool- %11 Elastane	30"20	326.4	11.02	Front Face: PES Back Face: PES/Wool+ Elastane
F5	Gimped Punto Di Roma	-Ne 30/1, % 50/50 Combed Cotton/Polyester -75/36+40 Denye Ecru PES/Elastane % 70 Cotton/PES - %30 PES/ Elastane	34"20	253.72	14.74	1.Yarn: Cotton /PES 2.Yarn: PES/Elastane

In addition, subjective evaluation scales were used for measure the subjective hot-cold sensation and subjective hand value of the fabrics. Five-point Likert scales were used the subjective thermal and hand sensations (Table 2). The rating of perception was reported by the subjects at each scheduled time before exercise, after-exercise and post-rest periods.

Table 2. Five-point Likert scale for subjective sensations and an example of thermal image with tight sample

Hot-Cold Sensation		***Subjective Hand***		***Subjective Weight***		***Hardness-Softness Sensation***		***Thermal Image of Tight Sample***
1	Cold	1	Very bad	1	Very light	1	Very hard	
2	Cool	2	Bad	2	Light	2	Hard	
3	Neutral	3	Medium	3	Medium	3	Medium	
4	Slightly Warm	4	Good	4	Heavy	4	Soft	
5	Hot	5	Very good	5	Very heavy	5	Very soft	

3. RESULTS AND DISCUSSION

3.1. Thermal Image Evaluations of Tight Surface at 16 °C Ambient Conditions

The purpose of using microencapsulated phase change materials in textiles is to arrange the heat flow in the textile structure and act as an active thermal insulation layer formed around the structure. At this temperature and under three different activity conditions, the temperatures of the tights with and without PCM were measured between 30-31.5 °C (Figure 1) and the temperature values post-rest period were higher than those in other periods. This may be due to the energy expenditure of the body to prevent a decrease in the skin surface temperature in an inactive state because the ambient temperature is below the normal conditions. When the temperature values of fabrics with and without PCM were compared in the before exercise condition, it was observed that the temperature values were almost equal, except for the two fabric types (F2 and F3). Because the PCM material is activated with temperature change, in this case the ambient condition is constant at 16 °C and there is no activity, it is expected that the temperature values of the fabrics with and without PCM are close. When the after exercise temperature values were compared, it can be said that the use of PCM in all fabric structures caused an increase in the maximum surface temperatures of the tights (except F1). Because the material changes phase with activity and because the environment has a low temperature value, it increases the surface temperature of the garment.

3.2. Thermal Image Evaluations of Tight Surface at 20 °C Ambient Conditions

The average of the ten subjects' maximum surface temperature values of tight garments at 20 °C ambient conditions is shown in Figure 2. At this temperature and under three different activity conditions, the temperatures of the tights with and without PCM were measured between 29-32 °C. The highest temperature values were measured under the after exercise condition. This is expected because with an increase in activity, an increase in body temperature also occurs. Because the ambient temperature is close to 21°C where the fabric tests were performed, test garments exhibit a different attitude than it is 16 °C in the post-rest state. The maximum surface temperature values of the tights containing PCM after exercise and post-rest were higher than those without PCM. Because the ambient temperature is not high, the phase change material is activated with an increase in activity and increases the maximum surface temperature value of the garment. It can be said that the reason for the high maximum surface temperatures of the tights (F2, F3, and F4) produced from the double face jersey knit containing phase-change material in the before exercise state is due to the knitting structure. Because these fabrics are produced double-face and the fabric weights are higher than those of the other two fabrics. Considering the effect of thermal resistance values on the surface temperature values, the highest surface temperatures were measured for the F5 coded fabric, which had the highest thermal resistance value, at the post rest activity condition both without PCM and PCM included fabrics.

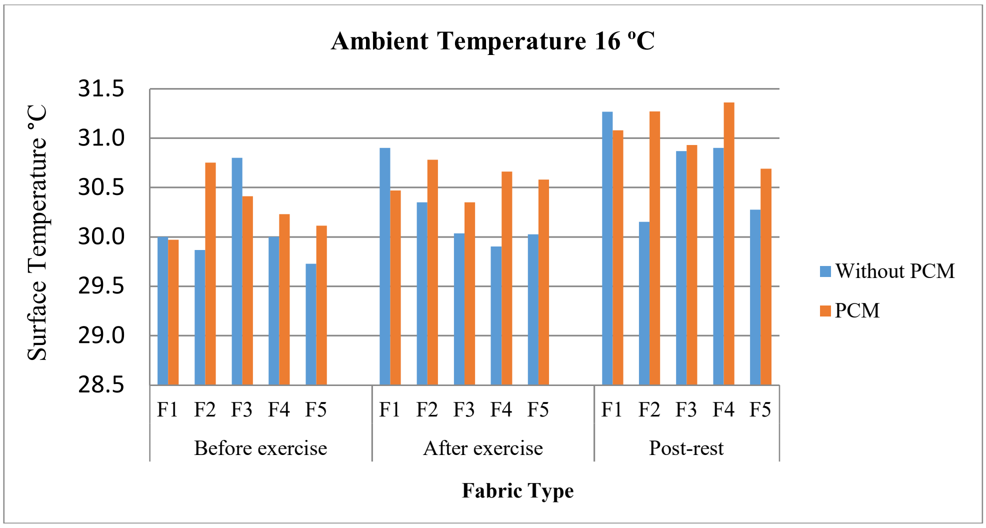


Figure 1. Maximum surface temperature values of tights garments at 16 °C ambient temperature

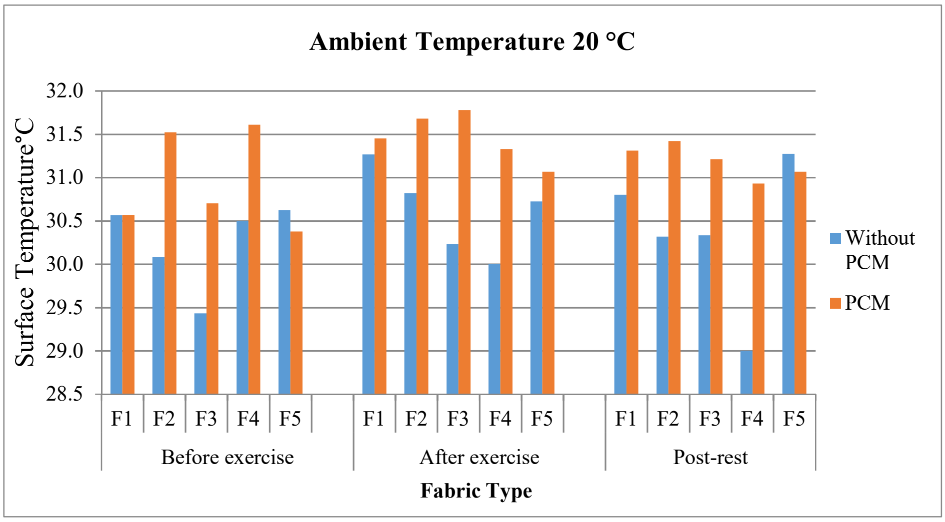


Figure 2. Maximum surface temperature values of tights garments at 20 °C ambient temperature

3.3. Thermal Image Evaluations of Tight Surface at 25 °C Ambient Conditions

At this temperature and under three different activity conditions, the temperatures of the tights with and without the PCM were measured between 30-33 °C (Figure 3). Owing to the increase in ambient temperature, a high measurement of the maximum surface temperature of the tight garments was observed. It can be said that the highest temperature values were measured after exercise period, as at 20 °C ambient condition. The body temperature increased with an increase in activity, and the PCM material was activated, thereby increasing the maximum surface temperature of the tights. Because the ambient temperature was not very high here, PCM was activated again to increase the surface temperature of the garment. When the after exercise data were compared, the temperature of the untreated fabric with F1 coded cotton elastane single jersey knit was higher than that of the material containing PCM. When fabrics with and without PCM were compared at before exercise period, the surface temperatures of tights containing PCM were found to be higher than those without PCM (except for F5). When the post-rest period was examined, it was observed that the thermal camera surface temperature values of the fabrics containing PCM were higher than those without PCM in all tight samples (except F5). In this activity section, the highest temperature values were observed in the tights made from the F1 coded cotton single jersey fabric sample.

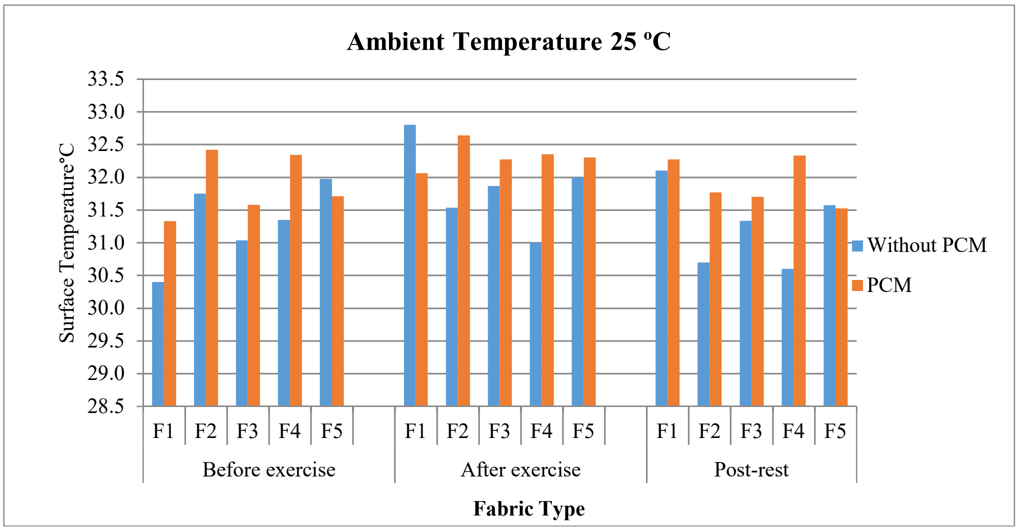


Figure 3. Maximum surface temperature values of tights garments at 25 °C ambient temperature

4. SUBJECTIVE COMFORT EVALUATIONS

4.1. Hot-Cold Sensation

In the activity sections defined as before exercise, after exercise, and post-rest, the subjects were asked to evaluate the sensation of hot-cold with the help of the five point Likert scale. In Figure 4a, a radar graphic representation of the averages of the responses given by the subjects under three different environmental conditions is shown. It was observed that the F5 coded fabric, which had the highest thermal resistance value, was measured at higher temperature values in all temperatures and activity sections. It was observed that the F3 coded fabric, which had the lowest thermal resistance value, was generally perceived as having lower temperatures under all activity and ambient conditions.

4.2. Subjective Hand Value

The fabric hand is defined as a feeling that occurs when the fabric is in contact with the body surface; in particular the fabric hand value is evaluated using the fingers. In the activity sections defined as before exercise, after exercise, and post-rest, the subjects were asked to evaluate the fabric's subjective hand perception with the help of the scale used. In Figure 4b, a radar graphic representation of the averages of the responses given by the subjects in three different environmental conditions was given. The highest fabric handle value was seen in the fabric produced with cotton elastane yarn single jersey knitted F1 coded fabric. The lowest fabric handle value was measured in the fabric sample containing the gimped yarn with the F5 code, which had the highest thermal resistance value. In general, the fabric handle values of all the fabrics were in the range of 3-4 values. In other words, the subjective hand values of all the fabric samples varied between moderate and good.

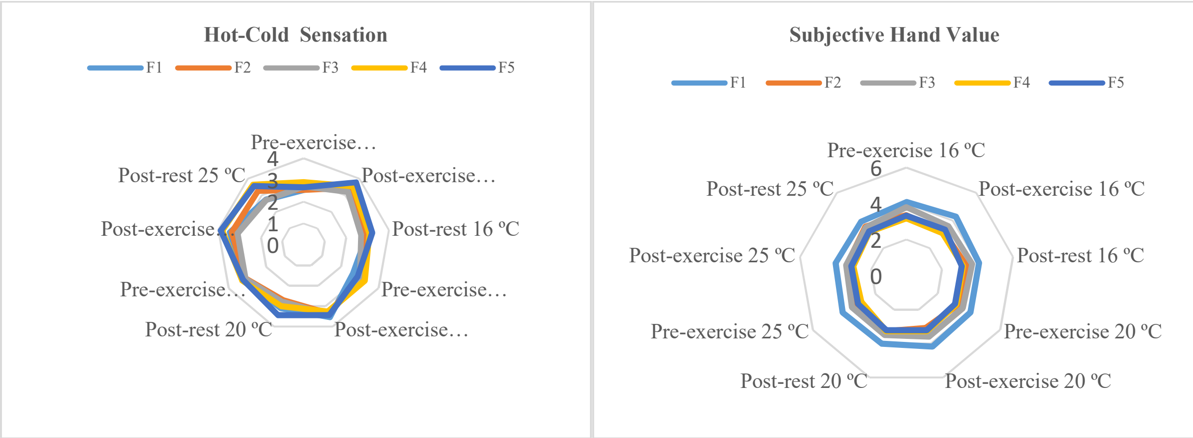


Figure 4. The average of ten subjects a) hot-cold sensations b) subjective hand evaluation

5. CONCLUSIONS

The results showed that the surface temperature of the tight was higher in fabrics with and without the PCM, as the ambient temperature increased. In addition, the highest tight surface temperatures were measured in the after exercise period, except for the tests performed at 16 °C, which was defined as slightly cold. F5 coded tight with the highest thermal resistance value measured subjectively at the highest temperature and lowest hand value. The tight made of F1 coded cotton single jersey fabric had the highest fabric handle value.

ACKNOLEDGEMENTS

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6. REFERENCES

[1] TÖZÜM, S., DEMIRBAĞ, S., AKSO, A.S. Investıgatıon of Thermoregulatıon Propertıes of the Heat Storıng Mıcrocapsule Applıed Fabrıcs. Textile and Engineer, 2011, Vol. 84, pp 8-14.
[2] CHAPMAN, R. Development in smart fabrics. United Kingdom: Edited: Pira International Ltd., 2006.
[3] KURU, A., ALAY AKSOY S. Phase Change Materials and Their Textile Applications. Textile and Engineer, 2012, Vol. 19, No.86, pp 41-48.
[4] ÇIMEN, E. Mikrokapsülleme Yöntemiyle Dokuma Kumaşlara Yeni Özellikler Katma Olanakları, İstanbul Teknik Üniversitesi, Fen Bilimleri Enstitüsü İstanbul, 2007.
[5] DEVECI, Ş., Mikrokapsüllenmiş Faz Değiştiricilerin ve Özel Liflerin Elastik Bandajların Konfor Özelliklerinin İyileştirilmesinde Kullanımı, Ege Üniversitesi, Fen Bilimleri Enstitüsü, Yüksek Lisans Tezi, İzmir, 2009.
[6] NELSON, G. Application of Microencapsulation in Textiles. International Journal of Pharmaceutics, 2002, Vol. 242, pp 55–61.
[7] PAUSE, B. Development of Heat and Cold Insulating Membrane Structures with Phase Change Materials. Journal of Coated Fabrics, 1995, Vol. 25, No. 7, pp 59-64.
[8] BOAN, Y., Physical Mechanism and Charactarization of Smart Thermal Clothing. The Hong Kong Polytechnic University, PhD Thesis, 2005.
[9] MATTILA, H.R. Intelligent Textiles and Clothing, Woodhead Publishing Limited,The Textile Institute, Cambridge, England, 2006.

[10] GÜLER, Z., KUT, D. Preparatıon and Application of Microcapsules For Thermal Regulating Polyester Curtain. Uludağ Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi, 2011, Vol. 16, No. 1, pp 105-115.

A HYDROGEL/TEXTILE BASED ACTUATOR FOR SOFT ROBOTIC APPLICATIONS

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ABSTRACT

The growing interest in smart textiles for soft robotics stems from textiles' advantages over traditional materials in wearable robots. However, meeting the demand for better soft and wearable robots requires integrating soft actuators, which respond to various stimuli and are mostly made from hydrogels. These soft actuators often lack the necessary toughness and flexibility for effective use in soft robotics. Thus, our study combines PEGDA hydrogel with silk and polyester fabric to create a humidity-responsive smart composite material aimed at addressing this challenge in soft robotics.

Key Words: Smart textiles, moisture-responsive fabric, soft actuator, hydrogel, silk fabric

1. INTRODUCTION

"Soft robotics" refers to a subfield of robotics that focuses on designing and constructing robots using flexible and deformable materials. These robots are often inspired by the natural movements and structures of living organisms, and they offer several advantages over traditional rigid robots, particularly in terms of adaptability, safety, and interaction with humans [1].

Recently, there's been a growing interest in creating smart textiles for use in soft robotics [2]. This shift is because textiles have many advantages over the usual materials like hard metals, composites, and plastics used in wearable robots [3,4]. However, to meet the increasing demand for better soft and wearable robots, we also need to incorporate soft actuators.

Soft actuators are flexible parts that respond to external inputs to produce the desired movements and forces [5]. Currently, most soft actuators are made from special hydrogels that can change shape when you apply external forces [5,6]. There are several options to control hydrogel-based soft actuators because they can respond to various stimuli. Depending on the input stimulus, a hydrogel-based actuator can be classified into six groups: thermally responsive actuators, chemically responsive actuators, optically responsive actuators, electrically responsive actuators, magnetically responsive actuators, hydraulically responsive actuators[7].

Thermally Responsive Actuators: Thermally responsive hydrogel actuators change their volume in reaction to changes in the surrounding temperature. These actuators selectively react to a specific temperature range to cause significant deformations. A wide range of applications is possible with these actuators since their critical temperature range can be altered.

Chemically responsive actuators: Chemically responsive hydrogel actuators change their volume in response to chemical stimuli. These hydrogels have the ability to directly translate the chemical potential of the environment into mechanical motion.

Optically responsive actuators: Optically responsive hydrogel actuators change their volume or shape in response to light irradiation. These actuators can selectively respond to light of certain wavelengths. Furthermore, they do not need a physical connection for energy transfer.

Electrically responsive actuators: Electrically responsive hydrogel actuators change their volume or shape in response to electric stimuli.

Magnetically responsive actuators: Magnetically responsive hydrogel actuators change their volume in response to an external magnetic field.

Hydraulically responsive actuators: Hydraulically responsive hydrogel actuators change their shape changes in response to hydraulic pressure [7].

However, these soft actuators often lack the toughness, flexibility, and stretchiness needed for effective use in soft robotics. So, there's a clear need for further development of soft actuators that can meet the tough requirements of soft robotics.

In this study, we aimed to address this issue by combining PEGDA hydrogel with silk and polyester fabric, creating a humidity-responsive smart composite material designed for use in soft robotics.

Poly(ethylene glycol) (PEG) is a widely known polymer that finds application in numerous biomedical applications due to its hydrophilic nature, water solubility, and high biocompatibility [8]. PEGDA, a derivative of PEG, is obtained by replacing two hydroxyl end groups on PEG diol with acrylates. PEGDA is well-known for its biological inertness and ease of photo-polymerization [9].

Textile fabrics are two-dimensional plane-like structures formed of textile materials that have acceptable strength, elongation, and flexibility [10]. Textile fabrics are traditionally used for apparel and home furnishing production, but they have also several technical application areas such as filtering, wound dressing, composite, tire cord, etc. In this study, woven fabrics made from silk and polyester fibers were used to create composite structures. Silk was selected for its hydrophilic properties, while polyester was selected for its hydrophobic properties.

In the first part of this study, PEGDA hydrogels were produced using the photopolymerization process. To create stable hydrogels, various PEGDA concentration rates and photoinitiator types were applied. Following hydrogel production, fabrics were treated with hydrogel solutions. Finally, the water absorption capacity and humidity response properties of hydrogel-treated fabrics were determined.

2. EXPERIMENTAL

2.1. Materials

Poly(ethylene glycol) diacrylate (PEGDA) (Mw= 575)and photoinitiators: HOMPP and Irgacure 2959 were purchased from Sigma Aldrich. Ethanol (≥ 99.9%) and distilled water were used as solvents.

The plain weave silk fabric (35 g/m²) was obtained from Mert İpek Factory, and the plain weave polyester fabric (35 g/m²) was supplied from Dokumacı İthalat İhracat ve Tekstil San. Ltd.

2.2. Methods

Initially, an optimization study was conducted to identify the most suitable solution and process parameters required for the synthesis of PEGDA hydrogel. Based on the results obtained from this preliminary investigation, a mixture was prepared, consisting of 2230 μl of PEGDA, 1385 μl of water, and 1385 μl of ethanol. This mixture was then vigorously stirred at a speed of 950 rpm for a duration of 90 minutes. Subsequently, 232 μl of HOMPP was introduced into the solution, and the resulting mixture was further agitated for an additional 90 minutes, all of which was carried out in the dark.

To compare the performance of HOMPP and Irgacure 2959 photoinitiators, another solution was prepared using Irgacure 2959. This solution consisted of 0.25 gr of Irgacure 2959, 1385 µl of water, and 1385 µl of ethanol, which were mixed at a speed of 950 for 90 minutes. Following this, 232 µl of PEGDA was added to the mixture, and it was stirred for an additional 90 minutes in the dark. Table 1 shows the constituents of hydrogel solutions.

Table 1. Experimental parameters

Experiments	PEGDA(µl)	Photoinitiators	Water(µl)	Ethanol(µl)	Time(min)
1	2230	HOMPP 232 µl	1385	1385	180
2	2230	Irgacure 2959 0,25 gr	1617	1385	180

After the hydrogel preparation, both silk fabric and polyester fabrics were cut into dimensions of 2.5cm x 2cm. Then a 25 µl hydrogel solution was applied to fabrics. The fabrics were then exposed to UV light using a CN-6 device emitting light at a wavelength of 365 nm for a duration of 5 minutes. Subsequently, any insoluble residues were removed by washing the fabrics with water over a span of 4 days. Following the washing process, the fabrics were subjected to drying in an oven at 40 °C for a duration of 24 hours.

The swelling ratio (SR) of the hydrogel-treated fabrics was determined as below: Eq.(1)

$$SR_t = \frac{w_s - w_d}{w_d} * 100 \ (1)$$

Ws: Swollen hydrogel- treated fabric (g); Wd: dried hydrogel- treated fabric (g)

The response of the hydrogel-treated fabric to humidity was tested by applying water to the fabric and observing its response.

3. RESULTS

Table 2 shows the water absorption behaviors of hydrogel-treated fabrics during 2 hour period. The weight of silk and polyester fabrics increased when HOMPP was used as a photoinitiator in the first 15 minutes, followed by a decrease in the 30th minute. Subsequently, the weight of the silk fabric increased once more in the first hour and remained stable. On the other hand, the weight of the polyester fabric also increased again in the first hour but then decreased in the second hour.

When Irgacure 2959 was used as a photoinitiator, both silk and polyester fabrics showed an initial weight increase within the first 5 minutes, followed by a decrease in the 15th minute. Notably, at the 30th minute, the weight of the silk fabric continued to decrease, while the weight of the polyester fabric increased. Beyond this point, the weight of the polyester fabric stabilized after 30 minutes, while the weight of the silk fabric exhibited another increase and subsequent stabilization in the first hour.

Table 2. Water absorption of hydrogel-treated fabrics at different time periods

Photoinitiator Type	Fabric Type	Fabric Weight (g)				
		5min.	15 min.	30 min.	1 hour	2 hours
HOMPP	Silk	0,1321	0,1405	0,1295	0,1379	0,1373
HOMPP	Polyester	0,1438	0,1472	0,1452	0,1548	0,1438
Irgacure 2959	Silk	0,0447	0,0438	0,0387	0,0424	0,0423
Irgacure 2959	Polyester	0,0601	0,0575	0,0610	0,0606	0,0602

Figure 1 illustrates the swelling ratios of hydrogel-treated fabrics using different types of photoinitiators. It is evident that silk fabric exhibited a higher swelling ratio in comparison to polyester fabric for both photoinitiators. This difference can be attributed to the inherently hydrophilic nature of silk fibers. Additionally, it was observed that when HOMPP was employed as the photoinitiator, the swelling ratio was higher in comparison to the use of Irgacure 2959.

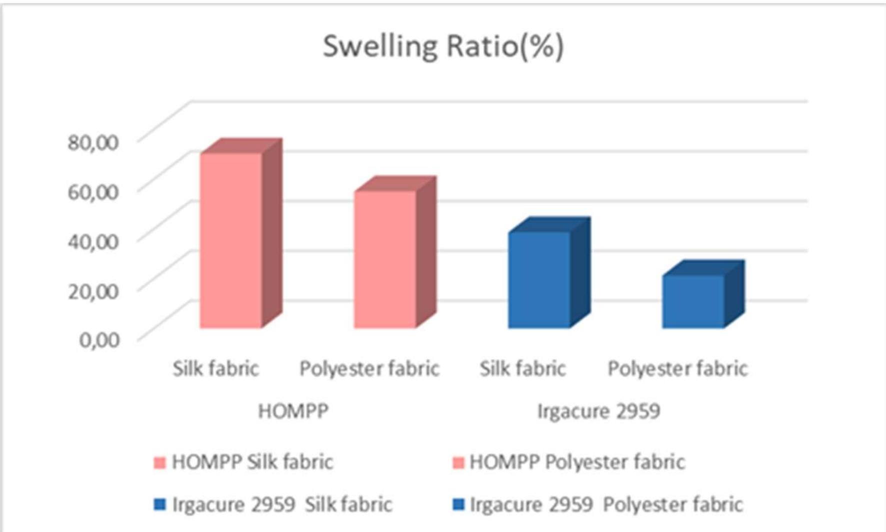

Figure 1. Swelling Ratios (%) of fabrics

To observe the response of hydrogel-treated fabrics to water, a drop of water was poured onto the fabric. As the hydrogel on the fabric dehydrated, it shrunk and pulled the fabric along its path of least resistance. Rehydration of the fabric caused the swelling of the hydrogel, which in turn caused the fabric to change its shape. Figure 2 shows a silk fabric that has been treated with a hydrogel solution using HOMPP as a photoinitiator. After a water droplet was applied, the curled fabric became flat within 10 seconds.

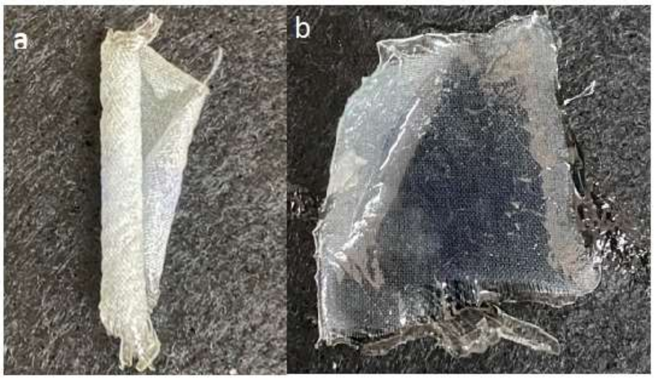

Figure 2. The humidity-responsive actuation of silk fabric treated with a hydrogel solution using HOMPP as a photoinitiator. a. Dehydrated fabric; b.Rehydrated fabric

The polyester fabric in Figure 3 was treated with the same hydrogel as the silk fabric in Figure 2. However, the polyester fabric became flat within 4 seconds. After drying, these fabrics returned to their original shapes.

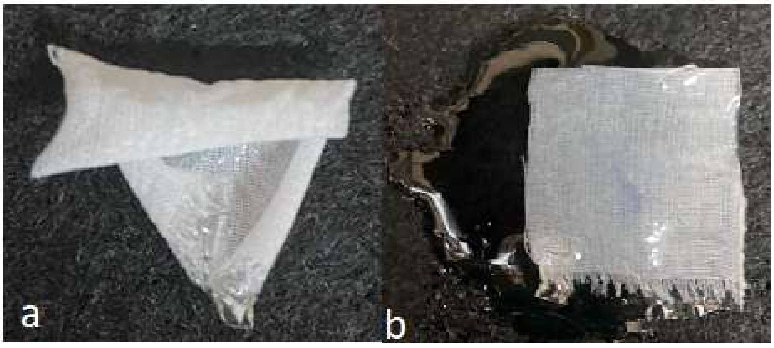

Figure 3. The humidity-responsive actuation of hydrogel-applied polyester fabric treated with a hydrogel solution using HOMPP as a photoinitiator. a. Dehydrated fabric; b.Rehydrated fabric

Figure 4 shows a silk fabric that has been treated with a hydrogel solution using Irgacure 2959 as a photoinitiator. The dry, curled fabric flattened within 1 second after a water droplet was applied, and returned to its original curled form after 1 second.

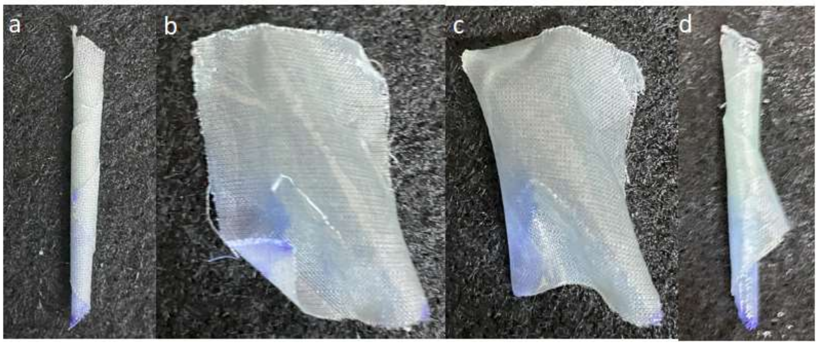

Figure 4. The humidity-responsive actuation of silk fabric treated with a hydrogel solution using Irgacure 2959 as a photoinitiator .a. Dehydrated fabric; b-c-d.Rehydrated fabric

Figure 5 illustrates a polyester fabric that has been treated with a hydrogel solution using Irgacure 2959 as a photoinitiator. Similar to the silk fabric in Figure 4, the polyester fabric flattened upon application of a water droplet and curled again in 1 second.

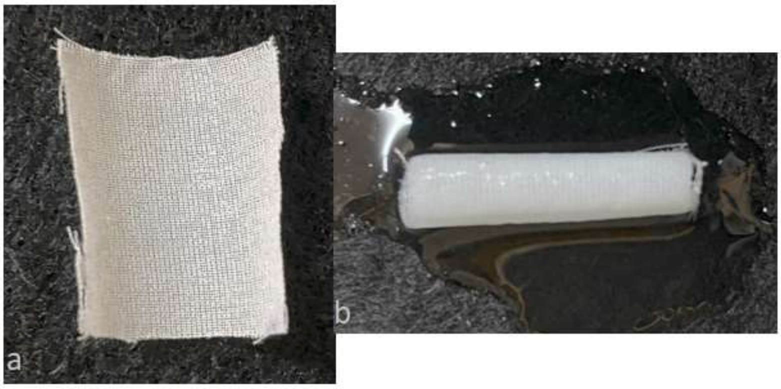

Figure 5. The humidity-responsive actuation of polyester fabric treated with a hydrogel solution using Irgacure 2959 as a photoinitiator a. Dehydrated fabric; b.Rehydrated fabric

4. CONCLUSION

Smart textiles are increasingly being utilized as actuators in the field of soft robotics. These textiles are engineered with materials that can change shape, stiffness, or conductivity in response to various stimuli such as humidity or temperature. In this study, a hydrogel textile composite was produced to use as an actuator in soft robotic applications. Initial results showed that hydrogel textile composite response to humidity. Presently, ongoing research is focused on examining the influence of hydrogel amount and application pattern on the shape change response of fabrics.

5. REFERENCES

[1] YASA, O., TOSHIMITSU, Y., MICHELIS, M. Y., JONES, L. S., FILIPPI, M., BUCHNER, T., & KATZSCHMANN, R. K. (2023). An Overview of Soft Robotics. Annual Review of Control, Robotics, and Autonomous Systems. 2023, vol. 6.
https://doi.org/10.1146/annurev-control-062322-100607

[2] V. SANCHEZ, C.J. WALSH, R.J. WOOD, Textile Technology for Soft Robotic and Autonomous Garments, Adv. Funct. Mater., 02/2021, vol.31, no. 6. https://doi.org/10.1002/adfm.202008278.

[3] C. FU, Z. XIA, C. HURREN, A. NILGHAZ, X. WANG, Textiles in soft robots: Current progress and future trends, Biosens. Bioelectron.,2022, vol.196. https://doi.org/10.1016/j.bios.2021.113690.

[4] A.F. YILMAZ, F. KHALILBAYLI, K. OZLEM, H.M. ELMOUGHNI, F. KALAOGLU, A.T. ATALAY, G. INCE, O. ATALAY, Effect of Segment Types on Characterization of Soft Sensing Textile Actuators for Soft Wearable Robots, Biomimetics (Basel, Switzerland), 2022, vol.7, no.4. https://doi.org/10.3390/biomimetics7040249.

[5] J. KIM, J.W. KIM, H.C. KIM, L. ZHAI, H.U. KO, R.M. MUTHOKA, Review of Soft Actuator Materials, Int. J. Precis. Eng. Manuf.,2019, vol.20, no.12. https://doi.org/10.1007/s12541-019-00255-1.

[6] M. DING, L. JING, H. YANG, C.E. MACHNICKI, X. FU, K. LI, I.Y. WONG, P.Y. CHEN, Multifunctional soft machines based on stimuli-responsive hydrogels: from freestanding hydrogels to smart integrated systems, Mater. Today Adv.,2020, vol.8 https://doi.org/10.1016/j.mtadv.2020.100088.

[7] Y. LEE, W.J. SONG, J.-Y. SUN, Hydrogel soft robotics, Materials Today Physics, 2020, vol.15, https://doi.org/10.1016/j.mtphys.2020.100258.

[8] C.C. LIN, K.S. ANSETH, PEG hydrogels for the controlled release of biomolecules in regenerative medicine, Pharm. Res., 2009, vol.26, no.3. https://doi.org/10.1007/s11095-008-9801-2.

[9] Y. WANG, B. ZHANG, M. MA, W. LU, J. WANG, Y. GUO, Synthesis of GelMA/PEGDA Hydrogel by UV Photopolymerization, Yingxiang Kexue Yu Guanghuaxue/Imaging Sci. Photochem., 2017, vol.35, no.4, https://doi.org/10.7517/j.issn.1674-0475.2017.04.019.

[10] RAY, S.C. (ED.). Fundamentals and Advances in Knitting Technology (1st ed.). WPI Publishing. 2012. https://doi.org/10.1201/b18245.

THE COATING OF POLIACRILONITRILE STRIP WITH NANOFIBERS PRODUCED BY ELECTROSPINNING

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ABSTRACT

In this study, it is aimed to coat polyacrylonitrile (PAN) stripswith nanofibers by electrospinning. Coating the PAN strip with nanofiber is the process of applying nanometer scale fibers to the surface of the strip. In the experimental study, the concentration of the polymer solution (PAN/DMF), voltage, flow rate, etc. parameters are optimized. Firstly, the nanofiber coating was studied depending on the time. Then, the PAN strip was twisted during coating. The properties of coated nanofiber strips such as distribution of nanofibers, bead formation, diameter of nanofibers, porosity and uniformity of nanofibers by scanning electron microscopy exanimated in this study.

Key Words: Polyacrylonitrile strip, nanofiber, electrospinning, coating, hybrid yarn

1. INTRODUCTION

The nanofibers are ultrafine fibers with diameters typically ranging from a few nanometers to several hundred nanometers. These fibers are produced through various techniques that allow the manipulation of materials at the nanoscale level, resulting in unique properties due to their small size and high surface area-to-volume ratio. Small size imparts exceptional properties to nanofibers, allowing them to exhibit behavior distinct from their larger counterparts. High surface area makes them attractive for applications where increased surface interactions are desirable, such as in filtration, sensing, catalysis and energy storage, tissue engineering, drug delivery, water treatment, electrodes in fuel cells, lithium-ion batteries, etc. [1-7]. These applications are largely caused by their high surface area-to-volume ratio, scalable porosity, and low density [1, 8].

Over the past decade, a range of techniques has been for the production nanofibers. One of them is electrospinning method thanks to its simples etup, low cost, and the ability to generate various types of fibers [9]. The electrospinning basically consists of three basic parts: needle, collector and high voltage power supply. This process is effected by different parameters: polymer solution (viscosity, molecular weight, concentration, electrical conductivity, surface tension, dielectric constant), processing condition (flow rate of the solution, applied voltage, type of the collector, needle tip to collector distance), and environmental parameter (temperature and humidity) [2, 10].

Recently, it has been seen that nanofibers produced by electrospinning method are combined with fiber stripes, filament yarn, and spun yarn to produce composite nanofiber yarns. The first stage of yarn preparation is the parallel orientation of the filament fibers in the sliver. The next step is to twist the filament bundle. In this way, it is aimed to increase the adhesion and friction force between the fibers. The use of nanofibers at these stages improves the mechanical properties of traditional yarns [1, 11]. Hence, new composite nanofiber yarns have great potential for applications in many fields.

Yuhang Wanh [1] classified research and development studies on composite nanofiber yarns as core-spun yarn [12-20], ultralow proportion nanofiber composite yarns [21-23], and multi-component nanofiber yarns [24, 25]. Literature research concerning core-spun yarns generally speaks of a yarn with a core-shell configuration. The outer layer is comprised of nanofibers with an extensive surface area and openness. The core layer is either a filament or yarn, featuring mechanical features and flexibility, and is able to enhance the mechanical strength of the nanofiber yarn. In the literature studies of the second type, the process begins with electrospinning technology, where nanofibers are deposited onto a microfiber web. Subsequently, traditional spinning techniques like drawing, roving, and spinning are used to transform this combination into micro-nano composite yarns. This approach is known for its exceptional efficiency in yarn preparation, ensuring a consistent dispersion of nanofibers and the production of composite yarns with high strength and multiple functionalities. The literature studies of the last type have achieved the synthesis of multi-component nanofiber composite yarns through the combination of functional electrospinning fiber preparation technology and a yarn preparation device, which satisfy the requirements of multifunctional nanofiber yarns.

In this study, firstly, the electrospinning parameters in the production of polyacrylonitrile (PAN) nanofibers were optimized. Then, PAN nanofibers produced by electrospinning were deposited on the surface of the PAN strip. The coating time was optimized for nanofiber coating on the strips. The strip was then twisted during nanofiber coating. Finally, the surface morphology of the nanofiber coating analyzed by scanning electron microscopy. In these analyzes examined parameters such as distribution, bead formation, nanofiber diameter, porosity and uniformity of nanofibers.

2. EXPERIMENTAL

2.1 Materials

The polyacrylonitrile polymer (PAN, Mw: 150,000 g/mol) used in the study was obtained from Aksa Akrilik Kimya Sanayii A.Ş. dimethylformamide (DMF), used as solvent in the preparation of the electrospinning solution, was purchased from Sigma Aldrich. The PAN/DMF solution was prepared at a concentration of 12 % by weight, at 80 °C, by mixing for 4 hours.

2.2 Electrospinning Design and Installation

In this study, needle electrospinning setup was made. The setup consists of a syringe pump, a collector plate, and two DC high-voltage power supplies (+40 kV and -40 kV). The positive and the negative power supplies are connected to the needle and the collector, respectively. Needle tip to collector distance (TCD) was 20 cm, and the distance between the collector and the PAN strip was kept constant as 5 cm. A high voltage of +20 kV was applied to the needle tip and -5 kV to the collector. The feed pump speed was kept constant at 16 µL/min. For coating the strips with nanofiber were used 1.7 dtex PAN strips. The systematic presentation of the electrospinning setup is given in Figure 1.

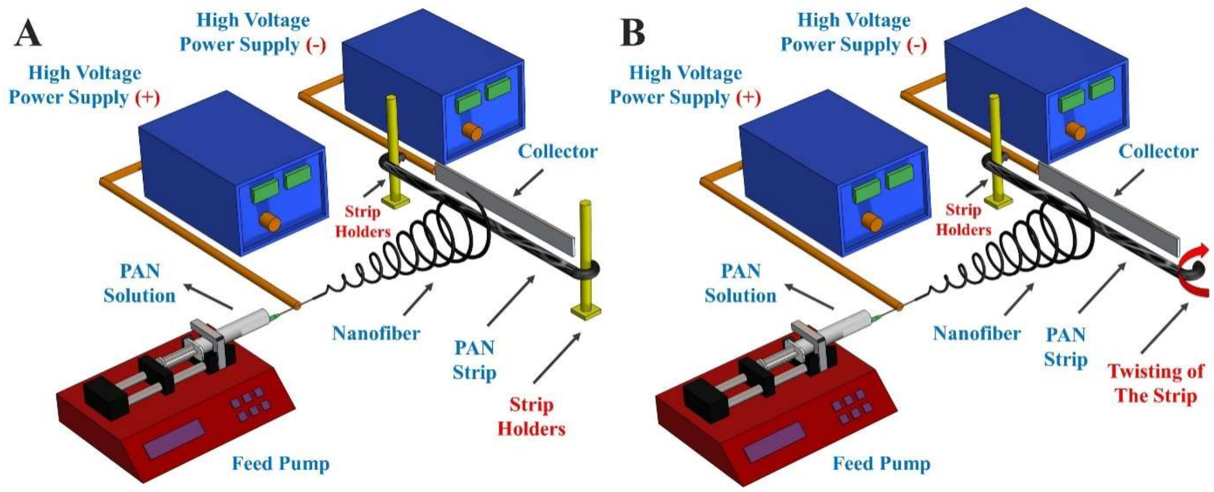

Figure 1. Schematic representation of the electrospinning setup: a) fixed strip, b) twisted strip

In the study, two different setups were used to coating PAN strips with nanofibers (Figure 1). In the first setup, the nanofiber strip was fixed at both ends with holders and placed in front of the collector (Figure 1a). In this setup, the strips were covered with nanofibers in two different times, 5 and 15 minutes. In the second setup, the nanofiber strip was placed in front of the collector and fixed at one end and twisted at the other end during production (Figure 1b). In this setup, the strip was covered for 15 minutes. The nanofibers were produced at a temperature of 25 ± 2 °C and with a relative humidity (RH) of 50 ± 5 %.

2.3 Characterization and Analysis

Attention Theta optical tensiometer was used to measure the surface tension of the PAN solution, Brookfield DV-III Ultra rheometer was used to measure its viscosity and electrical conductivity was measured by Orion 4 Star Plus meter. A field-emission scanning electron microscope (FE-SEM, ZEISS Gemini SEM 300) was used to obtain micrographs of electrospun nanofibers. The SEM images at 35 X, 500 X and 3,000 X magnifications were evaluated to examine the nanofiber coatings on the PAN strips. The measurement of nanofiber diameters was made from the SEM images of 20,000X magnifications. For the nanofiber diameter, at least 50 measurements were taken from each sample.

3. RESULTS AND DISCUSSION

The properties of the PAN/DMF solution were analyzed and the viscosity, surface tension and conductivity of the solution were measured as 925 cP, 34.01mN/m and 96.3 µS/cm, respectively. The SEM images of PAN strips (reference) used for nanofiber coating are given in Figure 2.

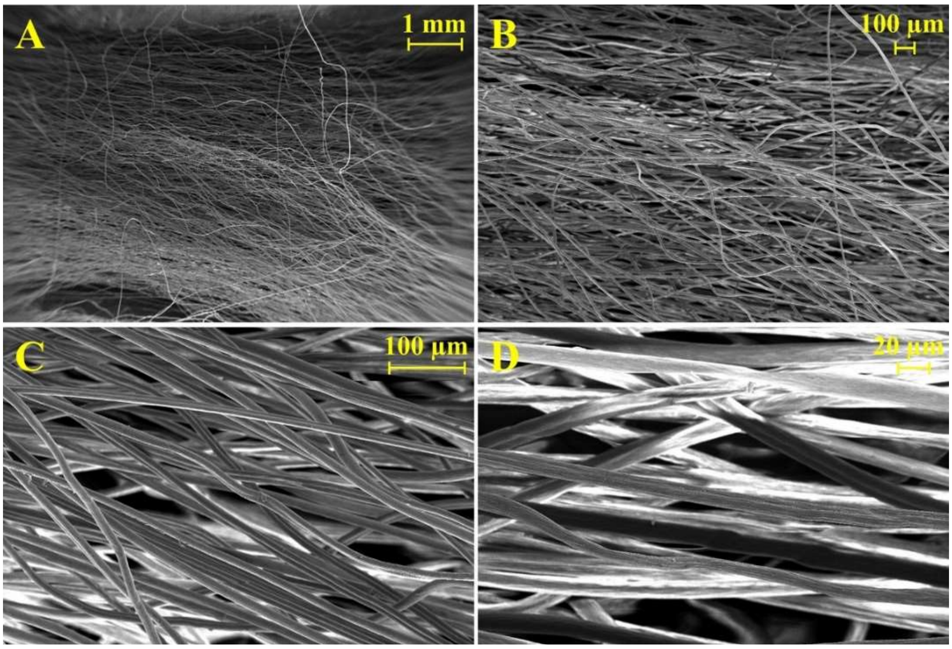

Figure 2. The SEM image of PAN fiber strip without nanofiber coating at different magnifications: a) 35 X, b) 120 X, c) 500 X, d) 1,000 X

The SEM images taken at different magnifications were examined. The SEM images show that the strips are uncoated. The fibers were a uniform structure (Figure 2c-d). The diameters of the fibers in the strips were measured as 12.6 ± 2.2 µm.

The fixed strips were firstly coated with nanofibers at 5 and 15 minutes. The SEM images of nanofiber coated strips are given in Figure 2 and Figure 3.

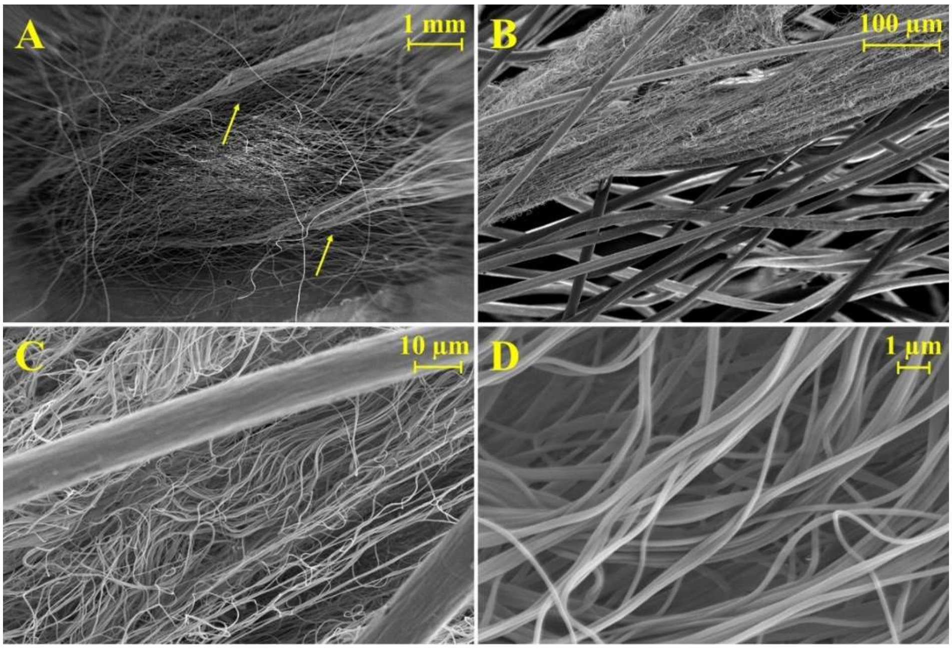

Figure 3. The SEM image of nanofiber coated PAN strip in 5 minutes different magnifications: a) 35 X, b) 500 X, c) 3,000 X, d) 20,000 X

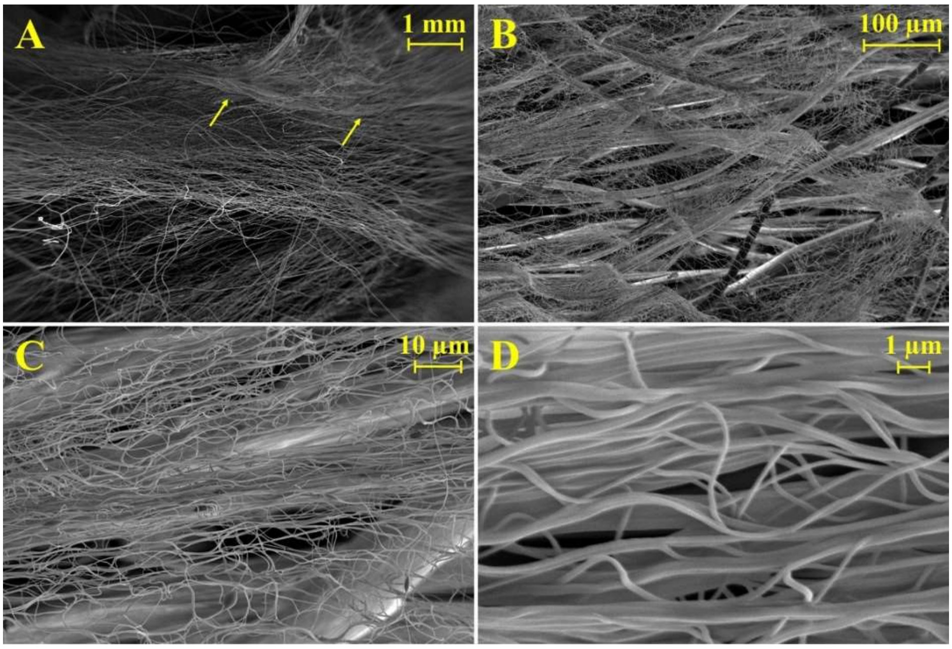

Figure 4. The SEM image of nanofiber coated PAN strip in 15 minutes different magnifications: a) 35 X, b) 500 X, c) 3,000 X, d) 20,000 X

It has been observed that the strips are coated with nanofibers at different times. The nanofibers are above the strip surface (Figure 3b and Figure 4b). The nanofiber coating takes longer than 5 minutes in 15 minutes. While the coating was in a partial area in 5 minutes, this area increased even more in 15 minutes. The nanofibers covered the web-like strip (Figure 4c). The nanofibers are in a uniform structure and no bead formation was observed (Figure 3d and Figure 4d). The SEM images of the twisted nanofiber coated strips are given in Figure 5.

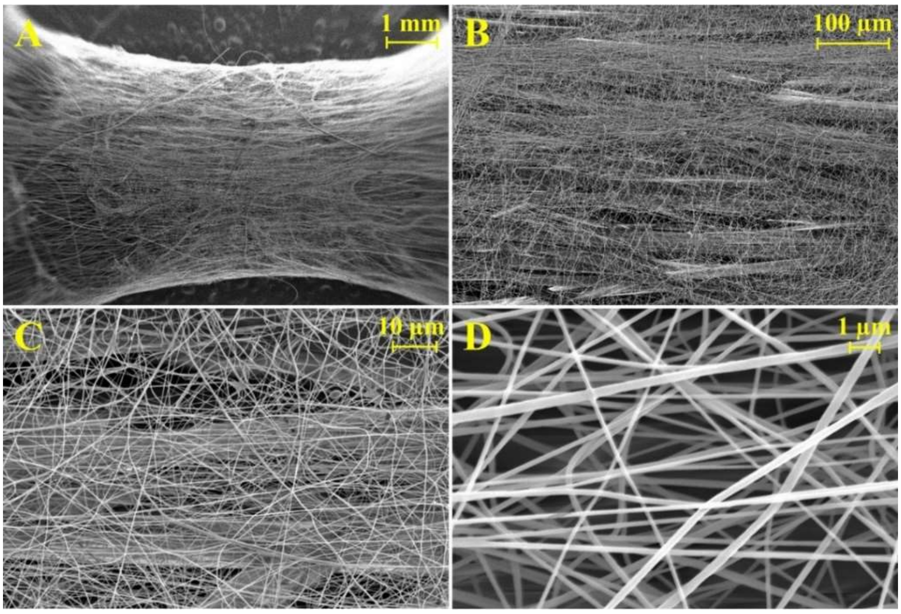

Figure 5. The SEM image of PAN strip coated with nanofibers while twisting: a) 35 X, b) 500 X, c) 3,000 X, d) 20,000 X

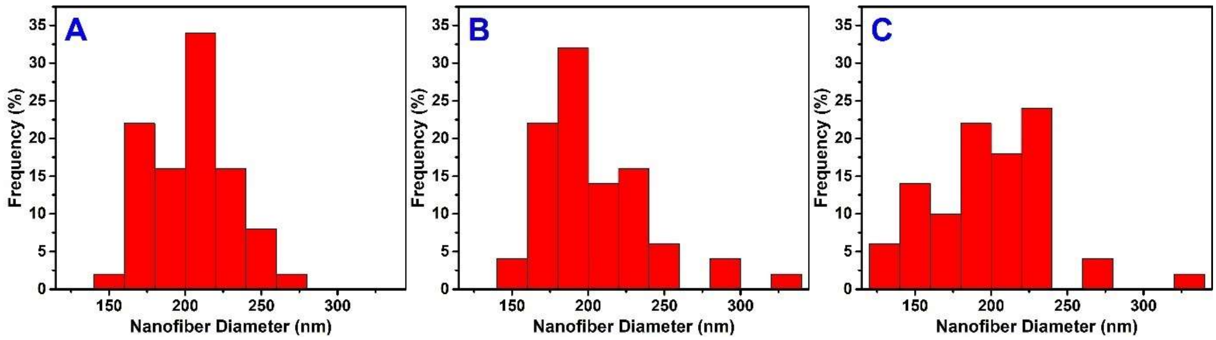

Figure 6. The distribution of coated nanofiber diameters: a) fixed strip at 5 minutes, b) fixed strip at 15 minutes, and c) twisted strip

The nanofibers coated the strip by twisting during production. While it was observed that the nanofibers were focused on certain points in the fixed coating, the strip remained inside the nanofiber in the coating while twisting (Figure 3a, Figure 4a and Figure 5a). The nanofiber is in the mesh form and the pore size is quite low (Figure 5b and Figure 5c). The nanofibers are allowed to reach all directions of the strip as it is twist. However, in the fixed strip, the nanofiber cannot reach the back regions. The coated nanofibers were uniform, and no bead formation was observed (Figure 5d).

The nanofiber diameter distributions are given in Figure 6. The nanofiber diameters of the fixed strip 5 and 15 min and the twisted strips are 205 ± 26, 204 ± 36 and 199 ± 39 nm, respectively. While the nanofiber diameter distributions of the fixed strips were close to each other, the nanofiber diameter distribution of the twisted strips was in a wider area. The twisting of the strip during production had a low effect on the nanofiber diameter.

4. CONCLUSIONS

The PAN strips were coated for 5 and 15 minutes, and then coated with nanofibers while the strip was twisted for 15 minutes. The amount of coating increased with increasing time. While the coating of the fixed strips was in a partial area, the nanofibers covered the entire strip in the twisting coating. The nanofibers were produced in a uniform structure. With this production type, new properties can be added to traditional strips. By coating traditional strips with nanofibers, properties such as antibacterial activity, conductivity and absorbency can be gained.

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5. REFERENCES

[1] WANG, Y., WANG, Z., FU, H., Lİ, H., TAN, J. AND YANG, W. (2023), Chapter 5 - Preparation and functional applications of electrospun yarns, Functionalized Nanofibers, Synthesis and Industrial Applications, Pages 109-133.
[2] RAKHİ, T., PRAGATİ, M., PRERNA, B. AND JYOTİ, S. (2023), Multifaceted approach for nanofiber fabrication, Fiber and Textile Engineering in Drug Delivery Systems, The Textile Institute Book Series, Chapter 8, Pages 253-283.

[3] LİU, Y. AND WU, F. (2023), Synthesis and application of polypyrrole nanofibers: a review, Nanoscale Adv., 5, 3606–3618.
[4] JİN, S., XİN, B. AND KAN, C. (2020), Electrospun Nanofibers and Applications: A Review. AATCC Journal of Research.
[5] NEMATİ, S., KİM, SJ., SHİN, Y.M. ET AL (2019), Current progress in the application of polymeric nanofibers to tissue engineering. Nano Convergence 6, 36.
[6] QİAO, H. AND WEİ, Q. (2012), Functional nanofibers in lithium-ion batteries. Functional Nanofibers and Their Applications, 197–208.
[7] TLİLİ, I. AND ALKANHAL, T. A. (2019), Nanotechnology for water purification: Electrospun nanofibrous membrane in water and wastewater treatment. Journal of Water Reuse and Desalination, 9(3), 232–248.
[8] PARK,J.H. AND RUTLEDGE,G.C.(2017),50th Anniversary perspective: advanced polymer fibers: high performance and ultrafine, Macromolecules 50 (15), 5627–5642.
[9] TEO, W. E. AND RAMAKRİSHNA, S. (2006), A review on electrospinning design and nanofiber assemblies. Nanotechnology,17(14).
[10] KAJDİČ, S., PLANİNŠEK, O., GAŠPERLİN, M. AND KOCBEK, P. (2019), Electrospun nanofibers for customized drug-delivery systems. Journal of Drug Delivery Science and Technology, 51, 672–681.
[11] WEİ, L.AND QİN, X.H. (2016), Nanofiber bundles and nanofiber yarn device and their mechanical properties: a review, Text. Res. J. 86 (17), 1885–1898.
[12] ZHOU, F.L., GONG, R.H. AND PORAT, I. Nano-coated hybrid yarns using electrospinning, Surf. Coat. Technol. 204 (21–22) (2010) 3459–3463.
[13] BAZBOUZ, M.B. AND STYLİOS, G.K.(2012).A new mechanism for the electrospinning of nanoyarns, J. Appl. Polym. Sci. 124 (1) 195–201.
[14] KORKMAZ MEMİS, N., KAYABAŞI, G. AND YILMAZ, D. (2019), Development of a novel hybrid yarn production process for functional textile products, J. Ind. Text. 48 (9) (2018) 1462–1488.
[15] CHOİ, S., MOON, S.H. AND KİM, T.K. Fabrication of capacitive yarn torsion sensors based on an electrospinning coating method, Polym. Int. 68 (11), 1921–1927.
[16] RAVANDİ, S.A.H., SANATGAR, R.H. AND DABİRİAN, F.(2013), Wicking phenomenon in nanofiber-coated filament yarns, J. Eng. Fibers Fabr. 8 (3), 10–18.
[17] LİU, C.K., HE, H.J., SUN, R.J., FENG, Y. AND WANG, Q.S. (2016), Preparation of continuous nanofiber core-spun yarn by a novel covering method, Materials & Design, 112, 456–461.
[18] ZHOU, Y., WANG, H., HE, J., Qİ, K. AND DİNG, B. (2019), Highly stretchable nanofiber-coated hybrid yarn with wavy structure fabricated by novel airflow-electrospinning method. Materials Letters, 239, 1–4.
[19] HE, J.X., ZHOU, Y.M., WU, Y.C. AND LİU, R.T. (2014), Nanofiber coated hybrid yarn fabricated by novel electrospinning-airflow twisting method. Surface and Coatings Technology, 258, 398–404.
[20] ZHOU, F.L. AND GONG, R.H.(2009), Isaac Porat Nanocoating on filaments by electrospinning, Surface & Coatings Technology 204, 621–628.
[21] JİANG, G.J., ZHANG, J.R. AND Jİ,D.X.(2017), A novel approach for fabricating antibacterial nanofiber/cotton hybrid yarns, Fibers Polym. 18 (5), 987–992.
[22] YANG, Y.C. AND QUAN, Z.Z. AND ZHANG, H.N.(2022), Investigation on the processability, structure and properties of micro-/nano-fiber composite yarns produced by trans-scale spinning, J. Ind. Text. 51 (3_Suppl), 5409s–5426s.

[23] MAO, N., QİN, X.H. AND WANG, L.M. (2021), The migration behavior of electrospun nanofibers within cotton slivers in roller drafting and their effects on composite yarn quality, Text. Res. J. 91 (13–14), 1555–1564.
[24] YU, W., Lİ, X. AND HE, J. (2021), Graphene oxide-silver nanocomposites embedded nanofiber core-spun yarns for durable antibacterial textiles, J. Colloid Interface Sci. 584, 164–173.
[25] ZHOU, Y.M., HE, J.X. AND WANG, H.B.(2016), Carbon nanofiber yarns fabricated from co-electrospun nanofibers, Mater. Des. 95, 591–598.

DEEP LEARNING-BASED CONVOLUTIONAL NEURAL NETWORKS FOR ROTARY SCREEN PIGMENT PRINTING MACHINE PARAMETER ESTIMATION

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ABSTRACT

Rotational pigment printing is a very preferred method of fabric coloring. Screen mesh number (holes/inch), bar size (mm), machine press, and speed (m/min) parameters are determined before mass production. These production parameters are determined by skilled laborers. In experience-based systems, errors are inevitable. Applications of artificial intelligence in textiles have been found in recent years, including categorization, error detection, estimation, process optimization. In this project, the machine parameters of the ready-to-print pattern in rotation printing were estimated with a deep learning method based on Convolutional Neural Network (CNN). For screen mesh count, bar size, magnet pressure, and machine speed, respectively, it was determined that overall accuracy was 84, 81, 78, and 97%.

Key Words: Rotary pigment printing, convolutional deep learning, machine parameters class prediction.

1. INTRODUCTION

The textile manufacturing industry is based on human labor. Traditional rotary screen printing contains many processes requiring human labor, such as pattern design, printing paste preparation, screen preparation, and printing machine parameter determination. Before mass production, sample printing is done with an experience-based system a couple times. This requires time, consumes unnecessary resources, and increases the rate of faults and waste in production.

Deep learning is a sub-field of machine learning and is one of the most widely used artificial intelligence technologies today [1]. It is used in the textile industry to increase productivity, digitalization, recommendation systems, detect defects in fabric, reduce subjective analysis and decision errors. The last 20 years of deep learning models for fabric defect detection and classification have been reviewed. The most commonly used deep learning models are CNN-based and generative models [2]. In [3], built an online CNN-based deep learning model for recommending customer preferences for patterns and colors in textile products. The basis of the approach for making recommendations is the proposal of a pillow with a design that fits well with the couch's color for customers looking to purchase a pillow that matches the sofa. A survey was conducted to determine the preferences of consumers. The patterns were grouped into five groups as a result of the survey, from the most favored to the least preferred. The model's performance was evaluated using precision, accuracy, recall, and f1-score. The results were 82.08 %, 82.00%, 83.5%, and 82.3%, respectively. In [4], the subjective evaluation error in fabric wrinkle testing was eliminated using an RVFL algorithm optimized by the TSA method based on logistic maps and the usage of ResNet18 for crease imagine feature extraction. 540 wrinkled images of knitted and woven natural and synthetic fabrics, dyed in 90 various colors, were used in this study. In order to increase the quantity of data in the deep learning model, 3775 images were generated by multiplying them using approaches including rotation, mirroring, and adding noise. The performance of the study was evaluated with different deep network models. The performance of the study was evaluated with different deep network models. When all models are assessed, the accuracy rate in estimating the degree of wrinkling of the fabric after washing is between 92-98%.

In order to classify and automatically recognize textile fabric patterns, transfer learning [5] and conventional neural network [6] deep learning models have been used.

In this study, multi-class classification deep learning conventional artificial neural network method was preferred to determine rotary screen printing machine parameters.

2. MATERIAL AND METHOD

The mass production data from the research [7] was used in the present study. Plain weave fabrics from 100% cotton, 100% polyester, and cotton/polyester blends used as sheets were used for this study. Reggiani UNICA240/12/12 model with 12 colour was used for printing. A database has been created with data on productions that are over 2000 meters. The model was created using mass-produced printed pattern data. Screen mesh number (holes/inch), bar size (mm), machine press, and speed (m/min) parameters were categorized using CNN based on color and figure images.

The study was carried out under four headings, which is given below, respectively.

1. First, applying the K-means algorithm to images, the pattern figures are divided into clusters based on color.
2. The color images of the pattern were then categorized in accordance with the printing parameters.
3. The number of pattern images was not sufficient to apply deep learning; therefore, images were rotated, mirrored and shifted to generate images.
4. A multi-class classification deep learning conventional artificial neural network model was built and evaluated with precision, accuracy, recall, and f1-score.

Table 1. Machine parameters classification used in the CNN.

Bar Size (mm)	Screen Mesh Count (holes/inch)	Magnet Pressure	Machine Speed (m/min)
12	80	40	30
16	125	50	40
-	155	60	50
-	-	70	-

On a rotary printing machine, each screen represents a single color and figure. Each figure shape may have a distinctive structure. These features are one of the most relevant variables to consider while selecting rotation machine parameters. The CNN model was created to identify the different patterns' structures and predict the printing machine's parameters for new patterns. The printed patterns are divided by color as in Figure 1 and Figure 2 using the K-means method.

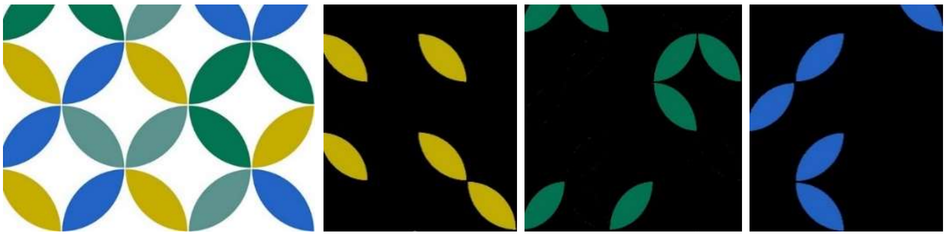

Figure 1. Example-1 of using K-means to divide the printed pattern into colors.

Figure 2. Example-2 of using K-means to divide the printed pattern into colors.

For each classification, an individual set of images was used. This is because of mass manufacturing data is used. It is due to the variety of frequently and rarely used parameters, since an equal number of images should be used in the CNN model. It is owing to the wide range of often and seldom utilized parameters in mass manufacturing. A total of 600 images for bar size, 450 for screen mesh, 120 for machine speed, and 400 for magnet pressure were utilized as data in the model. The original size of the images is 6805x1813. All images were resized to 148x39. The photos were then padded to be 148x148 in square size. Machine speed classification data was only resized to 560x149. For classifying machine speeds, the K-means method was not applied. To increase the amount of data, images are horizontally flipped, angularly rotated (15°, 45°, and 105° degrees), and shifted in width and height for data augmentation. Data was divided into train set, validation set, and test set with a split of 80/10/10% in the model. Models were trained with 32 batch size and Adam optimizer for 40 epochs. In Table 2 and Table 3, the CNN models' architecture is shown.

Table 2. Architecture of the CNN for screen mesh count, bar size and magnet pressure classification.

Layer	Filter size	Stride	Output
Input Image	-	-	148x148x3
Conv, Batch Norm, ReLU	3x3	1	146x146x32
Max-Pooling	2x2	1	73x73x32
Conv, Batch Norm, ReLU	3x3	1	71x71x64
Max-Pooling	2x2	1	33x33x64
Conv, Batch Norm, ReLU	3x3	1	31x31x64
Max-Pooling	2x2	1	11x11x64
Flatten	-	-	1x1x7744
Fully Connected 1	-	-	1x1x256
Dropout	-	-	1x1x256
Softmax	-	-	1x1x3

Table 3. Architecture of the CNN for machine Speed classification.

Layer	Filter size	Stride	Output
Input Image	-	-	149x560x3
Conv, Batch Norm, ReLU	3x3	1	147x558x32
Max-Pooling	2x2	1	73x279x32
Conv, Batch Norm, ReLU	3x3	1	71x277x64
Max-Pooling	2x2	1	35x138x64
Conv, Batch Norm, ReLU	3x3	1	33x136x64
Max-Pooling	2x2	1	16x68x64
Flatten	-	-	1x1x69632
Fully Connected 1	-	-	1x1x128
Dropout	-	-	1x1x128
Softmax	-	-	1x1x3

3. RESULTS

Python 3.9 and Jupyterlab were used for processing data and perform CNN algorithms. The Intel(R) Core(TM) i5-8250 CPU ran at 1.60GHz and 1.80GHz, with 8.0GB of RAM, and an NVIDIA GeForce 930MX GPU as the laptop's hardware specifications. Table 4, Table 5, Table 6, and Table 7 show the results of the classification of bar size, screen mesh count, magnet pressure, and machine speed, respectively. Evaluation of the suggested model's performance in terms of overall accuracy, precision, recall, and f1-score metrics.

Table 4. Results of classification report for screen mesh count.

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Screen Mesh Count (holes/inch)	Precision	Recall	F1-Score
80	0.75	1.00	0.86
125	1	0.67	0.80
155	0.75	1.00	0.86

Table 5. Results of classification report for bar size.

Bar Size (mm)	Precision	Recall	F1-Score
12	0.78	0.88	0.82
16	0.86	0.75	0.80

Table 6. Results of classification report for magnet pressure.

Magnet Pressure	Precision	Recall	F1-Score
40	0.85	0.92	0.88
50	0.86	0.55	0.67
60	0.62	0.83	0.71
70	0.75	1.00	0.86

Table 7. Results of classification report for machine speed.

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Machine Speed (m/min)	Precision	Recall	F1-Score
30	1.00	0.89	0.94
40	0.94	1.00	0.97
50	1.00	1.00	1.00

Overall accuracy was determined to be 84, 81, 78, and 97% for screen mesh count, bar size, magnet pressure, and machine speed, respectively. The results show that the proposed CNN model could minimize human error and fabric waste.

4. CONCLUSION

As a result of this study, owing to the model proposed, it will be possible to predict the printing machine parameters while the patterns are in the printing process. Another purpose of this project is to eliminate the need for sample printing so that fewer worker mistakes with decisions will happen, and the conventional rotary printing process has been digitalized. Lastly, this R&D project is an ongoing project. In the continuation of the project, different model performances will be tested with more data and different classification models.

ACKNOWLEDGEMENTS

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5. REFERENCES

[1] DOĞAN, F., TÜRKOĞLU, İ. Derin öğrenme modelleri ve uygulama alanlarına ilişkin bir derleme. Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Dergisi, 2019, 10(2), 409-445.
[2] KAHRAMAN, Y., DURMUŞOĞLU, A. Deep learning-based fabric defect detection: A review. Textile Research Journal, 2023, 93.5-6: 1485-1503.
[3] TURKUT Ü., TUNCER A., SAYRAN, H., Yılmaz, S. An online recommendation system using deep learning for textile products. International congress on human-computer interaction, optimization and robotic applications (HORA): book of proceedings, Ankara, Turkey: IEEE, June, 2020, pp. 1-4.
[4] ZHOU, Z., MA, Z., WANG, Y., ZHU, Z. Fabric wrinkle rating model based on ResNet18 and optimized random vector functional-link network. Textile Research Journal, 2023, 93(1-2), 172-193.
[5] NOPRISSON, H., ERMATITA, E., ABDIANSAH, A., AYUMI, V., PURBA, M., SETIAWAN, H. Fine-Tuning Transfer Learning Model in Woven Fabric Pattern Classification. Int. J. Innov. Comput. Inf. Control, 2022, 18(06), 1885.
[6] MENG, S., PAN, R., GAO, W., ZHOU, J., WANG, J., HE, W. A multi-task and multi-scale convolutional neural network for automatic recognition of woven fabric pattern. Journal of Intelligent Manufacturing, 2021, 32, 1147-1161.
[7] HUSEYIN T., BURCIN O., DURUR G. Rotary printing: paste reduction and paste calculation using statistical analysis. 18th Romanian Textiles and Leather Conference: book of proceedings, HARPA, Iasi, Romania, Sciendo, November, 2022, pp 30-35.

WOOL BASED ACTIVATED CARBON FIBERS FOR CARBON DIOXIDE CAPTURE

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ABSTRACT

The aim of this study is the development of activated carbon fibers from wool fibers for CO_2 capture applications. Wool felts were subjected to stabilization, carbonization and chemical activation processes, respectively. Elemental analysis, SEM and BET analysis were carried out and CO_2 adsorption performance was tested. Wool samples carbonized at 900 °C and activated with a KOH impregnation ratio of 1:3 showed the highest CO_2 adsorption value. Wool fibers were shown to be a potential natural alternative for the production of ACF based CO_2 adsorbents.

Key Words: Carbon dioxide adsorption, activated carbon fiber, wool

1. INTRODUCTION

Global warming, which has become an alarming threat to the environment and human life, has emerged as a result of the increasing release of greenhouse gases into the atmosphere. Although many greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), SOx are emitted into the atmosphere, carbon dioxide has the largest share among these gases. According to the IPCC report, in order to limit the increase in global warming to 1.5 °C compared to pre-industrial period, CO_2 emissions should be zeroed until the 2050s and other greenhouse gas emissions, especially methane, should be reduced simultaneously [1]. It was reported that it will not be possible to keep the world average temperature increase below 3 °C without the implementation of emission reduction practices as well as large-scale emission capture and storage [2]. Therefore, the development and use of CO_2 capture and storage (CCS) technologies is crucial to cope with the global demand for CO_2 emission reduction.

CO_2 capture by adsorption is of interest due to its low capital requirement, easy applicability and low energy consumption [3]. Metal oxides, zeolites, metal organic cages, silica materials and activated carbons can be used for carbon dioxide capture by adsorption. Activated carbons are advantageous due to their high adsorption capacity, low cost, unaffected by moisture due to high hydrophobicity and low energy requirement for regeneration [4]. Moreover, activated carbon fibers, defined as a hybrid material that is a combination of activated carbon and carbon fibers (ACFs) [5], have been appeared as an important candidate for carbon dioxide capture thanks to their higher adsorption rate, adsorption capacity, pore rate and micropore capacity compared to activated carbons in different forms (powder, granule, etc.). CO_2 adsorption is provided by the synergistic effect of physical adsorption within the micropores of the adsorbent material and chemical adsorption with nitrogenous functional groups on the surface. Therefore, the precursor materials including nitrogenous groups are believed to be advantageous. In this context, CO_2

adsorption by activated carbon fibers were investigated, where wool felts were used as the precursor material was investigated in this study.

2. EXPERIMENTAL

Wool felts were subjected to stabilization, carbonization (800-900 °C, 1 h) and activation processes for ACF production. Stabilization of wool felts were carried out at 300 °C for 2 h in a high temperature oven (Protherm PLO 450/50 PC442T). The stabilized sampled were carbonized under nitrogen flow at 800 and 900 °C for 1 h in a laboratory scale vertical fixed bed pyrolysis reactor. Chemical activation method with potassium hydroxide (KOH) was used for activation process after carbonization. KOH impregnated carbonized samples were activated at 700 °C for 1 h in a laboratory scale vertical fixed bed pyrolysis reactor, followed by washing. The obtained samples were named as following "C-Carbonization temperature-A activation ratio" sequence (e.g. C800-A1:3 stands for the sample carbonized at 800 °C and activated at 1:2 KOH impregnation ratio).

Mass yield calculation, elemental analysis, SEM analysis, BET analysis and CO_2 adsorption tests of the samples were carried out. The effects of carbonization temperature and KOH impregnation ratio on the characteristics and CO_2 adsorption performance of wool based ACFs were investigated.

3. RESULTS AND DISCUSSION

Table 1 shows the mass yield and elemental analysis results of the samples. Mass yield between 53-33% were obtained depending on the carbonization temperature and the KOH impregnation ratio. The mass yield after carbonization was similar for both carbonization temperatures. On the other hand, the mass loss after activation was found to be lower for the samples carbonized at higher temperature. Increase in the KOH impregnation ratio led to a decrease in the mass yield. Similary carbon and nitrogen ratio decreased by the increase in the KOH impregnation ratio.

Table 1. Elemental composition and mass yields of the samples

	Elemental composition					**Mass yield, %****
	C	**H**	**N**	**S**	**O***	
Untreated	44.99	6.42	15.09	2.89	30.61	-
Stabilized	57.34	3.69	17.02	0.91	21.04	79
C800	76.38	1.61	9.47	0.00	12.54	56
C800-A1:1	71.11	1.76	5.84	0.00	21.29	51
C800-A1:2	67.34	3.14	1.75	0.00	27.77	42
C800-A1:3	70.15	2.33	0.53	0.00	26.99	33
C900	81.15	1.27	6.09	0.00	11.49	56
C900-A1:1	73.35	0.99	4.70	0.00	20.96	53
C900-A1:2	67.11	1.54	1.13	0.00	30.22	45
C900-A1:3	67.61	2.01	0.76	0.00	29.62	42
*calculated by difference **according to precursor wool fiber						

Figure 1 illustrates the SEM images of wool based ACFs. It was seen that the fibrous structure was preserved at all stages. As a result of the activation processes, tubular structures appeared at the fiber ends.

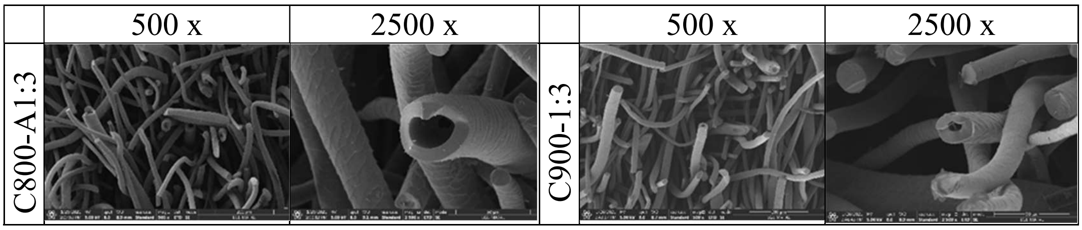

Figure 1. SEM images of obtained ACFs

BET surface area and CO_2 adsorption of the produced ACFs were given in Table 2. It was observed that the surface area of the wool-based activated carbon fibers varied greatly according to the KOH impregnation ratio, and the surface area increased as the increase in the KOH impregnation ratio. Carbonization at 800 °C and activation at 1:3 KOH ratio led to a very high surface area of 1807 m^2/g. Although the surface area was very different for each processing parameter, the carbon dioxide adsorption performance of the samples carbonized at 800 and 900 °C and activated at 1:2 and 1:3 KOH impregnation ratios was found to be analogous and quite high (3.85-4.06 mmol/g). This was thought to be due to the synergistic effect of different microporosity and nitrogen content in each case.

Table 2. BET surface area and CO_2 adsorption of wool based ACFs

	BET surface area, m^2/g	CO_2 adsorption, mmol/g
C800-A1:1	477.5	2.64
C800-A1:2	1236.8	3.85
C800-A1:3	1807.3	3.90
C900-A1:1	5.4	1.89
C900-A1:2	878.4	3.93
C900-A1:3	1107.0	4.06

4. CONCLUSION

Wool fibers were used as precursor for the production of ACFs and CO2 adsorption performance of the resultant samples were investigated. In conclusion it was revealed that wool fibers can be considered as a suitable natural alternative for the production of activated carbon fibers with very high surface area and considerable CO_2 adsorption capacity.

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5. REFERENCES

[1] IPCC, 2018: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press. [cited 05.06.2023]. Available on https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf

[2] HARVEY, C, GRONEWOLD, N, Greenhouse gas emissions to set new record this year, but rate of growth shrinks. [cited 05.06.2023]. Available on https://www.sciencemag.org

[3] BECHELANY, M, DROBEK, M, VALLICARI, C, ABOU CHAAYA, A., JULBE, A, MIELE, P. Highly crystalline MOF based materials grown on electrospun nanofibers. Nanoscale, 2015, 7, 5794-5802.

[4] BEN-MANSOUR, R, HABIB, MA, BAMIDELE, OE, BASHA, M, QASEM, NAA, PEEDIKAKKAL, A, LAOUI, T, ALI, M. Carbon capture by physical adsorption: Materials, experimental investigations and numerical modeling and simulations – A review. Applied Energy, 2016, 161, 225-255.

[5] LEE, T., OOI, C.H., OTHMAN, R., YEOH, F.Y. Activated carbon fiber-the hybrid of carbon fiber and activated carbon. Reviews on Advanced Materials Science, 2014, 36(2), 118-136.

A NEW METHOD IN PRODUCTION OF MULTI-COMPONENT HYBRID YARN AND YARN PROPERTIES

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ABSTRACT

With the rapid development of technology worldwide, the importance of yarn variety and fabric designs with new properties has increased as a result of the combination of textile products with different structures and properties using different production methods. In recent years, a new type of core yarn called Dual core spun yarn has been developed in order to improve the properties of core yarns.
In this study, it is aimed to compare the performance of hybrid yarns in which core components are combined with hollow spindle technique with "S" and "Z" twist direction and conventional ring double core yarns technique.

Key Words: Core component, hybrid yarn, new method, yarn properties.

1. INTRODUCTION

As a result of research in the textile industry, product diversity in textile increased after the 1970s and with this increase, single core yarns were produced. Single core yarns are a structure consisting of two concentric fiber bundles. After the processes carried out in single core yarns, there was a need to develop dual core spun yarn in order to get better results in yarn quality.[1] In recent years, fibers such as PBT, T400, and PES (polyester) have been widely used in fabric production in the textile industry.[2]

Babaarslan and Tüzün (2000) used polyester/viscose coated yarns with three different cores in their study.Textured polyester (78 dtex lycra - 34 filament), textured nylon 6.6 (78 dtex lycra - 34 filament) and 78 dtex lycra (elastane) were used as core yarn in this study.As the cover material, polyester/viscose was used in a 50/50 mixture ratio.As a result of the study, they stated that core yarn production could be possible by using different core yarns. [3]

Sarıoğlu (2019) used polyethylene terephthalate/polytrimethylene terephthalate (PET/PTT) bicomponent filament + Spandex, PET/PTT bicomponent filament, which has high elasticity in its core, to investigate the effects of yarn type and layout on the unidirectional stretching properties of woven denim fabrics and obtained single and double core yarns using Spandex (a polyurethane fiber). A total of 18 different denim fabrics were produced using plain PET/PTT bicomponent filament with the yarns obtained, with different weft placement patterns in the fabric. One-way elasticity and permanent deformation properties of denim fabrics were determined after 2 hours of waiting for this process. Thus, the test results were used in the SPSS package program and as a result of statistical evaluation with analysis of variance within a 95% confidence interval, it was stated that the weft yarn type and the placement of the weft yarns in the fabric had a statistically significant effect on the elasticity and permanent deformation properties of the fabric.[4]

Sinha et al. (2017), in their study, research was conducted on the elongation and strength properties of elastane core cotton yarns suitable for denim fabric production. As a result of the research, it was observed that as the yarn thickness increased, the yarn strength rate decreased [5]. Öner et al. (2004), in their study, the effects of elastane fineness and draft rate on the structures of cotton-covered elastane core yarns were investigated. As a result of the research, they determined that the yarns with a count of 10 tex had the highest elastic return values when used with an elastane core with a fineness of 22 dtex/2f and a draw value of 4.00 [6].

In this study, it is aimed to compare the performance of hybrid yarns in which core components (T400/Elastane, PBT/Elastane, PES/Elastane) are combined with hollow spindle technique with "S" and "Z" twist direction and conventional ring double core yarns technique.

2. MATERIAL METHOD

In this study, T400, PBT and PES were used together with elastane as double core material. All yarns are produced in the same fineness. The experimental set consisting of 3 groups (A, B, C) is shown in Table 1. Groups A and B were obtained by twisting in different directions with the hollow spindle technique and group C is produced with conventional ring spinning system. The physical properties of all yarns were tested with the "Uster tensorapid" test device with 5 repetitions.

2.1. Material

2.1.1. Cover Material

Within the scope of the study, 100% cotton fiber was used as a sheath for core yarn production in a modified conventional ring spinning machine. Domestic production cotton originating from Şanlıurfa was supplied from Çalık Denim Tekstil company operating in the Malatya region.

2.1.2. Core Component Filaments

PES, Polybutylene terephthalate (PBT), T400® (PET/PTT) and elastane filaments were used in the production of double core hybrid yarn. Double core yarn production is made in the form of PES + elastane, PBT + elastane and T400 + elastane.

Table 1. Set of experiment

Sample	Description
A-1	18/1 (55 DEN T400+78 LYC S Twist)
A-2	18/1 (55 DEN PBT +78 LYC S Twist)
A-3	18/1 (55 DEN PES + 78 LYC S Twist)
B-1	18/1 (55 DEN T400+78 LYC Z Twist)
B-2	18/1 (55 DEN PBT +78 LYC Z Twist)
B-3	18/1 (55 DEN PES + 78 LYC Z Twist)
C-1	18/1 (55 DEN T400+78 LYC)
C-2	18/1 (55 DEN PBT +78 LYC)
C-3	18/1 (55 DEN PES + 78 LYC)

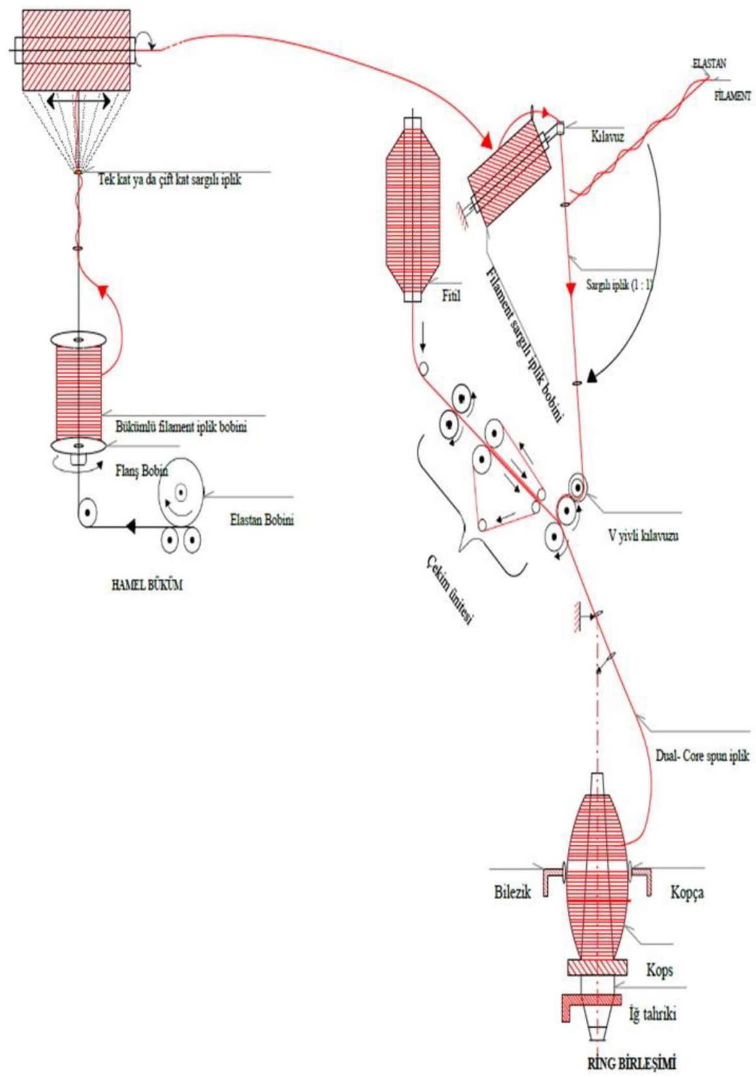
2.2. Method

2.2.1. Yarn Production Method

Within the scope of the study, the combination of materials that will form the core was studied with two different methods. The working principle of the 2 methods is shown in figure 1.

1.Method: According to the dual core spun yarn production system on the ring spinning machine, core production was carried out with 55 denier PES + 78 dtex elastane (lycra) + Cotton, 55 denier PBT + 78 dtex elastane + Cotton and 55 denier T400 + 78 dtex elastane + Cotton yarns (Invista Method).

2.Method: Core components (55 denier PES + 78 dtex elastane (lycra), 55 denier PBT + 78 dtex elastane and 55 denier T400 +78 dtex elastane) are spun in S and Z directions with the hollow spindle technique. These components were then modified to remain in the core and spun by placing them in the center with cotton on the same machine (hollow spindle technique).



(a) (b)

Figure 1. a: Hollow Spindle Technique, b: Ring spinning Technique

2.2.2. Test Methods

Before physical and mechanical tests of the double core yarns obtained within the scope of the study were carried out, the yarn samples were conditioned for 24 hours according to TS EN ISO 139: 2008 standard.
Twist determination and direct counting test in yarns were carried out using the Uster Tester 5-S800 device in accordance with TS 247 EN ISO 2061 and TS EN ISO 2061: 2015 standards. The strength (cN/tex) and breaking elongation (%) tests of the yarns were carried out on the Uster Tensorapid 4 test device, at a jaw distance of 500 mm and a test speed of 5000 mm/min, in accordance with the TS EN ISO 2062:2010 standard. Additionally, a pre-tension of 0.5 cN/tex was applied. Measurements of yarn irregularity and yarn defects (thin places, thick places and neps) were carried out in accordance with the TS EN ISO 2060 standard, on the Uster Tester 5-S800 device, at a test speed of 400 m/min, with a test time of 1 minute. The hairiness test of the yarns was carried out on the Uster Tensorapid 4 test device in accordance with the TS 12863:2002 standard. For each test, 5 measurements were taken from each yarn sample. All tests, was carried out in Çalık Denim Tekstil company.

3. RESULTS AND DISCUSSION

Yarn test results for the yarns produced within the scope of the study are shown in Table 2.

Table 1. Yarn test results

Yarn Properties	A-3	A-2	A-1	B-3	B-2	B-1	C-3	C-2	C-1
	PES	PBT	T400	PES	PBT	T400	PES	PBT	T400
Denier	55	55	55	55	55	55	55	55	55
Strength (cN/tex)	14.14	12.14	15.3	14.97	12.34	14.4	16.01	13.03	14.3
Elongation at break (%)	5.21	4.36	6.32	12.34	12.63	13.31	9.09	12.91	12.44
Irregularities (%CVm)	16.53	15.92	16.02	16.05	14.65	15.5	15.41	14.59	15.03
Thin Place (-50)	1.5	1	2.0	2.5	0	1	1	0	1
Thick Place (+50)	519.5	454	458.5	476	332	385	408	310	341.5
Neps (+200)	224.5	283	199	193	289	162.5	283.5	225.5	226
Hairness (H)	5.99	5.92	6.02	6.23	6.11	6.27	6	6.84	6.09

It is seen that there are differences in the strength values of Ne 18/1 count yarns depending on the type of core material and the way of joining. It has been observed that ring double core yarns containing PES have higher breaking strength values. It is seen that PBT-containing yarns have lower strength values in all combination shapes due to their fiber properties. It has been observed that the elongation at break value is high in the Z-twist yarns produced with the hollow spindle technique in the yarn groups produced with all three filament structures (PES, PBT and T400). It has been observed that ring double core yarns containing PES have low breaking elongation values. It has been observed that double core yarns have a high tendency to unevenness. Production method of the core components It has been observed that there is a tendency for the irregularities of the yarns to increase from ring spinning to hollow spindle S twisting. Since the hairiness value of all yarns is higher than 5%, it has been observed that they have a hairier structure. When the hollow spindle method yarns in the S and Z twist directions were examined in terms of hairiness, it was seen that the hairiness rate of the Z twist was higher due to the different twist direction compared to the S twist.

4. CONCLUSION

In this study, the effect of the hollow spindle technique method, which can be an alternative to conventional ring spinning systems on yarn performance was comparatively analyzed.
As a result of these experiments, the effect of the method used on the performance of the yarn varies not only depending on the method but also on the type of material. In general, since there is not much difference in performance values between the two methods, it can be considered that the hollow spindle technique can be an alternative method.

5. REFERENCES

[1] ÖRTLEK, G., H. (2011). Metal İçerikli Katlı İplik Üretim İmkanlarının Araştırılması, Erciyes Üniversitesi Bilimsel Araştırma Projeleri Koordinasyon Birimi, Proje Sonuç Raporu, Proje No: FBA-08-523, Kayseri.
[2] ÖZÇELİK, F.F. (2005). İçi Boş Lif Üretiminde Bazı Parametrelerin Lif Özelliklerin Üzerine Etkilerinin İncelenmesi, Uludağ Üniversitesi, Fen Bilimleri Enstitüsü, Tekstil Ana Bilim Dalı, Yüksek Lisans Tezi, Bursa.
[3] BABAARSLAN, O., TÜZÜN, Z. (2000). Core-spun Properties,Textile Asia, 31(12), 29–31. Demir, A. (1997). Filament İplik Üretim Teknolojileri. İ.T.Ü., Makine Fakültesi, Sürekli Eğitim Notları.
[4] SARIOĞLU, E. (2019). İplik Tipi ve Yerleşim Düzeninin Dokuma Denim Kumaşların Tek Yönlü Esneme Özellikleri Üzerindeki Etkileri, El-Cezerî Fen ve Mühendislik Dergisi, Cilt: 6, No: 3, ss 789-798, Gaziantep Üniversitesi, Güzel Sanatlar Fakültesi, Moda ve Tekstil Tasarımı Bölümü, 27310, Gaziantep.
[5] SİNHA S. K., BANSAL P., MAİTY S. (2017). Tensile and elastic performance of cotton/lycra core spun denim yarn," Journal of The Institution of Engineers (India), Series E, pp. 1–8.
[6] ÖNER, E. (2019). Elastan Özlü Pamuk İpliklerinin Kalite Özelliklerinin Araştırılması, Düzce Üniversitesi Bilim ve Teknoloji Dergisi, Araştırma Makalesi, Sayı 7, ss 342- 351.

PRODUCTION AND CHARACTERIZATION OF MICROCRYSTALLINE CELLULOSE PARTICLES FROM CELLULOSIC FIBER WASTES

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ABSTRACT

Cellulose, the most abundant natural polymer globally, is vital for sustainable applications. The textile industry's environmental impact, contributing to significant waste and emissions, demands innovative solutions. Utilizing cellulosic waste as a raw material holds promise for eco-friendly recycling. This study focuses on fabricating micro-sized cellulose particles from waste jute yarns and regenerated cellulose (viscose) fibers. The particles exhibit appealing attributes such as strength and surface area. Comprehensive characterizations involving microscopy, spectroscopy, and thermal analyses were performed. Notably, particle morphology and structure varied with the source material and processing conditions. The findings present a pathway for cellulose waste upcycling and offer potential for reinforcing composite materials across diverse industries.

Key Words: Jute, regenerated cellulose, cellulosic waste, microcrystalline cellulose

1. INTRODUCTION

Cellulose is a natural polymer that is recognized as the most widespread macromolecule on Earth, with an estimated annual production rate of more than 1011 tons [1, 2]. Textile industry is estimated to be the second largest contributor to water and carbon footprint, accounting for 10% of global carbon emissions [3]. Tens millions of tons of textile waste is estimated to be produced every year [4]. Using cellulosic fiber wastes can support economic and environmental recycling. One of the usage areas of these wastes is the production of nano and micro-sized fibers, which has attractive properties like high strength, good stiffness, and a large surface area. Composites incorporating nano/micro cellulose can be beneficial in a variety of industries, including biomedical, automotive, and construction applications regarding improved mechanical and fluid handling properties.

In this work, we synthesized and analyzed micro-scale cellulose particles from textile waste in order to use them as reinforcing components in composites. Waste jute yarns and waste regenerated cellulose fibers were provided from textile companies. Microparticles were produced via a two-stage chemical-mechanical acid hydrolysis technique involving a nitric acid (HNO_3)-acetic acid (HAc) solution and mechanical grinding. Viscose fibers were directly used after pre-cleaning, while jute fibers underwent cellulose extraction, acid hydrolysis, and mechanical grinding. The resulting cellulose particles were analyzed for size, shape, chemical attributes, crystalline structures, and thermal properties. A comparison was also made with commercial microcrystalline cellulose.

2. MATERIALS AND METHODS

Waste jute yarns were provided by a carpet manufacturer Atlantik Halı A.Ş. (Türkiye). Waste viscose fibers were supplied by Ugurlular Tekstil A.Ş. (Türkiye). Microcrystalline cellulose (α-

Cel) was purchased from Merck, Germany for comparison. Other chemical agents used in this study were of analytical research grade.

The micro cellulose particle production process involved pre-cleaning of the fibers and subsequent cellulose extraction. Jute fibers were pre-cleaned by washing with distilled water, followed by drying and cutting into 2-4 mm lengths. For jute fibers, Soxhlet extraction using a benzene/ethyl alcohol mixture eliminated wax and lipophilic components. Waste viscose fibers underwent pre-cleaning with 4 g/L ECE B detergent and were cut into small 2-4 mm pieces.

Cellulose extraction from jute fibers involved delignification processes, including formic acid treatment at 95°C for 2 hours, followed by washing and rinsing. Subsequent peroxyformic acid treatment at 80°C for 2 hours further delignified the fibers. Bleaching with hydrogen peroxide at 60°C and pH adjustment to 10 were performed, followed by after-treatment steps. The modified method from Morán et al. [5] was applied to produce micro-sized cellulose particles. Acid hydrolysis with nitric acid (HNO_3)-acetic acid (HAc) solution was employed, with fibers treated at different temperatures and times using a 1:40 liquor ratio. Products were washed, precipitated, and dried before final mechanical grinding to reduce size. Samples are named, including fiber types: viscose (VC) or jute-cellulose (JC), process temperatures (100 and 125°C), and treatment durations (15 or 30 min) (e.g., VC-100-15, fiber type-temperature-duration).

Characterization of micro cellulose particles involved various techniques: optical microscopy and SEM for morphological analysis, AFM for topography at the atomic scale, laser scattering for particle size distribution, FT-IR for chemical structure analysis, XRD for crystalline structure examination, DSC and TGA for thermal properties analysis, the analysis of degree of polymerization, and the gravimetric method for moisture content determination according to the ASTM D629-15 standard.

3. RESULTS AND DISCUSSION

SEM micrographs of cellulose particles at different magnification were displayed in Figure 1. Cellulose particles obtained from regenerated cellulose fibers (VC-125-15 and VC-125-30) and jute fibers (JC-125-15 and JC-125-30) are significantly smaller than those obtained from the commercial products (α-Cel). Particle sizes of the samples range between 10-15 µm, and the lengths range between 10-100 µm. It was found that when the processing temperature increased, particle distribution became more homogeneous. Although there are smaller particles in the sample, cross-section of the α-Cel sample is flattened, its width is in the range of 30-40 µm, and the fiber length is in the range of 300 - 500 µm.

AFM was utilized to assess the size, shape, and surface morphology of cellulose particles and α-Cel. Similar to SEM observations, α-Cel appeared coarser and larger than cellulose particles. However, due to particle agglomeration, precise size measurements through AFM were challenging. AFM characterization affirmed that cellulose particles were obtained at a smaller micro-scale with higher processing time and temperature. Viscose-derived samples exhibited more uniform distribution compared to jute-derived ones. Consistent with SEM, VC-125-30 displayed the lowest surface roughness.

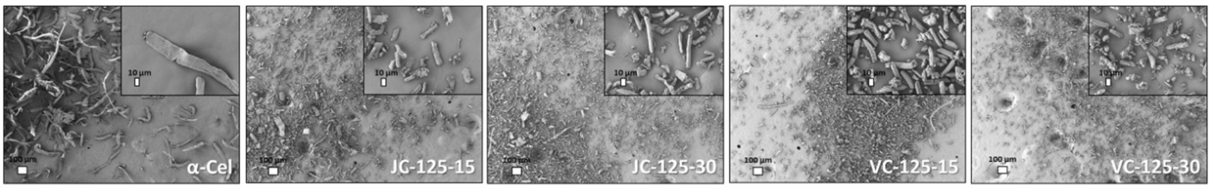


Figure 1. SEM images of micro-crystalline cellulose particles

Figure 2 illustrates the particle size distribution results. α-Cel exhibited an irregular distribution graph ranging from 5.9 µm to 1 mm with a dual peak indicating uneven distribution, averaging 196.15 µm. Cellulose particles' size distribution was more uniform than the commercial product. For samples JC-125-30 and VC-125-30 treated at 125°C for 30 minutes, sizes were more uniform and smaller compared to 15-minute treatments (JC-125-15 and VC-125-15). JC-125-30 ranged from 5.9 µm to 262.4 µm with an average of 28.9 µm and a mode size of 21.2 µm, while VC-125-30 ranged from 5.1 µm to 262.4 µm with an average of 28.4 µm and a mode size of 18.7 µm. These optimal products were chosen for further characterizations. Considering the effect of process parameters on cellulose particles, average particle size and distribution of the samples obtained from jute and regenerated cellulose wastes under optimum conditions (125 °C and 30 minutes) were similar. But the regenerated cellulose samples (28.41 µm) had a relatively smaller average particle size than the jute samples (28.91 µm) and the particle distribution was more homogeneous. It is feasible to use the products created as part of the study as additives in composites and as green adsorbents.

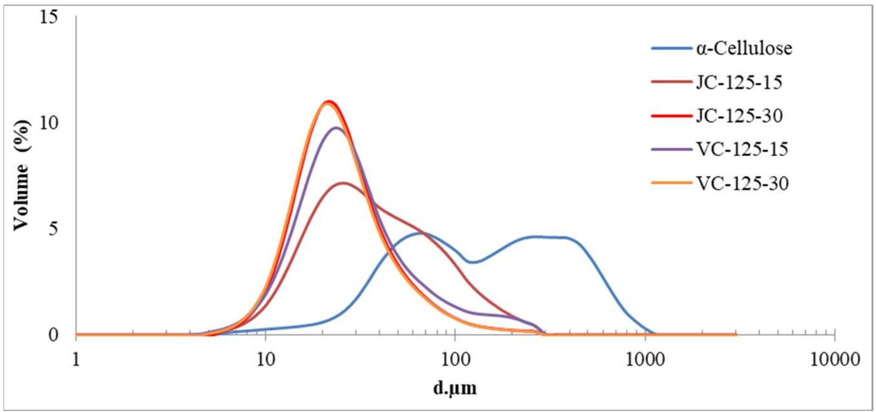


Figure 2. Particle size distributions of the cellulose particles

FT-IR analysis was used to analyze and compare the chemical structures of micro-crystalline cellulose particles to commercial α-Cel (Figure 3). FT-IR spectra of the samples made from viscose and jute wastes matched the most prominent bands determined in α-Cel; however, the intensities of the transmission bands differed. The band at 1430 cm^{-1} is related to the crystalline structure of cellulose, whereas the band at 896 cm^{-1} is related to the quantity of amorphous area. The empirical crystallinity index is defined as the ratio of these two bands. Ratio of these peaks was found to be higher for jute samples than regenerated cellulose samples.

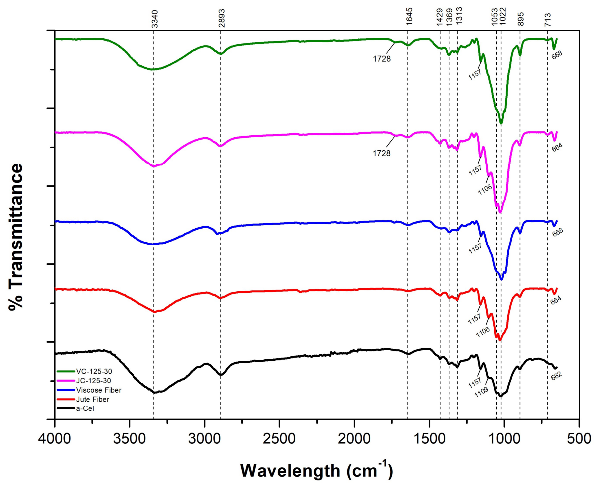
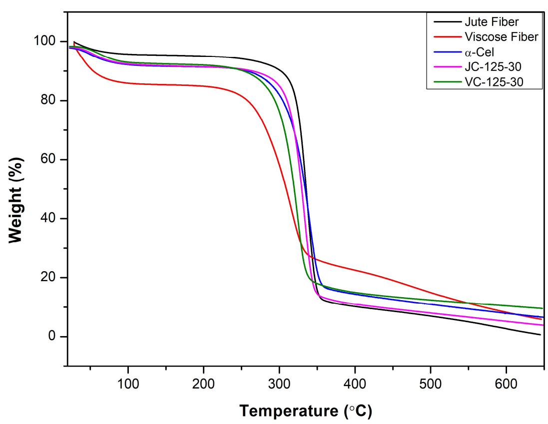


Figure 3. FT-IR spectra of micro-crystalline cellulose particles

Thermal properties of the products were evaluated through DSC and TGA (Figure 4) analyses. Characteristic endothermic peaks of cellulose in the 50 – 150°C range signify dehydration, with peak temperatures increasing as cellulose crystallinity decreases. In VC-125-30, this peak occurred at 104°C, contrasting with 83°C in JC-125-30 and α-Cel samples. DSC thermograms (200 – 450°C) indicated rapid pyrolysis (250 – 350°C) due to cellulose dehydration and decomposition. Initial decomposition temperatures, representing oxidation onset, were lower for regenerated cellulose (VC-125-30) compared to α-Cel and jute-containing samples. TGA curves showed initial weight loss (50 – 100°C) due to surface water evaporation. At 100°C, weight loss in delignified jute fiber, viscose fiber, α-Cel, JC-125-30, and VC-125-30 was 4.3%, 14.11%, 7.9%, 7.6%, and 7.1% respectively. Onset temperatures highlighted the highest thermal stability in delignified jute fibers and JC-125-30. For the rest, thermal stability followed the order α-Cel > VC-125-30 > viscose fibers. Rapid pyrolysis occurred at 250 – 350°C, was related to hemicellulose and glycosidic bond decomposition. Cellulose decomposed between 320°C and 390°C. At 600°C, weight loss was 97%, 92%, 92%, 95%, and 90% for delignified jute fiber, viscose fiber, α-Cel, JC-125-30, and VC-125-30, respectively. α-Cel exhibited the highest decomposition rate at 340°C, with lowest T_{dmax} in VC-125-30 and viscose fibers compared to jute-based samples due to high-temperature acid treatment.



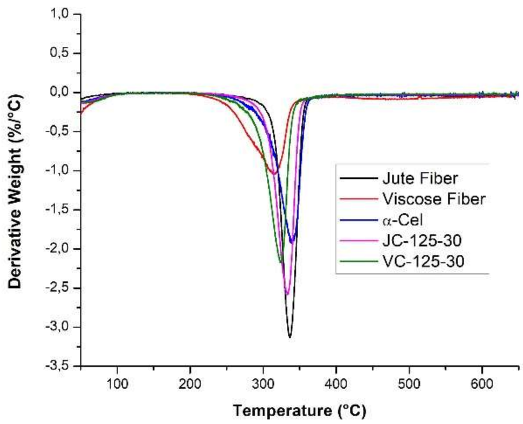


Figure 4. a) TGA **b)** DTG graphs of cellulose particles

Figure 5 displays the XRD diffraction patterns of α-Cel, JC-125-30, and VC-125-30. XRD pattern of VC-125-30 aligns with cellulose II, while JC-125-30 and α-Cel correspond to cellulose I patterns [6, 7]. Peaks at 2θ = 13.3°, 20.6°, and 22.2° were observed for VC-125-30, while JC-125-30 displayed peaks at 2θ = 15.6°, 16.4°, 22.4°, and 23.0°. α-Cel exhibited these peaks at 2θ = 15.1°, 16.7°, 22.7°, and 23.1°. The lattice peak intensity between 2θ = 22° and 23° for JC-125-30 was higher compared to VC-125-30 and α-Cel. However, the amorphous region's diffraction intensity (2θ = 18° to 19°) was lower in cellulose particles (VC-125-30) from viscose fibers than jute (JC-125-30), likely due to differences in chain packing during viscose processing.

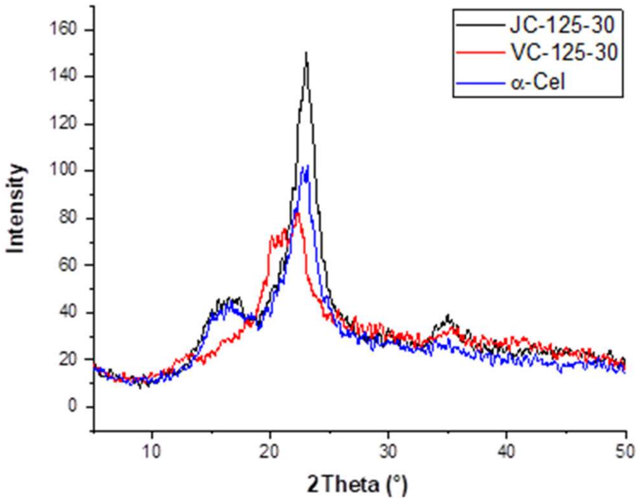


Figure 5. XRD graphs of α-Cel, VC-125-30, and JC-125-30

The degree of polymerization (DP) of viscose fibers and delignified jute fibers were measured as 341 ± 92 and 606 ± 27, respectively. Cellulose particles obtained from viscose exhibited a lower average DP compared to that of jute as longer processing time led to a reduction in DP. The DP values of the cellulose products were lower than that of the commercial product (α-Cel). Notably, the VC-125-30 sample showed the lowest DP among the cellulose particles produced (63 ± 11).

Moisture content of cellulose particles from cellulosic fiber wastes and commercial α-Cel is also determined. Cellulose particles from viscose and jute wastes exhibited moisture content of 7.34 ± 0.98% and 5.75% ± 1.22%, respectively. α-Cel showed lower moisture content compared to the cellulose particles (3.65 ± 0.19%).

4. CONCLUSION

In this study, waste products derived from viscose and jute-based textiles were utilized in the production of micro cellulose particles through a mechanical grinding-assisted treatment involving nitric acid and acetic acid. Optimal conditions determined at 125°C for 30 minutes resulted in reduced particle size and improved homogeneity. Cellulose particles exhibited similar properties under these conditions, with viscose-based particles having slightly smaller average size but higher moisture retention. The obtained cellulose particles displayed favorable chemical and thermal properties, suggesting their potential as fillers in composites and environmentally friendly adsorbents, utilizing the abundant and cost-effective nature of cellulose.

ACKNOWLEDGEMENT

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5. REFERENCES

[1] KIM, J.H., SHIM, B.S., KIM, H.S., LEE, Y.J., MIN, S.K., JANG, D., ABAS, Z. & KIM, J. Review of nanocellulose for sustainable future materials. International Journal of Precision Engineering and Manufacturing-Green Technology, 2015, 2, pp 197-213.
[2] BROWN JR, R. M. Cellulose structure and biosynthesis: what is in store for the 21st century?. Journal of Polymer Science Part A: Polymer Chemistry, 2004, 42(3), pp 487-495.
[3] CONCA J (2015) Making climate change fashionable - the garment industry takes on global warming. Forbes https://www.forbes.com/sites/jamesconca/2015/12/03/making-climate-change-fashionable-the-garment-industry-takes-on-global-warming/?sh=2d7b6d6179e4. Accessed 3 April 2023
[4] NIINIMÄKI, K., PETERS, G., DAHLBO, H., PERRY, P., RISSANEN, T., GWILT, A. The environmental price of fast fashion. Nature Reviews Earth & Environment, 2020, 1(4), pp 189-200.
[5] MORÁN, J.I., ALVAREZ, V.A., CYRAS, V.P., VÁZQUEZ A. Extraction of cellulose and preparation of nanocellulose from sisal fibers. Cellulose, 2008, 15(1) pp 149-159.
[6] KESHK, S.M.A.S., YAHIA, I.S. Physicochemical characterization of different cellulose polymorphs/graphene oxide composites and their antibacterial activity. Turkish Journal of Chemistry, 2018, 42(2), pp 562-571.
[7] REHAN, M., ELSHEMY, N.S., HAGGAG, K., MONTASER, A.S., IBRAHIM, G.E. Phytochemicals and volatile compounds of peanut red skin extract: simultaneous coloration and in situ synthesis of silver nanoparticles for multifunctional viscose fibers. Cellulose, 2020, 27(17), pp 9893-9912.

INVESTIGATION OF THE PVA SOLUTIONS PROPERTIES ON THE ELECTROSPINNING MAT

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ABSTRACT

The study focuses on the influence of the physico-chemical properties of Poly(vinyl alcohol) (PVA) on the ability to obtain an electrospun nonwoven mat for wound dressings. The type of PVA, characterized by different molecular weights (Mw) and degrees of hydrolysis (DH), directly affects the physical and chemical properties, working concentration, fibre morphology, cross-section, and bead formation during electrospinning. In this study, PVA with different Mw and DHs are used. The viscosity of the PVA solutions was measured and data was used to determine the intrinsic viscosity (η), and the Berry number (ηC) for each PVA type and concentration. SEM analysis was used to observe the surface morphology of the electrospun PVA mats, and image analysis techniques were used to evaluate the size distribution and fibre orientation. Results indicate that PVA solution viscosity rises with greater concentration and Mw. PVA concentration impacts electrospun mat morphology, yielding beaded fibres at lower concentrations and beadless fibres at higher concentrations. DH affects both viscosity and mat morphology, leading to increased viscosity and altered spinnability with higher DH.

Key Words: electrospinning, electrospraying, poly(vinyl alcohol), viscosity, molecular weight

1. INTRODUCTION

Electrospinning is a valuable method for creating nanofibrous surfaces with remarkable mechanical properties, large surface areas, and nanoscale diameters. PVA is an ideal choice for medical textile applications due to its low cytotoxicity, strong biocompatibility, and ease of electrospinning without the use of hazardous solvents [1]. The properties of electrospun PVA are greatly influenced by its Mw and DH, impacting physical and chemical characteristics, working concentration, fibre morphology, cross-section, and the occurrence of bead formation [2]. Lee et al. found that higher Mw PVA produces superior physical characteristics, enhancing stability and mechanical strength of electrospun mats [3]. Peresin et al. noted a significant increase in the degree of crystallinity of electrospun PVA due to improved crystallization under high shear stresses, although the polymer matrix's structure remained unaffected [4]. Additionally, Restrepo et al. reported that PLA/PVA blends with higher Mw and PVA hydrolysis levels exhibited superior thermal stability [5]. Considering the multi-disciplinary nature of PVA, it is notable that there exists limited research explicitly investigating the impact of physico-chemical parameters within PVA solutions on the fabrication of electrospun structures. This study aims to address this research gap by examining the complex cooperation between Mw and DH within PVA solutions. Our research contributes new perspectives to the expanding field of PVA-related studies. Understanding these relationships is crucial for optimizing electrospun mats, particularly for applications such as wound dressings, tissue engineering, and drug delivery systems. This study investigates the influence of PVA's physico-chemical properties on electrospun nonwoven mats before their functionalization with essential oils for wound dressing applications, exploring viscosity, concentration, and fibre morphology using both literature insights and experimental results.

2. MATERIALS AND METHODS

PVA samples with five distinct Mws, ranging from 9,000 to 130,000 g/mol, and degrees of hydrolysis (DH) spanning from 80% to 99%, were sourced from Sigma-Aldrich for use as the polymer in electrospun mats. Prior to electrospinning, PVA aqueous solutions were prepared 24 hours prior using a vertical setup with a single 22-gauge stainless-steel nozzle. Taylor cone formation was monitored through a digital camera under different working parameters, including PVA concentration and Mw variations (PVA-1: 22.5%, 25%, and 27.5% w/v; PVA-2: 15%, 17.5%, and 20% w/v; PVA-3: 11%, 12.5%, 15%, 17.5%, and 20% w/v; PVA-4: 7.5%, 10%, and 12.5% w/v; PVA-5: 4%, 5%, 6%, and 7% w/v in distilled water and a distilled water/HAc mixture). Voltage (16, 18, and 20 kV), tip-to-collector distance (10, 15, and 20 cm), and flow rate (0.5, 0.7, and 1 mL/h) were among the applied parameters. Once optimal Taylor cone parameters were determined for each solution, PVA surfaces were deposited onto a static collector.

The kinematic viscosity of PVA solutions was determined using an Ubbelohde viscometer, and intrinsic viscosity ([η]) was calculated using the Huggins-Kramer extrapolation [6]. Viscosity measurements at different shear rates (1.9-1000 s^{-1}) were conducted using a rotational viscometer at room temperature. Scanning electron microscopy (SEM) was employed to examine surface morphology, and image analysis determined size distribution. To assess the orientation distribution of nanofibre mats, a fibre orientation and alignment calculator based on Barocas' function was used. This technique utilizes fast Fourier transform (FFT) to analyse SEM micrographs, calculating fibre orientation tensors and anisotropy indices ($\alpha = 1-\lambda_1/\lambda_2$) [7]. α serves as an indicator for fibre orientation, where α=0 signifies a completely random distribution of nanofibres, while α=1 represents a perfectly aligned distribution.

3. RESULTS AND DISCUSSION

The Mw of commercially available PVA typically is generally between 9,000 and 186,000 g/mol. PVA solution viscosity increases with concentration, impacting the electrospinning process. Excessively viscous solutions can lead to beaded fibre formation, while insufficient viscosity prevents jet development and fibre growth. Colby et al. [9] identified four concentration regimes, i.e., (i) diluted, (ii) semi-dilute unentangled, (iiii) semi-dilute entangled, and (iv) concentrated. The critical concentration (C*) marks the transition to the semi-dilute unentangled regime, where beaded fibres form. The entanglement concentration (C_e) signifies a significant viscosity increase, ensuring consistent bead-free fibres. Highly viscous solutions can cause issues during feeding [10, 11]. Viscosimetric properties are provided in Table 1. The critical concentration (C*) was calculated as 1/[η], and the transition from semi-dilute untangled to entangled regimes was determined from viscosity vs. shear rate graphs. Gupta et al. [12] various c/C* values for different solution regimes, including dilute (c/C*<1), semi-dilute unentangled (1< c/C* <3), semi-dilute entangled (3< c/C* < 6), entanglement concentration (C_e) (c/C* > 6), and highly concentrated solutions (C**= c/C* > 10). Above C**, fibres become significantly concentrated, increasing in diameter and losing their circular cross-section. Notably, the theoretical crossover value of semi-dilute untangled to entangled regimes (c*) was higher than the experimentally determined value.
The viscosity of PVA solutions is directly related to PVA concentration, impacting entanglement. As PVA concentration increases, viscosity rises (Figure 1). Distinct slopes in the viscosity-concentration curve correspond to different PVA samples (PVA-1, PVA-2, PVA-3, PVA-4, PVA-5, and PVA-5-HAc), marking the transition from diluted to semi-diluted regimes. Increased concentration leads to greater entanglement. Concentrations above the entanglement concentration (C_e) were used for electrospinning experiments [12]. Viscosity influences the formation and

stability of the polymer jet and resulting mat. Morphologies of electrospun PVA mats were compared with literature based on Mw and Berry number (Be=[η]C). Be indicates chain entanglements, with Be>1 denoting entanglement. B_e values between 4 and 9 result in beaded fibres, while Be around 9 leads to beadless fibres [8]. In our study, beaded fibres were observed at Be values between 4.6 and 8.6. Beadless nanofibres were achieved with higher Mw PVA (Mw 31,000 and 61,000) at Be values of 7.2 to 10.8. To reduce C_e for high Mw PVA (130,000), acetic acid (HAc) was introduced, increasing electrical conductivity [13]. However, higher conductivity may lead to an unstable cone jet mode due to Coulomb repulsion [14]. A bead-free nanofibrous surface was achieved with 5% PVA-5 (7/3 distilled water/HAc) at Be=5.3, lower than beadless nanofibres produced with water alone.

Table 1. Viscosimetric parameters for PVA solutions

PVA	[η]	k_H	Experimental	Gupta et al. (2005)[12]			
			C_e	c/C*<1	1< c/C* <3	C_e	C**
	dL/g		g/dL	g/dL	g/dL	g/dL	g/L
PVA-1	0.234	0.641	16.5	4.3	12.8	25.6	42.7
PVA-2	0.291	0.489	10	3.4	10.3	20.6	34.4
PVA-3	0.447	1.146	7.5	2.2	6.7	13.4	22.4
PVA-4	0.514	1.156	6.25	1.9	5.8	11.7	19.5
PVA-5	0.960	0.830	4.25	1.0	3.1	6.3	10.4
PVA-5 HAc	1.318	0.524	3.25	0.8	2.3	4.6	7.6

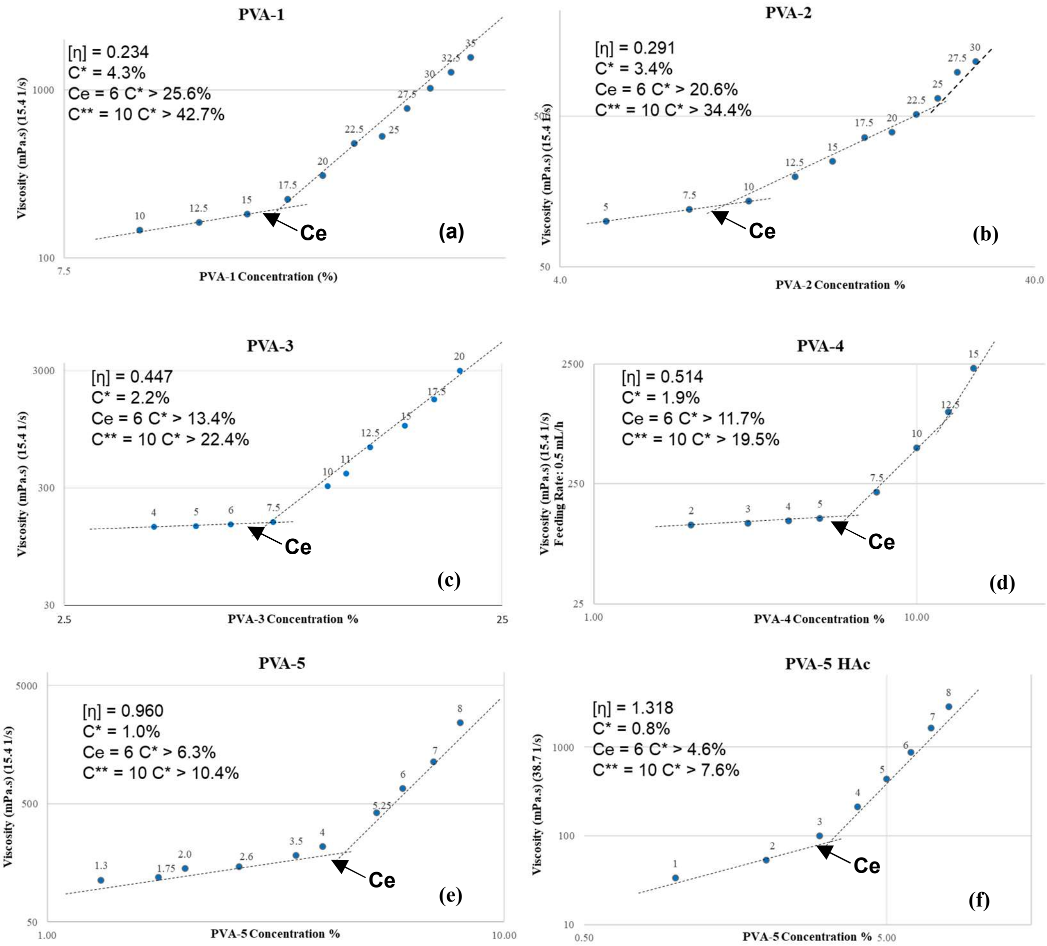

Figure 1. Viscosity (mPa.s) of the (a) PVA-1 and (b) PVA-2 (c) PVA-3 and (d) PVA-4 (e) PVA-5 in distilled water and (f) PVA-5 in Hac solution vs. PVA concentration (w/v%)

Experimental parameters and literature were used to define three zones: semi-dilute entangled (I), semi-dilute unentangled (II), and dilute (III) (Figure 2.b). PVA Mw was considered, and DH significantly influenced solution viscosity and electrospun mat morphology. Generally, higher DH led to higher viscosities [14]. Some outliers occurred due to unknown PVA Mws and varying DHs. Beaded fibre structures were obtained with PVA 2 (Mw 31,000) at concentrations of 15-20%, likely due to high solution viscosity. Similar observations in the literature suggest high viscosity as the reason for beadless fibre formation with medium Mw PVA (50,000–85,000; DH: 97%) at lower polymer concentrations.

Table 2. The theoretical intrinsic viscosity [η] and Berry number, [η]C, for different PVA Mws and experimental concentrations (C)

PVA Type	[η] (dL/g)	C (g/dL)	[η]C	C (g/dL)	[η]C	C (g/dL)	[η]C
PVA-1	0.21	22.5	4.6	25	5.1	27.5	5.6
PVA-2	0.43	15.0	6.5	17.5	7.5	20	8.6
PVA-3	0.66	11.0	7.2	12.5	8.2	---	---
PVA-4	0.86	7.5	6.5	10.0	8.6	12.5	10.8
PVA-5-HAc	1.06	5.0	5.3	---	---	---	---

The Mark-Houwink equation was used for the intrinsic viscosity: $[\eta]=KM_w^a$, K=6.51×10^{-4} and a=0.628 [2]

Figure 3 presents SEM micrographs of electrospun fibres classified into three distinct morphologies, i.e., (i) beaded, (ii) spindle, and (iii) beadless. Beaded fibres exhibit periodic or irregular bead-like structures along their length, spindle fibres feature a central thick region tapering towards the ends, while beadless fibres maintain a smooth and continuous profile. Lower Mw samples (MW: 9,000-10,000 at 22.5 wt%, 25 wt%, and 27.5 wt%; MW: 31,000 at 15 wt%, 17.5 wt%, and 20 wt%) showed beaded fibre formation with particle-to-fibre diameter ratios ranging from 5.4 to 13.0. At 20 wt% concentration for MW: 31,000, spindle fibres emerged, resulting in particle-to-fibre size ratios of 3.4-4.2. A similar trend was observed with MW: 89,000-98,000 at 7.5 wt%, yielding a ratio of 4.3 and spindle-like fibre morphology. In contrast, MW: 61,000 at 11 wt% and 12.5 wt%, MW: 89,000-98,000 at 10 wt% and 12.5 wt%, and MW: 130,000 at 5 wt% produced uniform fibres in nanoscale diameters with circular cross-sections, without beads. However, when using MW: 61,000 at a concentration of 12.5 wt%, the viscosity increased significantly, making it difficult to continue the fibre spinning process, eventually making electrospinning impractical.

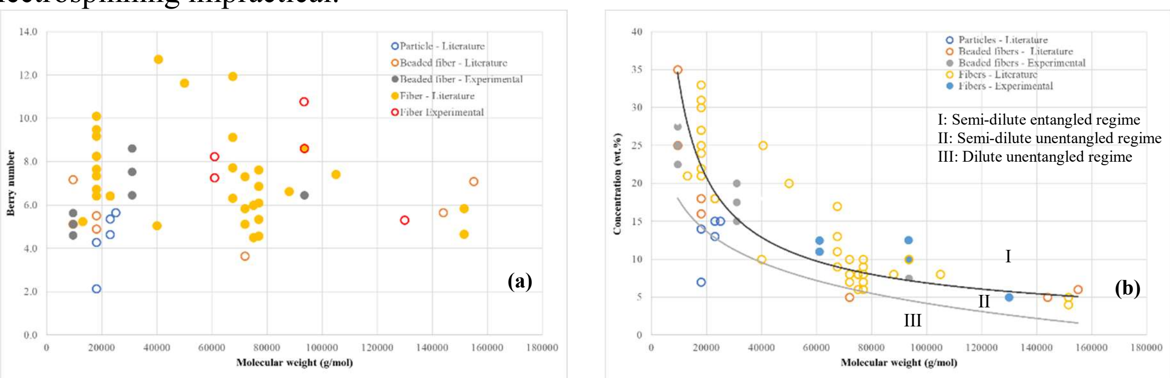

Figure 2. Morphologies obtained by different concentrations of PVA on different Mw a) Berry number vs Mw b) concentration (wt%) vs M_W (g/mol)

Challenges during PVA-3 electrospinning likely stem from its significantly higher surface tension compared to other PVAs ($p \leq 0.05$). Beaded PVA fibres displayed average diameters ranging from 58-106 nm, while uniform fibres measured 161 ± 28 nm (MW: 61,000 at 11 wt%, FR: 0.5 mL/h, TCD: 10 cm), 206 ± 33 nm (MW: 89,000-98,000 at 12.5 wt%, FR: 0.5 mL/h, TCD: 10 cm), and 219 ± 90 nm (MW: 130,000 at 5 wt%, FR: 1 mL/h, TCD: 15 cm). Generally, fibre diameter increased with higher Mw and concentration at the same Mw, consistent with literature reports [2, 8]. Beaded fibres exhibited circular cross-sections and smaller average diameters compared to beadless fibres. Notably, the use of an 18-gauge needle and higher voltage (30 kV) in similar vertical setups led to thicker fibres due to increased mass flow [15].

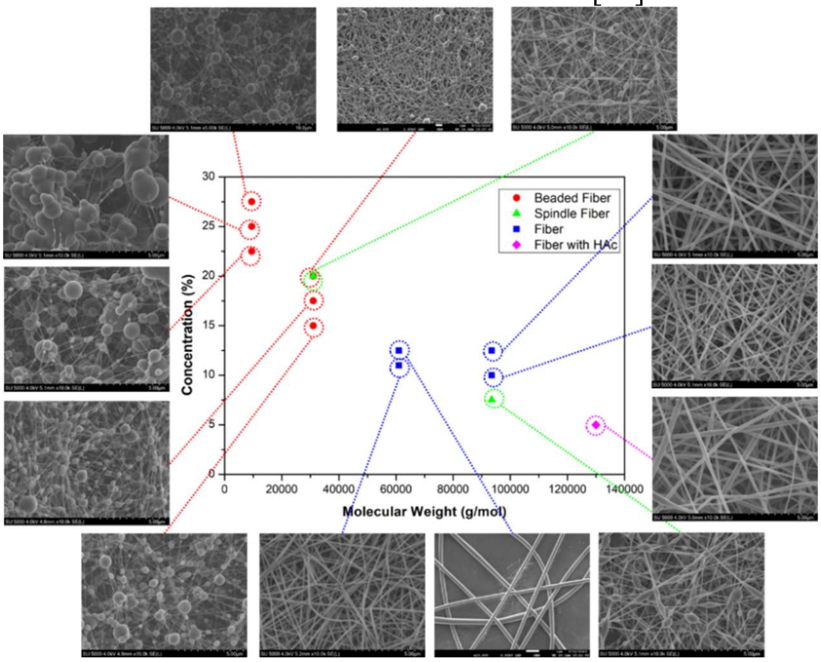

Figure 3. SEM micrographs of PVA electrospun mats with different concentration (wt%) and M_W (g/mol)

Viscosity plays an important role in fibre formation and morphology, directly influenced by solution concentration and polymer Mw. Figure 4 illustrates PVA fibre morphology in relation to Mw, concentration, and viscosity. The data does not exhibit distinct groupings. Notably, low Mw PVA (Mw: 9,000-10,000 g/mol) failed to produce beadless fibres even at high viscosity (776 mPa.s). To achieve non-beaded fibres, a viscosity of 399 mPa.s or higher is required, particularly for medium and high Mw PVA (Mw > 61,000 g/mol). However, it's essential to consider the DH. PVA with Mw: 9,000-10,000 g/mol has the lowest DH (80%), indicating a higher proportion of vinyl acetate monomers. The presence of acetyl groups in PVA can impact alcohol group interactions, potentially altering electrospinning conditions due to reduced hydrophilicity. The findings on the orientation show that regardless of various production parameters and PVA types, there is no significant variation in fibre alignment on the resulting web-like PVA surfaces

4. CONCLUSION

The physico-chemical properties of PVA, including Mw, DH, and concentration, significantly influence electrospinning and nonwoven mat morphology. Higher Mw PVA tends to yield beadless fibres, even at high viscosity, while lower Mw PVA can form beaded fibres. DH also affects fibre morphology due to altered hydrophilicity. Various morphological structures, including beads, beaded fibres, and fibres, can be produced by PVA with different physicochemical properties. In this study, beadless fibres had diameters ranging from 50-220 nm, while beaded fibres were finer (57-80 nm) and accompanied by nanosized particles. The particle-to-fibre diameter ratio ranged from 5.4 to 13.0, with a transition to spindle fibres occurring at a rate of 4.3. Transition points among morphologies varied among PVAs, indicating the influence of DH. Further research is required to elucidate the relationships between these parameters. For medical applications involving essential oils, PVA-2 at 15-20 w/v% with a beaded fibre structure, and PVA-4 at 10-12.5 w/v% and PVA-5-HAc at 5 w/v% with nanofibrous structures were chosen as optimal formulations. Overall, precise adjustments of Mw, concentration, and DH allow for the control and optimization of PVA nanofibre electrospinning and morphology, enabling the production of tailored nanofibre structures for specific applications.

ACKNOWLEDGEMENT

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5. REFERENCES

[1] CANO, A.I., CHÁFER, M., CHIRALT, A., et al. Physical and microstructural properties of biodegradable films based on pea starch and PVA. *Journal of Food Engineering, 2015, vol.167, pp 59-64.*
[2] KOSKI, A., YIM, K., SHIVKUMAR, S. Effect of molecular weight on fibrous PVA produced by electrospinning. Materials Letters, 2004, vol. 58, no. 3-4, pp 493-497.
[3] LEE, J.S., CHOI, K.H., GHIM, H.D., et al. Role of molecular weight of atactic poly(vinyl alcohol) (PVA) in the structure and properties of PVA nanofabric prepared by electrospinning. Journal of Applied Polymer Science, 2004; vol.93, no. 4, pp 1638–1646.
[4] PERESIN, M.S., HABIBI, Y., ZOPPE, J.O., et al. Nanofiber composites of polyvinyl alcohol and cellulose nanocrystals: manufacture and characterization. Biomacromolecules, 2010, vol. 11, pp 674–681.
[5] RESTREPO, I., MEDINA, C., MERUANE, V., et al. The effect of molecular weight and hydrolysis degree of poly(vinyl alcohol)(PVA) on the thermal and mechanical properties of poly(lactic acid)/PVA blends. Polímeros, 2018, vol. 28, pp 169–177.
[6] BERCEA, M., MORARIU, S., RUSU, D. In situ gelation of aqueous solutions of entangled poly(vinyl alcohol). Soft Matter, 2013, vol. 9, pp 1244–1253.
[7] SANDER, E.A., BAROCAS, V.H. Comparison of 2D fiber network orientation measurement methods. Journal of Biomedical Materials Research Part A, 2009, vol. 88, no. 2, pp. 322–331.
[8] TAO, J., SHIVKUMAR, S. Molecular weight dependent structural regimes during the electrospinning of PVA. Materials Letters, 2007, vol. 61, pp 2325–2328.
[9] COLBY, R.H., FETTERS, L.J., FUNK, W.G., et al. Effects of concentration and thermodynamic interaction on the viscoelastic properties of polymer solutions. Macromolecules, 1991, vol. 24, no. 13, pp 3873-3882.
[10] JIANG, M., SONG, X., YE, G., et al. Preparation of PVA/paraffin thermal regulating fiber by in situ microencapsulation. Composites Science and Technology, 2008, vol. 68, pp 2231–2237.
[11] Tiwari SK, Venkatraman SS. Importance of viscosity parameters in electrospinning: of monolithic and core–shell fibers. Materials Science and Engineering: C, 2012, vol. 32, pp 1037–1042.
[12] GUPTA, P., ELKINS, C., LONG, T.E., et al. Electrospinning of linear homopolymers of poly(methyl methacrylate): Exploring relationships between fiber formation, viscosity, molecular weight and concentration in a good solvent. Polymer, 2005, vol. 46, pp 4799–4810.

[13] FELICE, B., PRABHAKARAN, M.P., ZAMANI, M., et al. Electrosprayed poly(vinyl alcohol) particles: preparation and evaluation of their drug release profile. Polymer International, 2015, vol. 64, pp 1722–1732.
[14] KONTA, A., GARCÍA-PIÑA, M., SERRANO, D. Personalised 3D printed medicines: which techniques and polymers are more successful?, Bioengineering, 2017; vol. 4, no.79, pp 1-16.
[15] TOPUZ, F., UYAR, T. Electrospinning of cyclodextrin nanofibers: the effect of process parameters. Journal of Nanomaterials, 2020; vol. 2020, pp 1–10.

EXPANDING OPPORTUNITIES WITHIN THE UV PROTECTION OF ARAMID FIBERS: MATERIAL INDEPENDENT LBL TECHNOLOGY

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ABSTRACT

This paper presents the Layer-by-Layer self-assembly (LbL) approach to enhance the UV resistance of aramid yarns. Initially, a pretreatment was carried out by applying catechol-polyamine to create a strong adhesive molecular anchor on the aramid yarns. Subsequently, cerium dioxide nanoparticles were self-assembled onto these yarns through the LbL process. The findings suggest that the LbL nano-coating holds promise in improving both the UV resistance and tensile properties of the aramid yarns. This study underscores the potential opportunities provided by the LbL methodology, enabling the modification of aramid-based materials under mild conditions, and offering effective UV protection.

Key Words: Aramid, UV resistance, Layer by Layer self-assembly, nanocoating

1. INTRODUCTION

Aramid fiber is one of the key materials in numerous cutting-edge fields owing to its outstanding integrated performances, especially high strength. However, aramid fiber suffers from poor UV resistance which deteriorates its superior mechanical properties [1, 2]. From a strategic standpoint, severe UV-induced strength losses are unacceptable due to the special requirements in application fields like space, aviation, and defense. Therefore, minimizing these damages with UV protective coatings is of great interest both in academia and industry. The fact remains that the inert nature of aramid fibers makes coating a very challenging task. Hence, prior to any surface treatment, aramid fiber is mostly pretreated with acid or alkali, which results in fiber damage [1,2]. Likewise, semiconductors with strong UV absorption pose the risk of damaging the aramid fibers themselves since they are also photocatalysts [3]. Thus, the main challenge is not only developing a robust UV protective coating but also readily integrating it without compromising the mechanical properties of aramid fibers.

Currently, most methods promising effective results are unfortunately complicated, difficult or require special machinery [4, 5]. In contrast, the Layer by Layer (LbL) self-assembly approach, has been demonstrated to be a simple yet highly versatile and powerful strategy to exceed limitations in the existing UV protective modifications of aramid-based materials [6, 7]. Furthermore, utilization of the mussel-inspired surface chemistry, synthetic polymers with catechol and polyamine functionalities, has proven to be an efficient and practical approach for material-independent LbL deposition into inert surfaces such as aramid fibers [8,9]. This study puts particular emphasis on expanding opportunities of LbL technology with the goal of enhancing the UV resistance of aramid materials while minimizing fiber damage. Instead of using abrasive pretreatments, we propose a mussel-inspired coating approach for the LbL self-assembly of UV-protective nanoparticles onto aramid fibers. This approach offers a relatively easy, gentle, and eco-friendly UV protection alternative for aramid fibers.

2. MATERIAL AND METHOD

2.1 Material

Para-aramid multifilament yarns (DuPont Kevlar 49, 620 dtex) were purchased from Kipaş Textiles (Türkiye). Catechol and tetraethylenepentamine (TEPA) were purchased from Sigma Aldrich (Türkiye), sodium hydroxide (NaOH) and hydrochloric acid (HCl) were purchased from Merck (Türkiye). CeO_2 nanoparticles (8-28 nm) were purchased from Nanografi Nano Technology (Türkiye).

2.2. Method

2.2.1 Pretreatment

A CPA aqueous solution consisting of catechol (30 mM) and tetraethylenepentamine (10 mM) was prepared by 1-hour ultrasonication in an open container, and the resultant pH was 8.93. Aramid yarns were immersed in the CPA solution for 24 hours and then dried for 10 minutes at 100 °C.

2.2.2 Layer-by-Layer nanocoating

Aqueous anionic (pH 11) and cationic (pH 4) dispersions of CeO_2 nanoparticles (1 g/L) were prepared by 1-hour ultrasonication adjusting pH with NaOH and HCl, respectively. CPA coated aramid yarns were dipped into these anionic and cationic CeO_2 dispersions, respectively and washed in each sequential step. Ten layers of CeO_2 nano coatings were obtained on aramid yarns by repeating this cycle at room temperature and dried for 10 minutes at 100 °C.

2.3 Characterizations and Tests

Accelerated UV aging treatment were conducted for 96 hours based on TS EN ISO 4891-3 standard (cycle 1) at ATLAS C1005 UV test machine. The UV–Vis absorption spectra of CPA solution (diluted 1/50 with DI water) were measured at 1 hour and 24 hours with a wavelength scan range of 200–600 nm in a quartz cuvette. To assess CPA polymerization, absorption of aqueous sole catechol was also measured after 1 hour (resultant pH ~5.5). Fourier transform infrared spectroscopy data was recorded in attenuated total reflectance mode (FTIR-ATR) with a spectral resolution of 4 cm^{-1}, a wave number range of 600 ~ 4000 cm^{-1}, number of scans of 25. The surface chemical composition of aramid fibers was investigated by X-ray photoelectron spectroscopy (XPS). The morphologies of the aramid yarns were observed using a Scanning Electron Microscope (SEM) before and after UV aging. The tensile properties of aramid yarns were measured according to ASTM D2256M-21. Samples are coded as follows: K49 for untreated, CPA for CPA coated, and CPACe for CeO_2 coated yarns. After UV aging, they were designated with a '-UV' suffix.

3. RESULTS

UV-Vis measurement results are depicted in Figure 1. The absorption of catechol at 220 and 275 nm can be attributed to the $\pi\rightarrow\pi*$ transition associated with an aromatic ring and the $n\rightarrow\pi*$ transition involving the lone pairs of the hydroxyl substituent [10]. A new broad absorption peak at 362 nm for CPA solutions can be attributed to catechol-amine reactions followed by quinonemediated oxidation [9,11]. Furthermore, the decreasing intensity of the shoulder peak at 325 nm after 24 hours, possibly due to the oxidation of catechol into o-quinone [12], together with the developing peak at 478 nm, may indicate that quinone is consumed via Schiff base reaction [13, 14]. The UV-Vis spectrum of the CPA solution confirms polymerization, as evidenced by evolving catechol-amine reactions, and indicates the presence of favorable conditions for implementing a material-independent LbL coating.

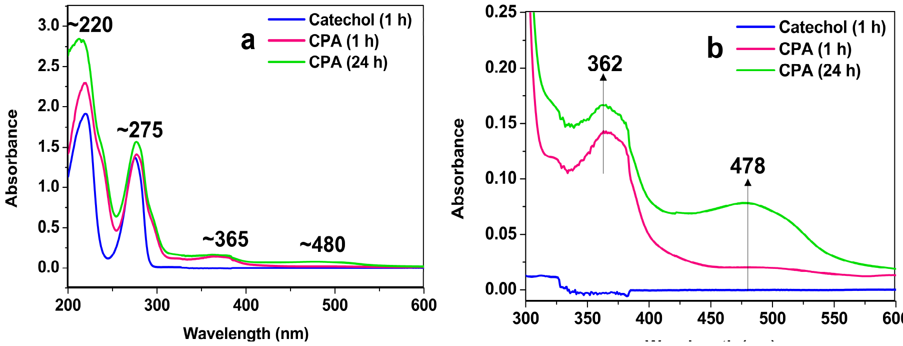

Figure 20. UV-Vis absorbance spectrum of catechol and CPA solutions a) 200-600 nm and b) 300-600 nm

The FTIR-ATR measurement results are displayed in Figure 2. The FTIR spectra exhibit specific amide-related peaks at around these wavenumbers: ~3310 cm^{-1} (Amide A), ~1640 cm^{-1} (Amide I), ~1538 cm^{-1} (Amide II), ~1305 cm^{-1}, ~1250 cm^{-1}, and ~1227 cm^{-1} (Amide III), ~725 cm^{-1} (Amide IV), ~655 cm^{-1} (Amide V) [15-17]. Additionally, bands at 822 cm^{-1} and 1018 cm^{-1} are characteristic of C–H out-of-plane and in-plane bending vibrations, respectively, affirming para-substitution in aramid [18]. The absorption bands at ~1510 cm^{-1} and ~1397 cm^{-1} might be attributed to the C=C [18] and C–C vibrational modes in benzene [15], respectively, while 1109 cm^{-1} can be assigned to C–O stretching vibrations [19].

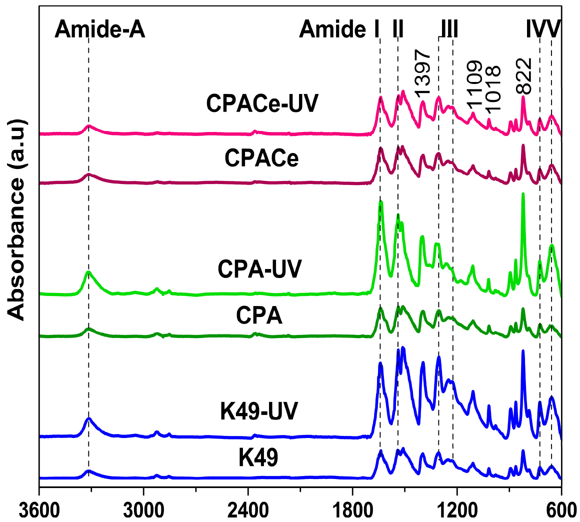

Figure 21. FTIR-ATR spectra of aramid yarns before and after UV aging

There is a slight increase in the relative intensity of Amide A/Amide I, suggesting CPA deposition on the fibers [9]. Nevertheless, it should be noted that the signal from K49, representing the fiber substrate, was overwhelming. Determining the presence of the CPA coating was challenging due to the overlapping bands, such as Amide A, O–H stretching vibration of catechol, and N–H stretching vibration of TEPA [20]; the Amide I region, and possibly the C=N stretching vibration from the Schiff base reaction [20, 21]; the Amide II region, and the bending vibration of N–H in TEPA [20, 22].

After UV aging, the ratios of Amide I/Amide II and Amide I/Amide III in the CPA coating appeared to increase substantially, in contrast to the decreasing trend observed in K49. This phenomenon may result from the breakage of C–N bonds in the main chain of aramid fiber, followed by chain end group oxidation, the disruption of hydrogen bridges between C=O and N–H groups on adjacent chains, and/or partial chain scission, leading to the generation of amide and N–H groups [16, 23]. The increase in the case of the CPA coating may indicate an increasing oxidation of catechol species with UV light [9] and some dissociation of amine chains in TEPA. Overall, these distinctions observed during UV aging seem to indirectly confirm the effectiveness of the CPA coating. However, it is essential to assess both the individual and combined effects of photo-oxidation on catecholamine moieties and aramid yarns due to similarities in molecular units. On the other hand, the CPACe coating remained almost unchanged, implying that the CeO_2 coating can protect the molecular structure from chain rupture caused by UV radiation.

XPS survey analysis and C1s core-level spectra for both K49 and CPACe samples are depicted in Figure 3. In both samples, the C1s, O1s, and N1s peaks were found in the wide-scan spectra at ~285, ~532, and ~400 eV, respectively. However, the Ce3d peak (~900 eV) was only seen in the CPACe survey spectrum, proving the LbL CeO_2 coating. Other species (Na1s and P2p for K49, and Si2p for CPACe) may have been introduced during the manufacturing of aramid fibers and/or could be related to contamination. The deconvolution analysis of the C1s peak of K49 revealed four distinct peaks: C–C (~284.6 eV), C–N (~285.8 eV), C=O (~287.5 eV), and O–C=O (~288.6 eV). Notably, a C–O peak (~286.8 eV) was observed for CPACe, suggesting catechol deposition, as previously reported [9]. Furthermore, the O/C ratio decreased, while the N/C ratio increased. This finding may support the UV-vis results that suggest aliphatic amines favor Schiff base reactions.

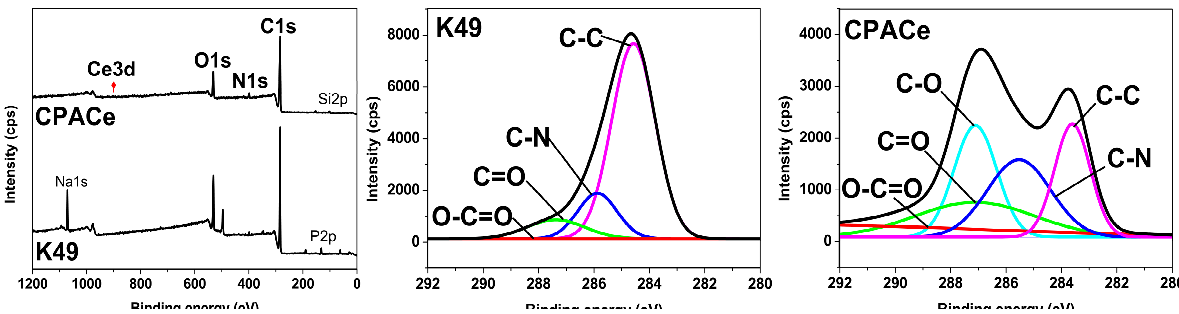

Figure 22. XPS spectra survey data and C1s core-level spectra of K49 and CPACe

SEM images of aramid yarns collected at 5000x magnification are displayed in Figure 4, showing K49, K49-UV, CPACe, and CPACe-UV in that sequence. Some small grooves are uniformly distributed along the fiber's longitudinal axis (K49), indicating axial orientation [24, 25]. Punctiform stains attributed to the fiber production process are also noticed [26]. UV irradiation has little effect on the morphology of K49, suggesting inadequate UV aging, but it also implies that the sizing applied during the manufacturing process supplied some degree of protection. On the fiber surface, a dense CPA coating is apparent, followed by the deposition of CeO_2

nanoparticles. UV radiation appears to increase the density of the CPA coating layer and promote stronger adhesion to the fiber, consistent with prior observations [27]. Furthermore, surface cracks are evident in the CPA coating layer, and UV light seems to cause the nanoparticles to flatten and embed into the CPA. In the case of CPACe, the CPA layer may serve a dual purpose: acting as a sacrificial layer to protect against direct UV light damage and mitigating potential harm from the photocatalytic activity of CeO_2 nanoparticles.

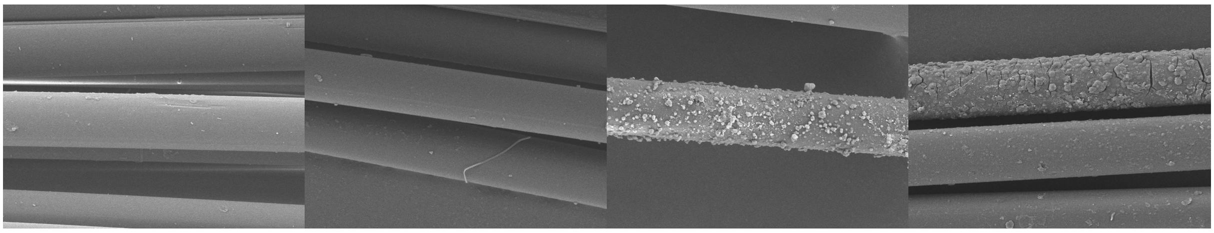

Figure 23. SEM images of aramid yarns from left to right: K49, K49-UV, CPACe, CPACe-UV

The tensile properties of aramid yarns, specifically tenacity at break (cN/dtex) and tensile strain extension at break (%), are presented in Figure 5. The CPA coating initially increases the tenacity of K49, but subsequent LbL coating appears to reduce it, almost returning to its original value. This effect may be attributed to the use of acid and alkali in the LbL coating process for pH adjustment. Following UV aging, both K49 and CPA samples exhibit similar tenacity, indicating that the CPA coating is very thin and insufficient to protect K49 against UV light. However, both show a tensile strength retention of 85%, which is surprisingly good when compared to the typically reported value of 75% [1, 2, 5, 7]. This can likely be attributed to the relatively shorter UV aging test duration (96 hours) in comparison to previous studies (168 hours). In the case of CPACe, tenacity is preserved at 93%, validating the efficacy of the LbL nanocoating. Regarding extension percentages, both the CPA and CPACe coatings seem to be less affected by UV light than K49.

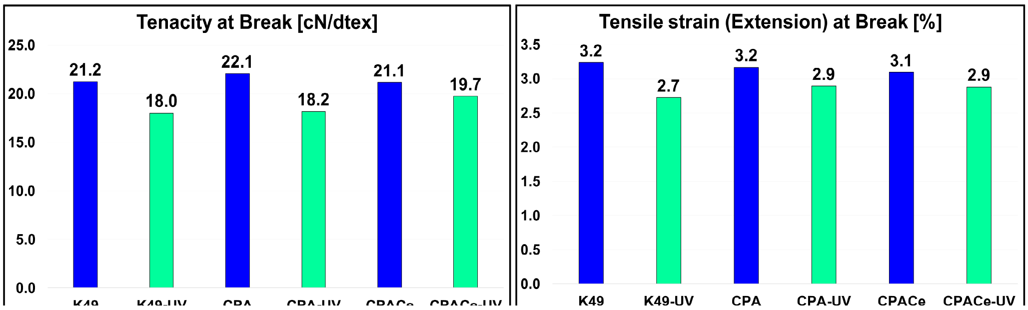

Figure 24. Tensile strength and strain values of aramid yarns before and after UV aging

4. CONCLUSIONS

This preliminary study highlights the potential of material-independent Layer-by-Layer self-assembly technology in the UV protective modification of aramid-based materials. The findings demonstrate that the use of mussel-inspired surface chemistry provides a strongly adhesive sublayer, effectively overcoming the inert nature of aramid fibers without the need for abrasive pretreatments. This opportunity was effectively utilized in the self-assembly of CeO_2 nanoparticles on CPA-coated aramid yarns, and the effectiveness of the LbL process was confirmed through

FTIR-ATR, XPS, and SEM findings. Tensile tests confirm the feasibility of creating nanocoatings via the LbL technique, ensuring high UV protection without compromising aramid fiber tensile properties.

In conclusion, the LbL self-assembly approach holds promise in addressing current limitations and challenges associated with coating aramid fibers using molecular anchors with strong adhesion to virtually any substrate. Therefore, it is considered highly suitable for achieving high protection rates through an easy, simple, and sustainable route in the UV protective modification of aramid-based materials. However, further comprehensive investigations are needed to elucidate the UV protection mechanism and to further expand the opportunities offered by LbL, thereby developing a robust and sustainable UV protection system for aramid fibers. Different LbL applications providing protection across the entire UV spectral range are currently in the development stage, and we hope to share them soon.

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REFERENCES

[1] ZHU, J., YUAN, L., GUAN, Q., LIANG, G., GU, A. A novel strategy of fabricating high performance UV-resistant aramid fibers with simultaneously improved surface activity, thermal and mechanical properties through building polydopamine and graphene oxide bi-layer coatings. Chemical Engineering Journal, 2017, 310, 134-147.
[2] ZHANG, H., LIANG, G., GU, A., YUAN, L. Facile preparation of hyperbranched polysiloxane-grafted aramid fibers with simultaneously improved UV resistance, surface activity, and thermal and mechanical properties. Industrial & Engineering Chemistry Research, 2014, 53 (7), 2684-2696.
[3] YASUKAWA, A., TAMURA, J. Preparation and structure of titanium-cerium-calcium hydroxyapatite particles and their ultraviolet protecting ability. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 2021, 609, 125705.
[4] CHEN, F., ZHAI, L., YANG, H., ZHAO, S., WANG, Z., GAO, C., ZHOU, J., LIU, X., YU, Z., QİN, Y., XU, W. Unparalleled armour for aramid fiber with excellent UV resistance in extreme environment. Advanced Science, 2021, 8 (12), 2004171.
[5] CAI, H., SHEN, D., YUAN, L., GUAN, Q., GU, A., LIANG, G. Developing thermally resistant polydopamine@ nano turbostratic BN@ CeO2 double core-shell ultraviolet absorber with low light-catalysis activity and its grafted high performance aramid fibers. Applied Surface Science, 2018, 452, 389-399.
[6] ÜNVAR, Y., SARIIŞIK, A.M. and UĞUR, Ş.S. Layer by layer self-assembly approach in the UV protective modification of aramid-based materials. In 8th International Technical Textiles Congress: Proceedings Book, Edited By ALPYILDIZ, T. Online: Dokuz Eylül University, Faculty of Engineering, Department of Textile Engineering, October, 2022, 48-53.
[7] ZHOU, L., YUAN, L., GUAN, Q., GU, A., LIANG, G. Building unique surface structure on aramid fibers through a green layer-by-layer self-assembly technique to develop new high performance fibers with greatly improved surface activity, thermal resistance, mechanical properties and UV resistance. Applied Surface Science, 2017, 411, 34-45.
[8] LEE, H., LEE, Y., STATZ, A. R., RHO, J., PARK, T. G., & MESSERSMITH, P. B. Substrate-independent layer-by-layer assembly by using mussel-adhesive-inspired polymers. Advanced materials, 2008, 20 (9), 1619-1623.

[9] WANG, L., SHI, Y., CHEN, S., WANG, W., TIAN, M., NING, N., ZHANG, L. Highly efficient mussel-like inspired modification of aramid fibers by UV-accelerated catechol/polyamine deposition followed chemical grafting for high-performance polymer composites. Chemical Engineering Journal, 2017, 314, 583-593.
[10] OFNER, J., KRÜGER, H. U., GROTHE, H., SCHMITT-KOPPLIN, P., WHITMORE, K., & ZETZSCH, C. Physico-chemical characterization of SOA derived from catechol and guaiacol–a model substance for the aromatic fraction of atmospheric HULIS. Atmospheric Chemistry and Physics, 2011, 11 (1), 1-15.
[11] HONG, S., SCHABER, C. F., DENING, K., APPEL, E., GORB, S. N., & LEE, H. Air/Water Interfacial Formation of Freestanding, Stimuli-Responsive, Self-Healing Catecholamine Janus-Faced Microfilms. Advanced Materials, 2014, 26 (45), 7581-7587.
[12] XU, Y. C., TANG, Y. P., LIU, L. F., GUO, Z. H., & SHAO, L. Nanocomposite organic solvent nanofiltration membranes by a highly-efficient mussel-inspired co-deposition strategy. Journal of Membrane Science, 2017, 526, 32-42.
[13] WU, J., ZHANG, L., WANG, Y., LONG, Y., GAO, H., ZHANG, X., ... & XU, J. Mussel-inspired chemistry for robust and surface-modifiable multilayer films. Langmuir, 2011, 27 (22), 13684-13691.
[14] SENUSI, F., NASUHA, N., HUSAİN, A., ISMAIL, S. Synthesis of catechol-amine coating solution for membrane surface modification. Environmental Science and Pollution Research, 2022, 1-11.
[15] SOHBATZADEH, F., SHAKERINASAB, E., & MIRZANEJHAD, S. Surface modification of aramid yarn by atmospheric pressure plasma: Reinforcement and floating properties. Polymer Testing, 2023, 117, 107836.
[16] ZHANG, H., ZHANG, J., CHEN, J., HAO, X., WANG, S., FENG, X., & GUO, Y. Effects of solar UV irradiation on the tensile properties and structure of PPTA fiber. Polymer degradation and stability, 2006, 91 (11), 2761-2767.
[17] AZPITARTE, I., ZUZUARREGUI, A., ABLAT, H., RUIZ-RUBIO, L., LOPEZ-ORTEGA, A., ELLIOTT, S. D., & KNEZ, M. Suppressing the thermal and ultraviolet sensitivity of Kevlar by infiltration and hybridization with ZnO. Chemistry of Materials, 2017, 29 (23), 10068-10074.
[18] MOSQUERA, M. E., JAMOND, M., MARTINEZ-ALONSO, A., & TASCON, J. M. Thermal transformations of Kevlar aramid fibers during pyrolysis: infrared and thermal analysis studies. Chemistry of materials, 1994, 6 (11), 1918-1924.
[19] ZHANG, L., KONG, H., QIAO, M., DING, X., & YU, M. Supercritical CO2-induced nondestructive coordination between ZnO nanoparticles and aramid fiber with highly improved interfacial-adhesion properties and UV resistance. Applied Surface Science, 2020, 521, 146430.
[20] LI, D., YANG, Z., YANG, J., XU, X., WANG, X., WANG, J., ... & XU, J. Application of a Catechol-Polyamine Co-Deposition method for synthesis of Heteroatom-Doped carbon nanomaterials. Chemical Engineering Journal, 2022, 429, 132363.
[21] BOUKHIR, M., WANG, W., CHEN, Z., ZHANG, K., ZHANG, S., & SONG, W. Low-cost mussel inspired poly (catechol/polyamine) coating of bamboo fibers surface and its use as a reinforcement of PLA matrix. European Journal of Wood and Wood Products, 2023, 1-16.
[22] FANG, Z., TU, Q., CHEN, Z., SHEN, X., PAN, M., LIANG, K., & YANG, X. Study on catechol/tetraethylenepentamine and nano zinc oxide co-modifying ultrahigh molecular weight polyethylene fiber surface to improve interfacial adhesion. Polymers for Advanced Technologies, 2022, 33 (12), 4072-4083.
[23] NASCIMENTO, R. F., DA SILVA, A. O., WEBER, R. P., MONTEIRO, S. N. Influence of UV radiation and moisten associated with natural weathering on the ballistic performance of aramid fabric armor. Journal of Materials Research and Technology, 2020, 9 (5), 10334-10345.

[24] MORGAN, R. J., PRUNEDA, C. O., & STEELE, W. J. The relationship between the physical structure and the microscopic deformation and failure processes of poly (p-phenylene terephthalamide) fibers. Journal of Polymer Science: Polymer Physics Edition, 1983, 21 (9), 1757-1783.
[25] HEARLE, J. W. S. High-performance fibres. Cambridge & Newyork: Woodhead Publishing Ltd and CRC Press LLC, 2001.
[26] YANG, X., TU, Q., SHEN, X., PAN, M., JIANG, C., ZHU, P., ... & HU, C. Surface modification of Poly (p-phenylene terephthalamide) fibers by polydopamine-polyethyleneimine/graphene oxide multilayer films to enhance interfacial adhesion with rubber matrix, Polymer Testing, 2019, 78, 105985.
[27] LI, M., CHENG, K., WANG, C., & LU, S. Functionalize aramid fibers with polydopamine to possess UV resistance. Journal of Inorganic and Organometallic Polymers and Materials, 2021, 31, 2791-2805.

ENVIRONMENTALLY-FRIENDLY AND SUSTAINABLE 100% COTTON FABRIC PRODUCTION FROM FIBERS OBTAINED FROM END CONSUMER TEXTILE WASTES

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ABSTRACT

Textile and clothing production consumes significant amounts of energy, water and other natural resources and causes the rapid generation of large amounts of waste. In our project work, Menderes Tekstil A.Ş. Considering the demands of the customers and considering the future generations, it is planned to obtain fiber from post-consumer textile waste in order to obtain more environmentally friendly and sustainable products, and in this context, new products are designed by developing fabric constructions. In our study, post-consumer waste quality was first determined. Later, various constructions were developed. Production of yarn and weaving depending on the developed construction. Performing unit operations by applying the process steps to be processed in finishing according to the type and quality of fabric produced. The resulting fabric is transformed into the product requested by the customer through the garment process. As a result of our project work, we aim to be one of the leading companies in home textile products by using post-consumer waste by adopting an eco-system sensitive, more environmentally friendly and zero waste method. Contributing to our company and our country's economy by producing such sustainable products in addition to our standard production.

Key Words: Textile, Post-consumer textile waste, Recycling, Sustainability

1. INTRODUCTION

Nowadays, the production of textile products is increasing rapidly due to the developing fashion pace and rapid population growth. As a result of this developing change, natural resources are rapidly consumed and nature is becoming more polluted day by day [1]. In order to prevent this pollution, it has become a sector that takes the entire ecosystem into consideration and aims to produce profitable and quality products by using holistic and preventive approaches. Although holistic and preventive approaches are expressed in different dimensions such as clean production, ecological production, sustainable production, green industry and environmentally friendly technologies, the main aim is to ensure economic efficiency and keep environmental impacts at a minimum level [2], [3], [4]. Sustainability focuses on meeting current demands without compromising the ability of future generations to meet their own needs. The three fundamental pillars of sustainability are economic, ecological and social. Companies are increasingly committing to sustainability through initiatives such as waste reduction, investment in renewable energy and support for groups working towards a more sustainable society [5]. Our goal in the project work we have carried out as a company is to protect natural resources and leave a cleaner environment for future generations.

2. MATERIAL AND METHOD

Bedding used by the end consumer was collected. These collected linens were divided into groups within themselves. During the grouping process, the post-consumer's waste quality was determined. When determining its quality, the raw material structure and the dyeing process of the fabric were taken into consideration. Post-consumer fiber was obtained from waste linens separated into groups. In the first stage, experiments were carried out with 30% post-consumer 70% virgin cotton in flannel fabric quality.

Table 3: Post-consumer sample fabric construction features

FR219
Warp: Ne 20/1 O.E.
Weft: Ne 8/1 O.E.
Warp: 70% Cotton 30% Post Cons. Cotton
Weft: 70% Cotton 30% Post Cons. Cotton
Warp density: 20 threads/cm
Weft density: 13.7 wire/cm
Weight: 165 gr/m²
Weave Type: 1x1

Table 4: Cotton sample fabric construction features

IF269
Warp: Ne 20/1 O.E.
Weft: Ne 8/1 O.E.
Warp: 100% Cotton
Weft: 100% Cotton
Warp density: 20 threads/cm
Weft density: 15 wires/cm
Weight: 165 gr/m²
Weave Type: 1x1

70% cotton 30% post-consumer blended sample fabric is carried out in the facility with the code FR219 and 100% cotton produced sample fabric with the code IF269. The construction properties of sample fabrics produced with codes FR219 and IF269 are given in Table 1 and Table 2. Fabrics whose weaving process is completed according to the specified woven construction are subjected to rotation printing in the finishing department. The process steps of the fabrics produced with FR219 and IF269 codes in the finishing department are given in Table 3.

Table 5: Process flow chart with codes FR219 and IF269

1.Raw to Mercerized
2. Rope Bleaching
3.Emulsion
4. Raising (One-sided hairy)
5. Washing + Drying
6. Transfer
7. Equalize
8. Edition
9. Steaming
10. Washing + Drying
11. Raised rose
12. Finish
13. Sanforizing
14. Quality Control

ISO 13934-1 tensile strength, ISO 6330 shrinkage and ISO 105-12 wet-dry friction fastness tests were performed on two sample fabrics. Test result images are shown in Figure 1 and Figure 2.

Figure 25: FR219 test result report

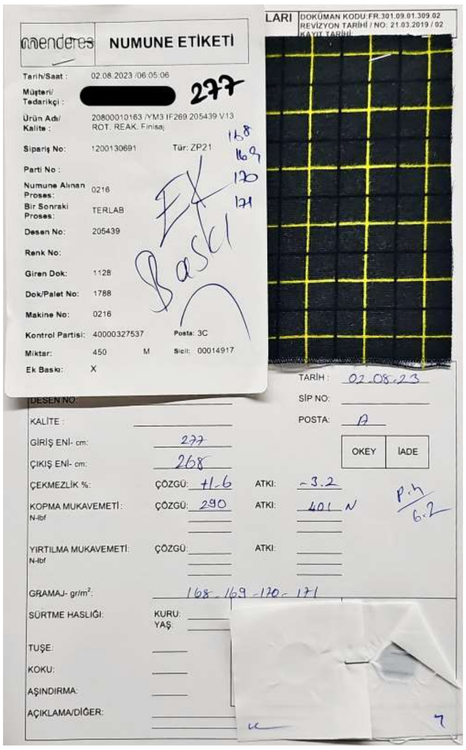

Figure 26: IF269 test result report

ISO 13934-1 breaking strength result is required to be 200 in standards. When we examined the test results, it was observed that the result in our sample fabric coded FR219, produced with 30% post-consumer and 70% virgin cotton, was below 200. Based on this observation, we can say that increasing the post-consumer mixture ratio reduces the tensile strength ratio. This is due to the shorter post-consumer fibers. It is thought that in order to ensure a more environmentally friendly production, the post-consumer rate can be kept low and by adding PES yarn, short fiber yarns can be provided with a stronger grip. It is planned to conduct studies on this subject in the future.

3.CONCLUSION

As Menderes Tekstil company, we have switched to eco-system sensitive, more environmentally friendly zero waste method production by using post-consumer fiber for the first time. We aim to ensure the continuation of our work.

4.REFERENCES

[1] ALPAT, F.E. What is slow fashion? Akdeniz Sanat, 2011, 4(8), 44-47.
[2] MORALI, E.K., UZAL, N. AND YETIŞ, U. Treatment of denim textile factory wastes before and after ozonation. The effect of cleaner production measures. J. Clean. Product. 2016, 137, 1–9.
[3] VENKATRAMAN, P.D. AND LIAUW, C.M. Use of carbon dioxide laser to create environmentally beneficial distressed/faded effects on indigo dyed denim fabric.Evaluation of color change, fiber morphology, degradation and textile properties. Optional Laser Technology. 2019, 111, 701–713.

[4] FIDAN, F.Ş., AYDOGAN, E.K. AND UZAL, N. An integrated life cycle assessment approach for denim fabric production using recycled cotton fibers and combined heat and power plant. J. Clean. Product. 2021, 287, 125439.
[5] FAYSAL, G.M., SONİA AZAD T.N., REPON, R., HOSSAİN T. AND JALİL, M.A. Sustainable yarn production sing leftover fabric from apparel industries. Heliyon, 2022, 8, 2405-8440.

EFFECT OF THERMAL TREATMENTS ON HYGROSCOPIC PROPERTIES OF BIOLOGICALLY DEGUMMED OKRA BAST FIBERS

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ABSTRACT

Bast fibers were extracted from okra (Abelmoschus esculentus) plant via biological degumming and thermally treated under different temperatures and durations. Effects of thermal treatments on fibers' physical and hygroscopic properties were investigated. Thermal treatments led to decreased linear density and moisture content. Water absorption and linear density results showed reverse trends. Water absorption first increased with increment in temperature and then decreased with further increment. Treatments at 160°C resulted in darker fiber color. The ranges of the linear density, moisture content and water absorption of okra bast fibers are 6.70-12.3 tex, 6.4%-8.6%, and 5 g/g to 9 g/g, respectively.

Key Words: Agro-residual, biodegradable, hygroscopicity, natural fiber, okra fiber, renewable

1. INTRODUCTION

Throughout the last several decades, environmental sustainability has become a major issue in production industries. Natural raw materials such as cellulosic fibers have started to be exploited as alternatives to synthetic counterparts. This forms demand for great amount of natural fibers [1]. Within this concept, agro-residual materials stand out promising as they exhibit availability, renewability and biodegradability. They do not lead to depletion of biocarbon resources and exhaustion of dump areas. Additionally, they do not necessitate allocation of arable land solely for raw material production. Furthermore, they provide quality addition to the farmers and boost economic growth for rural areas [2], [3].

Even though the fact that conventional bast fibers were grown in Anatolia since 2000 BC, the annual production figure of flax fiber has reduced from 3700 tons in 1969 to 3 tons in 2017. This has been due to the competition from cotton and cheap synthetic fibers [4]. Residues of edible agricultural practices can be utilized to compensate for the resultant lignocellulosic fiber deficit. Fibers have been extracted from various agro-residual resources such as banana fruit and bunch stems [5], corn husks [6], okra stems [7], and so on. Among different agro-residual fibers, okra bast fibers take an important place. They are mostly grown in less developed regions of the World. Fibers extracted present properties comparable to flax, hemp and jute fibers [8].

The response of plant fibers against high temperatures is important in predicting their performance during production, processing and use under high-temperature conditions. Furthermore, heat treatments may be considered as a type of physical surface modification means with lower impact on the environment in comparison to chemical treatments [9] such as alkalization, bleaching, maleic anhydride grafting, etc. [10], [11].

On the other hand, hydrophilicity of plant fibers is another important factor in evaluating their usefulness in different utilization areas. Hydrophilicity is a wanted phenomenon in textiles use for comfort purposes [12], whereas it is not welcome in technical applications such as use in polymeric composites as it ruins dimensional stability, structure integrity and mechanical strength in environments exposed to humidity [6], [13]. Water retention is determined by the hydrophilicity of the fiber. Hydrophilicity depends on fiber material, degree of polymerization of cellulose, and effects of carried out treatments according to ASTM D 2402 Standard Test Method for Water Retention of Textile Fibers.

Including cellulose, hemicelluloses and pectin, plant fibers show hygroscopicity; so that, they can absorb moisture in the atmosphere and water in liquid phase present in the environment. If a fibrous material contacts water, the liquid can instantaneously wick in among the fibers, that is in the pores and in the fiber material. Advancement of water in pores is realized due reduction of pressure and in the fiber material is by swelling. Absorption rates are determined by the fiber material and geometry of the structure. Modelling liquid absorption necessitates rational representative descriptions [14]. Darcy's law defines flow through porous medium:

$$\langle \mathbf{u} \rangle = -\frac{k}{\mu}\nabla p \tag{1}$$

Here $\langle \mathbf{u} \rangle$ represents the average flow rate, k stands for permeability, and μ symbolizes the dynamic viscosity, ∇ is the nabla operator and p is pressure. ∇p is the pressure gradient given by Eq. 2 [17]. Water can move in the fibrous material only if the pressure difference between the pores and the atmosphere is negative as revealed by Eq (1) [14].

$$\nabla p = \frac{\partial p}{\partial x}\hat{\mathbf{i}} + \frac{\partial p}{\partial y}\hat{\mathbf{j}} + \frac{\partial p}{\partial z}\hat{\mathbf{k}} \tag{2}$$

Studies related to effect of thermal treatments on okra bast fibers have not been found by the author in the literature. Time-dependent water absorption of okra bast fibers has not been investigated yet, either. This study has been carried out in order to fill this space in the academic literature.

2. EXPERIMENTAL

Okra plant stems were obtained from farms following completion of fruiting season. The collected okra stems were water-retted for 60 days in winter. Then, fibers were separated manually and scoured using soda and soap. The scoured fibers were heat treated at 100°C, 120°C, 140°C and 160°C for 2.5, 5, 7.5 and 10 h in a dry oven make Nuve FN120.

Fiber morphologies were observed using an Olympus SZ61 microscope with LCmicro software at 200X-400X magnifications with transmitted light pass. Fibers were characterized in terms of their linear density (ASTM D 1577-07) with 12 replicates using a Radwag precision balance and a ruler. For moisture content determination, fiber samples were conditioned for a minimum duration of 24 h and their mass (m_o) was measured at 0.1 mg accuracy, then the samples were kept in an oven at a temperature of 105 °C for a duration of 16 h. Followingly, the oven dried samples were cooled down to room temperature in a desiccator and their mass was measured again (m_d). Equation 3 was used to determine moisture content:

$$mc\% = \frac{m_o - m_d}{m_o} \times 100. \tag{3}$$

Water absorptive capacity of fibers were evaluated as EDANA 10.3-99, ISO 9073-6.2000 standard methods. Accordingly, fibers were weighed (m_o) and submerged in distilled water for 1 min at 2 cm depth from the surface, and let 2 min to let excess water to drain and weighed again (m_w). Five replications have been conducted for this test. Water absorptive capacity (WAC) was calculated by using the following equation:

$$WAC = \frac{m_w - m_0}{m_0}. \qquad (4)$$

In order to determine time-dependent hygroscopic behavior, untreated and heat-treated okra bast fibers were soaked in water and their water content is determined after different immersion durations. The testing process is a modified RILEM method specially designed for characterizing construction materials based on particles from plants such as hemp, maize, sunflower and other [18].

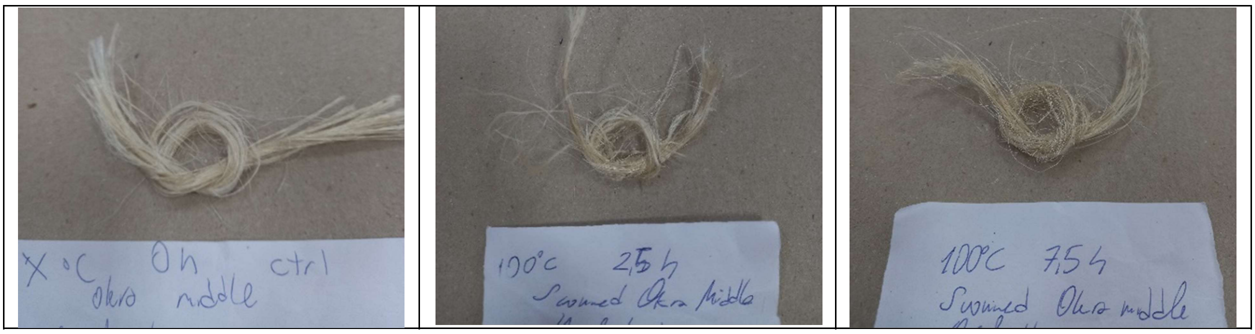
The method has been adapted and implemented on okra bast fibers as follows: Untreated and thermally treated fibers were oven dried at 105 °C for 16 h and cooled in a desiccator and weighed (m_d). Fiber samples in the form of flocs are submerged in water for different durations of 15 min, 30 min, 60 min, 120 min and 300 min. They are taken out of water, dried in a salad spinner for 50 secs at 2 rpm rotating rate and weighed ($m(t)$). Water absorption rate ($w(t)\%$) is determined by Equation 5 as a function of duration (t).

$$w(t)\% = \frac{m(t) - m_d}{m_d} \times 100 \qquad (5)$$

3. RESULTS AND DISCUSSION

Photography and microscopy images of representative fiber sample images are presented in Figure 1 and 2, in consecutive order. Linear density, moisture content, water absorption capacity and time-dependent hygroscopicity of untreated and heat-treated fibers are shown in Figure 3 (a), (b), (c) and (d), respectively.

From fibers' images, it is seen that fibers present similarity to flax fibers. They are stiff straight fibers. Their color resembles cornsilk yellow shade. Fibers treated at 160°C gets a darker shade with a coppery tint, which is not the case for lower temperatures. It should be borne in mind that the fibers were thermally treated in oxygen containing atmosphere without any covering.



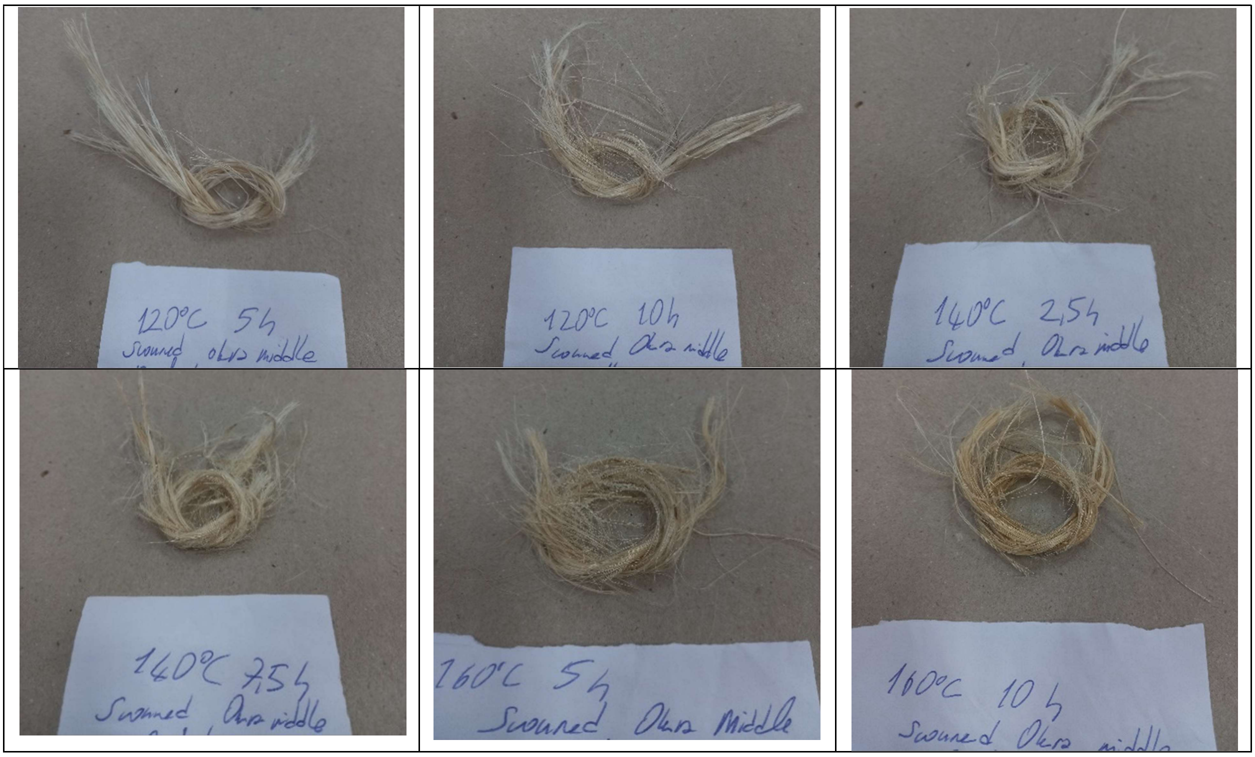
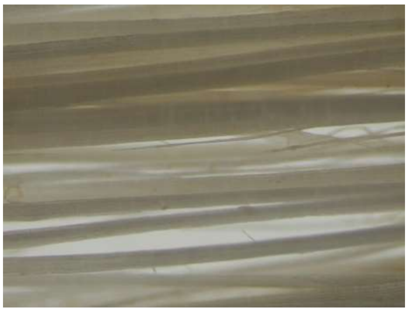


Figure 1. Photography images of untreated and thermally treated okra bast fibers.

a b c



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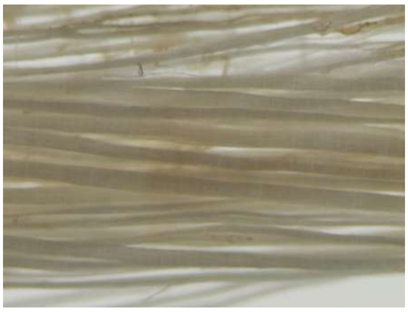
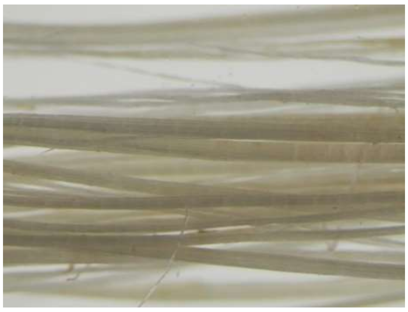


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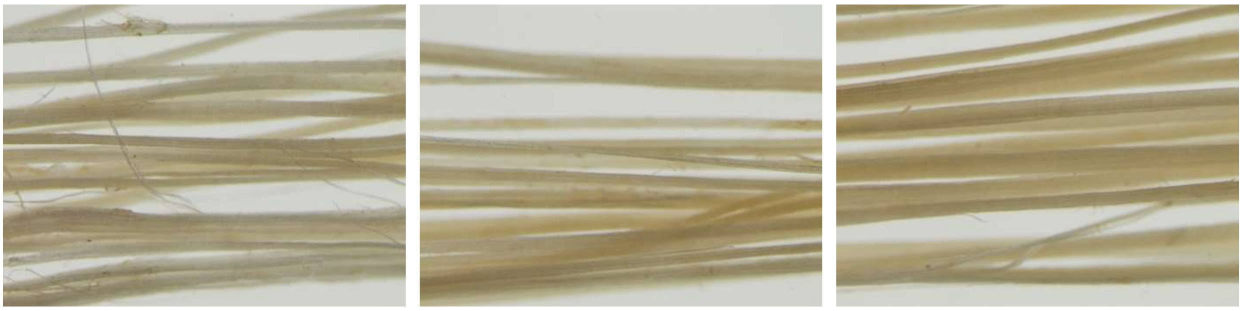
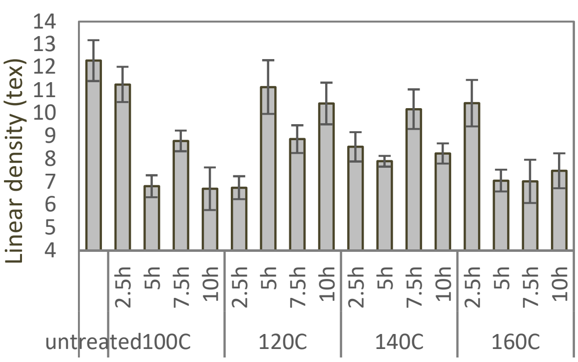


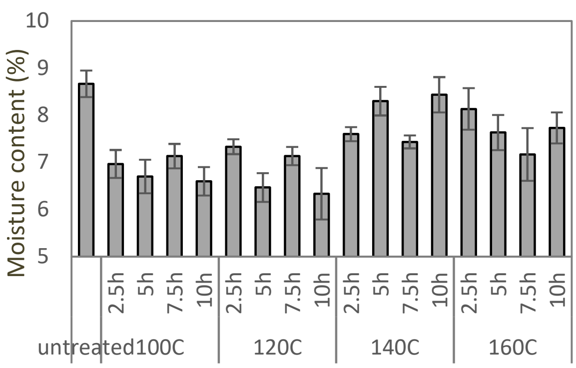
Figure 2. Microscopy images of (a) untreated and thermally treated okra bast fibers at (b) 100°C for 2.5 h, (c) 100°C for 7.5 h, (d) 120°C for 5 h, (e) 120°C for 10 h, (f) 140°C for 2.5 h, (g) 140°C for 7.5 h, (h) 160°C for 5 h and (i) 160°C for 10 h.

From microscopy images, it is seen that the okra bast fibers present a longitudinal straight shape. The variability in the fineness draws some concerns related to reliability of the fiber performances. On the other hand, there is great potential to attain substantially finer fibers. Some extra substances are observed to stick on the fiber. It is obvious that every fiber is in fact a bundle of parallel elementary fibers. Thus, okra bast fibers are multicellular technical fibers. The fibers treated at 160°C show a cleaner surface with lower amount of impurities, which may have been burnt. Brownish color of 160°C-treated fibers is also observable from microscopy images.

As a fiber of natural origin, okra fibers show great variability in results in contrast to synthetic fibers. Linear density of okra bast fibers range between 6.70-12.3 tex. This values are within the ranges of with those of [6], [19], [20] and finer than that of [7], [21] reported in the literature. The highest linear density belongs to untreated okra bast fibers. Being exposed to high temperature, constituents in the fiber structure may have disintegrated. For 100°C and 160°C treatments the linear density shows a decreasing trend with increment in duration.

As a lignocellulosic fiber, okra bast fibers show highly hydrophilic structure. Moisture content of okra bast fibers range between 6.4%-8.6%. This finding is in agreement with former literature on okra bast fibers 6.74% reported by Khan et al. [6]. Okra fibers can absorb 5 to 9 times of their initial weight. Water holding capacity of okra fibers increases with increment in immersion duration. Nouri et al. [13] reported a similar trend. On the other hand, heat-treated fibers show greater results. Water absorption first increased with increment in temperature and then decreased with further increase.





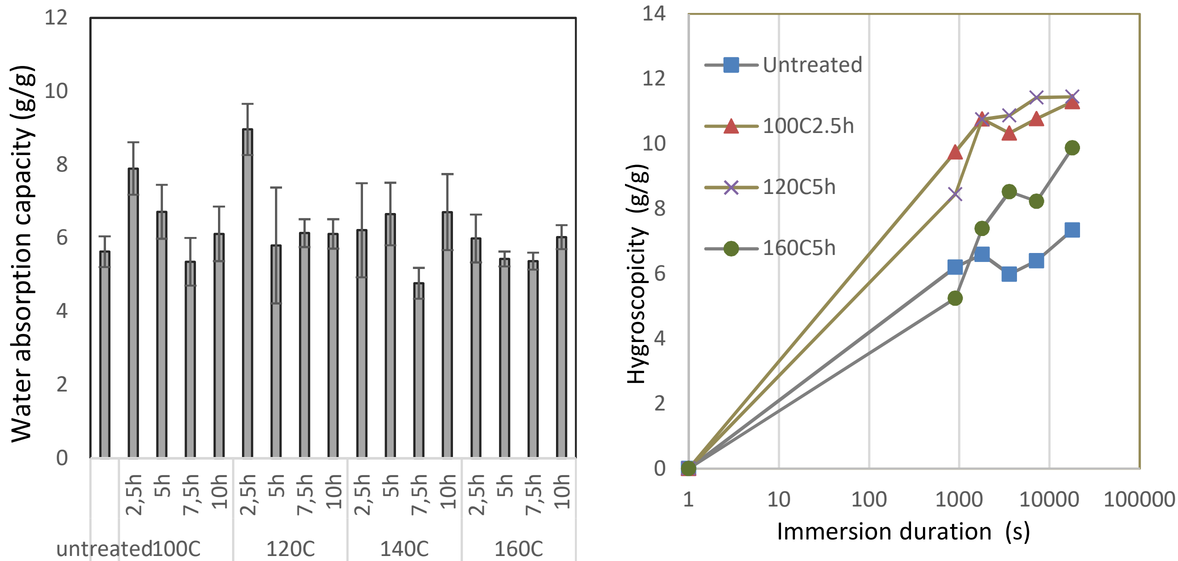


Figure 3. Effect of thermal treatments on a) linear density (tex), b) moisture content (%), c) water absorption (g/g), and d) time dependent hygroscopic behavior (g/g) of okra bast fibers. Error bars represent standard errors. Figure 1 (d) is shown in logarithmic scale.

4. CONCLUSION

In this study, bast fibers that have been extracted from okra (Abelmoschus esculentus) plant via biological degumming (water retting) were thermally treated under different temperatures for varying durations. Effects of thermal treatments on physical and hygroscopic properties of fibers have been investigated. Treatments at 160℃ result in darker fiber color, while no such effect can be observed for lower temperatures. Thermal treatments lead to decrease in linear density and moisture content. Water absorption and linear density results show reverse trends, as lower linear density fibers exhibit higher water absorption capacity. One-time and time-dependent water absorption first increase with increment in temperature and then decrease with further increase in the heat treatment parameters. Okra bast fibers can be utilized in applications where other conventional bast fibers such as flax, hemp and jute are used.

5. REFERENCES

[1] GUPTA, K. and CHAUHAN, N. R. “Comparative study of green composites using grewia optiva, Himalayan nettle and silk as fiber,” *Adv. Mater. Process. Technol.*, pp. 1–10, Aug. 2022, doi: 10.1080/2374068X.2022.2108579.
[2] OCHI, S., TAKAGI, H. and NIKI, R. “Mechanical properties of heat-treated natural fibers,” *Zair. Soc. Mater. Sci. Japan*, vol. 51, no. 10, pp. 1164–1168, 2002, doi: 10.2472/jsms.51.1164.
[3] KOCAK, E. D., MERDAN, N., MISTIK, I. et al. “Fiber Extraction from Okra Plant Agricultural Wastes, Their Characterizations and Surface Modifications by Environmental Methods,” pp. 53–80, 2018, doi: 10.1007/978-981-10-8578-9_3.
[4] YILMAZ, S. and UZUN, A. *Keten tarimi*. Karadeniz Tarım Araştırma Enstitüsü Müdürlüğü, 2019.
[5] YILMAZ, N. D., SULAK, M., YILMAZ, K. and KHAN, G. M. A. “Effect of chemical treatments on physico-chemical properties of fibers from banana fruit and bunch stems,” *Indian J. Fibre Text. Res.*, vol. 42, no. 1, pp. 111–117, 2017.
[6] KHAN, G. M. A. et al. “Effects of Alkalization on Physical and Mechanical Properties of Biologically Degummed Okra Bast and Corn Husk Fibers,” *J. Nat. Fibers*, vol. 19, no. 3, pp. 1126–

1136, Mar. 2022, doi: 10.1080/15440478.2020.1798840.
[7] YILMAZ, N. D. et al. "Characterization, modification and use of biomass: okra fibers," *Bioinspired, Biomim. Nanobiomaterials*, 2016, doi: http://dx.doi.org/10.1680/jbibn.15.00014.
[8] KHAN, G. M. A. et al. "Okra fibers: Potential material for green biocomposites," *Green Energy Technol.*, no. 9783319493817, pp. 261–284, 2017, doi: 10.1007/978-3-319-49382-4_12.
[9] NOURI, M. et al. "Plant Extraction and Physicochemical Characterizations of Untreated and Pretreated Diss Fibers (Ampelodesmos mauritanicus)," *J. Nat. Fibers*, vol. 18, no. 8, pp. 1083–1093, 2021, doi: 10.1080/15440478.2019.1687062.
[10] KHAN, G. M. A. et al. "Okra bast fiber as potential reinforcement element of biocomposites: Can it be the flax of the future," in *Handbook of Composites from Renewable Materials Volume 4: "Functionalization,"* Wiley Scrivener, 2017, pp. 379–406.
[11] KHAN, G. M. A. and YILMAZ, N. D. "Biologically Degummed and Chemically Treated Okra Bast Fibers-Reinforced Poly(Vinyl Alcohol) Composites," *Tekst. ve Konfeksiyon*, vol. 32, no. 4, pp. 366–375, Dec. 2022, doi: 10.32710/tekstilvekonfeksiyon.1083022.
[12] M, V., K, P. B., D, V. K., PRAKASH, C and V4, S. S. "Study on Single Jersey Knitted Fabrics Made From Cotton/ Polyester Core Spun Yarns. Part II: Moisture Management Properties," *Tekst. ve Konfeksiyon*, vol. 32, no. 1, pp. 37–46, Mar. 2022, doi: 10.32710/tekstilvekonfeksiyon.904228.
[13] NOURI, M., TAHLAITI, M., GRONDIN, F. and BELARBI, R. "The Influence of Chemical and Thermal Treatments on the Diss Fiber Hygroscopic Behaviors," *J. Nat. Fibers*, pp. 0–14, 2020, doi: 10.1080/15440478.2020.1848733.
[14] DUPRAT, C. "Moisture in Textiles," *Annu. Rev. Fluid Mech.*, vol. 54, no. 1, pp. 443–467, Jan. 2022, doi: 10.1146/annurev-fluid-030121-034728.
[15] YILMAZ, N. D., ÇILGI, G. K. and YILMAZ, K. "Natural Polysaccharides as Pharmaceutical Excipients," *Handb. Polym. Pharm. Technol.*, vol. 3, pp. 483–516, Sep. 2015, doi: 10.1002/9781119041450.CH14.
[16] GARIP, B., YÜKSEL, A., ÜNAL, S. and BEDELOĞLU, A. "Improving the Water Repellency of Polyester Filament Yarn and Fabrics," *Tekst. ve Konfeksiyon*, vol. 33, no. 2, pp. 161–168, Nov. 2022, doi: 10.32710/tekstilvekonfeksiyon.1065250.
[17] DE MARSILY, G. "Stochastic Description of Flow in Porous Media," in *Encyclopedia of Physical Science and Technology*, Elsevier, 2003, pp. 95–104.
[18] AMZIANE, S. et al. "Recommendation of the RILEM TC 236-BBM: characterisation testing of hemp shiv to determine the initial water content, water absorption, dry density, particle size distribution and thermal conductivity," *Mater. Struct. Constr.*, vol. 50, no. 3, pp. 1–11, 2017, doi: 10.1617/s11527-017-1029-3.
[19] KHAN, G. M. A. et al. "Effects of chemical treatments and degumming methods on physical and mechanical properties of okra bast and corn husk fibers," *J. Text. Inst.*, vol. 111, no. 10, pp. 1418–1435, Oct. 2020, doi: 10.1080/00405000.2019.1702492.
[20] STAWSKI, D. et al."Thermal and Mechanical Characteristics of Okra (Abelmoschus esculentus) Fibers Obtained via Water- and Dew-Retting," *Appl. Sci.*, vol. 10, no. 15, p. 5113, Jul. 2020, doi: 10.3390/app10155113.
[21] STAWSKI, D. et al. "Thermal Characteristics of Okra Bast and Corn Husk Fibers Extracted via Alkalization," *J. Nat. Fibers*, vol. 19, no. 14, pp. 9101–9110, Oct. 2022, doi: 10.1080/15440478.2021.1982440.

THE APPLICATION OF ARTIFICIAL INTELLIGENCE FOR ASSEMBLY LINE BALANCING IN THE CLOTHING INDUSTRY

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ABSTRACT

This review explores AI's role in clothing industry assembly line balancing, focusing on labor-intensive settings. Algorithms like neural networks, branch-and-bound, and meta-heuristics are evaluated through experiments, showing potential for cost reduction and efficient labor allocation. While AI holds promise for optimizing assembly lines, further research is needed for clothing-specific challenges. This study underscores the need for increased automation in clothing manufacturing processes and emphasizes AI's potential in enhancing production efficiency.

Key Words: AI, clothing industry, assembly line balancing, optimization

1. INTRODUCTION

The application of artificial intelligence (AI) techniques in manufacturing, specifically assembly line balancing, has received significant attention from researchers to remain competitive in the global market. However, the clothing industry lags behind other industries in the level of automation in the assembly phase of the manufacturing process. This review aims to investigate the implementation of AI in the clothing industry with an emphasis on balancing assembly lines that involve a significant amount of labor.

2. MATERIALS AND METHODS

When conducting literature searches, systematic steps were taken to ensure the transparency and quality of results. The first step is to set the search string to use for validation. These search strings are predefined keyword combinations related to the field of artificial intelligence research on assembly line balancing problems:

- “Artificial Intelligence” and “Conveyor Belt Balancing”
- "AI" and "Production line optimization"
- "AI" and "assembly line improvement"
- "AI" and "improvement of production line performance"
- "AI" and “minimization of production costs”

Major research collections include multiple search engines such as Science Direct and Google Scholar. A list of inclusion and exclusion criteria was developed to ensure transparency of study selection. This list contains dates and dependencies that should be considered during selection. Publications should be in English and related to artificial intelligence and assembly line balancing. All areas not related to assembly line management, production line optimization and the use of artificial intelligence to minimize production costs are excluded.

3. RESULTS AND DISCUSSION

AI is used to balance assembly lines across industries, including apparel. Still, research on dress balance is limited. Experimentation shows quick and optimal solutions to small problems. Neural networks and branch and bound improve task ordering, cycle time, and decomposition. Metaheuristics have proven effective in evaluating task algorithms and reducing production costs. Among the wealth of papers, we have included 10 papers that match our focus on AI assembly line balancing. In this section, we discuss the year of publication of these papers, the types of papers, their methodologies, industry challenges, and the benefits of AI.

3.1. Publication type and research methodology

This section reviews the types of publications and research methods used in the study. This helps researchers better understand how they have approached assembly line balance problems. (Figures 1 and 2)

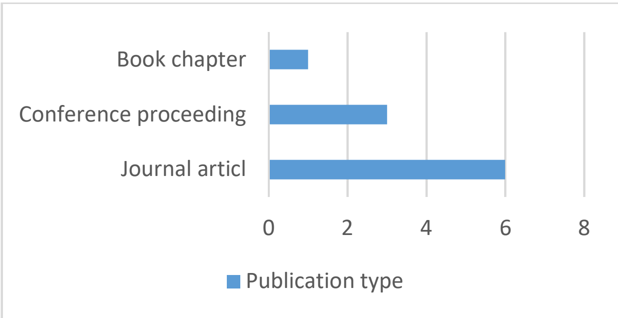

Figure 1. Publication type

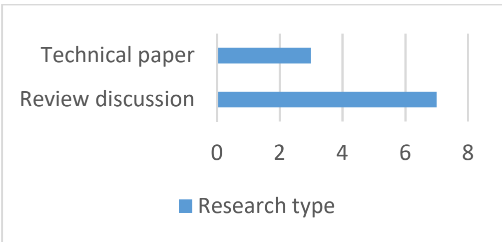

Figure 2. research type

3.3 Summary of the literature

AI offers key benefits in assembly line balancing: optimization and real-time decision-making. Improved process visibility, transparency, stakeholder satisfaction, and customer contentment are evident advantages. Accurate, real-time data aids efficient decision-making and deeper process understanding.

Table 1. Summary of the literature

N°	Main idea of the paper	Key Benefits of IoT
[1]	• This paper provides a comprehensive overview of research papers focused on decision support and intelligent systems in the textile and apparel supply chain. • Items reviewed are categorized according to their applicability in textile production, garment manufacturing and distribution/sales. • The main aim is to highlight the role of these systems in improving various aspects of the textile and garment industry.	• Key benefits • Better decision making • Increased supply chain transparency • Improve customer satisfaction • Cost reduction • Agility and adaptability • Sustainable practices
[2]	• This article provides an empirical study of approaches to balancing assembly lines in mass production. • The authors compare the Kilbridge-Wester heuristic method and the Helgeson-Birnie method. • The main goal is to optimize the efficiency of the assembly line.	• Improve mass production efficiency • Optimization of crew size • Improved system utilization • Task feasibility and time constraints Cost effective system design
[3]	• Main Idea: Introduction of ICA (Immune Clone Algorithm) to minimize cycle time and operator operating costs. • Proof of superiority over AG (Genetic Algorithms) in multi-objective optimization.	• Reduced cycle time • Optimizing employee operating costs • Multipurpose optimization • Improve production efficiency • Competitive advantage
[4]	• This paper presents a constrained two-sided assembly line coordination problem. • The Bee algorithm is used to solve this problem. • The bee algorithm and the artificial bee colony algorithm are used to solve large cases of the problem. • The goal is to reduce the number of work items and create a balanced assembly line.	• Improve production efficiency • Optimal use of resources • Saving measures • Scalability • Adaptability
[5]	• This study addresses the problem of balancing production lines in the textile industry involving multiple types of goods with different resource requirements. • The aim is to improve the existing state-of-the-art in balancing production lines in the textile industry.	• Improved Line Balancing • Resource Optimization • Increased Productivity • State-of-the-Art Advancement
[6]	• This article describes a multi-objective optimization balancing a stochastic assembly line using models and parallel stations.	• The proposed approach allows efficient optimization of assembly line balancing while simultaneously considering multiple goals.

	• The authors propose a hybrid simulated annealing algorithm to achieve the goal.	• By minimizing the smoothing index, assembly lines can achieve more even workload distribution, reduce idle time, and maximize productivity. • Minimizing design overhead optimizes resource allocation and reduces production costs.
[7]	• This paper focuses on the problem of work assignment and distribution on assembly lines.	• The proposed algorithm improves the quality of the solution, assigns workers to tasks efficiently, and achieves a balanced assembly line. • Algorithmic efficiency improvements enable faster and more effective work allocation and distribution, reducing downtime and improving overall productivity.
[8]	• The main purpose of this chapter is to provide a comprehensive overview of various applications of artificial intelligence in the fashion industry.	• This chapter explores potential applications of AI in fashion design and provides support systems that can enhance the creative process and streamline the design workflow. • The fashion recommendation system described in this chapter improves the customer's shopping experience, leading to increased customer satisfaction and loyalty.
[9]	• The main purpose of this article is to highlight the potential benefits of AI technology implementation in garment manufacturing, especially focusing on operational planning, quality control and inspection.	• AI technology significantly improves operational planning in apparel manufacturing, leading to better resource allocation, production planning and overall process optimization. • Using AI for quality control improves product consistency, reduces errors, and ensures apparel products meet high standards and customer expectations.
[10]	• This article categorizes research articles investigating the impact and importance of AI in the fashion and apparel industry across different stages of the supply chain, including design, fabric production, apparel production, and distribution.	• By categorizing research papers, the study provides a comprehensive and systematic overview of the diverse applications of AI in the fashion industry, helping researchers and industry professionals to understand the full impact of AI.

4. REFERENCES

[1] E. W. T. NGAI, S. PENG, P. ALEXANDER, ET K. K. MOON, « Decision support and intelligent systems in the textile and apparel supply chain: An academic review of research articles », *Expert Syst. Appl.*, vol. 41, nº 1, p. 81-91, 2014.

[2] D. G. MAHTO ET A. KUMAR, « An empirical investigation of assembly line balancing techniques and optimized implementation approach for efficiency improvements », *Glob. J. Res. Eng. Mech. Mech. Eng.*, vol. 12, 2012.

[3] R. RAMEZANIAN ET A. EZZATPANAH, « Modeling and solving multi-objective mixed-model assembly line balancing and worker assignment problem », *Comput. Ind. Eng.*, vol. 87, p. 74-80, 2015.

[4] P. TAPKAN, L. OZBAKIR, ET A. BAYKASOGLU, « Modeling and solving constrained two-sided assembly line balancing problem via bee algorithms », *Appl. Soft Comput.*, vol. 12, nº 11, p. 3343-3355, 2012.
[5] J. PEREIRA, « Modelling and solving a cost-oriented resource-constrained multi-model assembly line balancing problem », *Int. J. Prod. Res.*, vol. 56, nº 11, p. 3994-4016, 2018.
[6] B. CAKIR, F. ALTIPARMAK, ET B. DENGIZ, « Multi-objective optimization of a stochastic assembly line balancing: A hybrid simulated annealing algorithm », *Comput. Ind. Eng.*, vol. 60, nº 3, p. 376-384, 2011.
[7] M. VILA ET J. PEREIRA, « A branch-and-bound algorithm for assembly line worker assignment and balancing problems », *Comput. Oper. Res.*, vol. 44, p. 105-114, 2014.
[8] S. THOMASSEY ET X. ZENG, *Introduction: Artificial Intelligence for Fashion Industry in the Big Data Era*. Springer, 2018.
[9] R. ABD JELIL, « Review of artificial intelligence applications in garment manufacturing », *Artif. Intell. Fash. Ind. Big Data Era*, p. 97-123, 2018.
[10] C. GIRI, S. JAIN, X. ZENG, ET P. BRUNIAUX, « A detailed review of artificial intelligence applied in the fashion and apparel industry », *IEEE Access*, vol. 7, p. 95376-95396, 2019.

FULLTEXTS OF POSTER PRESENTATIONS

IMPROVING THE FUNCTIONAL PROPERTIES OF WOOL / POLYAMIDE BLEND UPHOLSTERY FABRIC

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ABSTRACT

Wool-Polyamide blend fabric combines the natural properties of wool with the synthetic properties of polyamide. This structure offers a range of functional properties. Some of the functional properties of wool-polyamide fabric include moisture management, breathability, insulation, durability, softness and comfort, odor resistance, easy care. These functional properties make it suitable for a wide range of applications, including outdoor clothing, activewear and upholstery.
In this study, it is aimed to improve some functional properties of wool/polyamide upholstery fabrics in line with customer demands. The company has already conducted some development work on these fabrics. Main focus on this research is to produce fabrics with multifunctional properties like water repellent, soil release and flame reterdancy. For this aim, fabrics were treated with fluorocarbon resin (nonionic), organic phosphorus-nitrogen compounds mixture (weak cationic), alkyl phosphonate (uncharged) chemicals. In this application, chemical concentration, application method and chemical types were changed.

Key Words: Upholstery Fabric, Multifunctional Properties, Flame Retardant, Water Repellent

1. INTRODUCTION

Wool-Polyamide blend fabric combines the natural properties of wool with the synthetic properties of polyamide. This structure offers a range of functional properties. Some of the functional properties of wool-polyamide fabric include moisture management, breathability, insulation, durability, softness and comfort, odor resistance, easy care. These functional properties make it suitable for a wide range of applications, including outdoor clothing, activewear and upholstery.

The wool fiber structure consists of more than one layer and each layer brings in wool fiber different functional properties (Figure 1). The cuticle is the layer of overlapping epithelial cell's surrounding the wool fibre. : There are three cuticles. The epicuticle is the outermost layer covers of the wool fibre. The overlapping epithelial cell forms the exocuticle. The endocuticle is the intermediate connecting layer bonding the epithelial cell of the cortex of wool fibre. The cuticle layer provides water repellency, resistance to pollution, controlled felting, odor absorption, easy removal of sweat to wool fiber. The cortex – the internal cells-make up 90% of the fibre. There are two main types of cortical cells i.e. ortho-cortical and para-cortical. Each has a different chemical composition. Change in fiber diameter causes to improve a super attitude and drape, softness and comfort and the cortex layer brings in the fiber breathability, porosity, soundproofing, hot-cold heat insulation. The cortical cells are surrounded and held together by a cell membrane complex, Similarly the cell membrane complex affects positively color retention, permanent effect, pleating, permanent abrasion resistance. Flame retardant, hygroscopicity and antistatic properties are gained by matrix structure and finally elasticity and wrinkle resistant, wash and wear feature are due to spiral structure & a-helix structure.

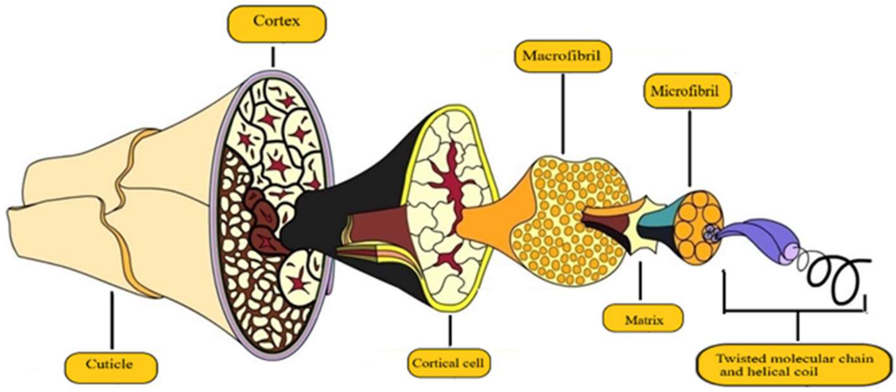

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Figure 1. Wool structure

Polyamide is a synthetic polymer made of petroleum-based plastics that are held together with amide bonds. The molecules that make up polyamide are extremely long and heavy providing strength and elasticity. Synthetic polyamide thermoplastics are important in engineering because they offer high performance at a reasonable cost. Polyamide (PA) fibers offer high strength and abrasion resistance to wool fabrics. In addition, the use of polyamide fibers in a mixture with wool fiber is also important in terms of dyeability. Due to the functional groups in their structures, they can be dyed in the same bath. At the same time, the use of PA fiber mixed with wool fiber can improve the performance of the finished product.

In this study, recipe optimization was studied in the finishing process in order to add multifunctional properties to the wool-polyamide blend fabric. After the application process, characterization analyzes of the fabric and performance tests suitable for the functional effect were made, and the results were evaluated.

2. EXPERIMENTAL

In the study, 70% wool-30% polyamide woven fabric was used as a blend. The finishing processes applied to the fabric and the structural properties of the fabric are given below.

Table 1. The properties of the WO/PA fabric.

Weave Type	Fabric Blend Ratio (%)	Weight (g/m^2)	Yarn Number (Nm)	
			Warp	Weft
2/2 Twill	70 Wool / 30 Polyamide	325	13/1	13/1

The treatment steps applied to the fabric are given below:

1.Open Width Washing	6.Stenter
2.Stenter Drying	7.Shearing
3.Raising	8. Finishing Application (Padding)
4.Carbonized	9.Stenter Drying
5.Milling	10.Decatizing

In order to give the wool/polyamide blend fabric a multifunctional properties, many recipes were tried during the finishing process. Evaluations were made on the four recipes that gave the best results. The experimental studies were carried out in the laboratory using the impregnation-drying and/or curing method.

Table 2. Recipes applied to provide water repellency and fire retardant properties to wool/polyamide fabric

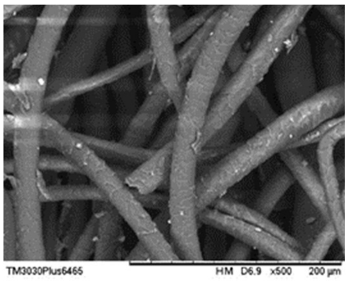
Recipe 1: 400 g/L Organic P-N compounds Wet pick-up % 80 Drying 160 C, 120 second 60 g/L FC polymer, weakly cationic Wet pick-up %8 Drying 160 C, 120 second	**Recipe 2:** 400 g/L Organic P-N compounds 30 g/L FC polymer, weakly cationic Wet pick-up % 80 Drying 130 C, 120 second Curing 160 C, 120 second
Recipe 3: 80 g/L FC resin, nonionic 1 ml/L Asetic acid (%60) Wet pick-up % 80 Drying 130 C, 120 second Curing 160 C, 90 second	**Recipe 4:** 100 g/L Alkyl phosphonate uncharged 80 g/L FC polymer, weakly cationic Wet pick-up % 80 Drying 190 C, 60 second

3. RESULTS AND DISCUSSION

In the study, experimental studies were carried out in order to improve the performance properties of the wool/polyamide blend fabric, and then measurements were taken. In addition to SEM, FT-IR measurements, water repellency, combustion behavior and thermal properties were evaluated to determine functional efficiency.

3.1. SEM Analysis

The characteristic surface structure of the wool fiber is clearly seen in the SEM images taken at the same magnification(500x) from untreated and treated fabrics with four different recipes.
It is observed that some deformations occur on the surface of the untreated fabric after pre-treatment, peeling and breaking occur. A similar effect was observed in the SEM images after the finishing treatments applied to the fabrics. When evaluated in terms of FC applied being given in the same bath and first FR application and then FC application, it can be said that there are substance residues on the fiber surface when the application is made in the same bath.



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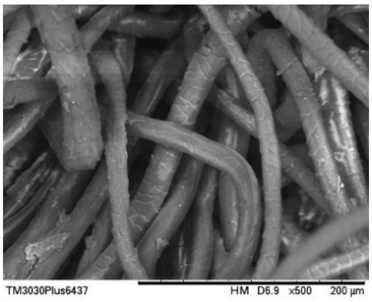

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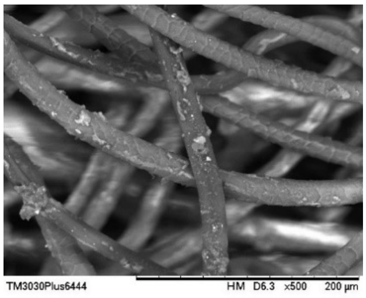

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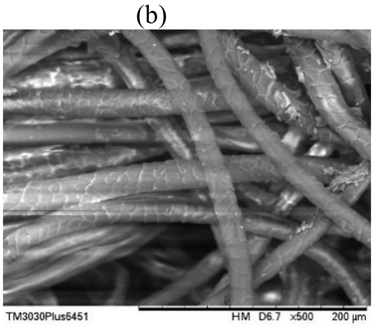

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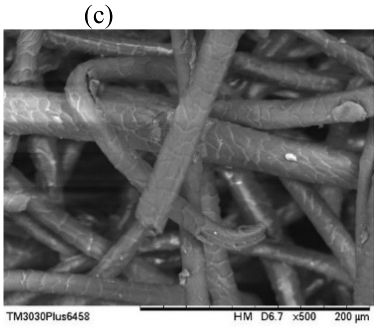

(e)

Figure 2. SEM images. (a) untreated fabric, (b) Fabric to which organic P-N compound and then FC polymer were transferred, (c) Fabric to which organic P-N compound and FC polymer were transferred in the same bath, (d) Fabric to which nonionic FC resin was applied, (e) Same fabric treated with uncharged alkyl phosphonate compound and FC polymer in the bath

3.2.FT-IR Analysis

After the water repellency and FR treatments applied to the fabrics, FT-IR measurements were made on both untreated fabrics and treated fabrics. The functional groups in the structure of wool and polyamide materials are similar to each other. When the FT-IR spectra of both fibers are examined, in the wool fiber 3394 cm^{-1} (N-H and O-H stretches), 2929 cm^{-1} (C-H stretches), 1650 cm^{-1} (amide I), 1511 cm^{-1} (N-H from amide II). bending), 1455 cm^{-1} (aromatic in the ring, C-C stretching), 1382 cm^{-1} (C-N stretching of amines), 1235 cm^{-1} (C-N stretching from amide III), 1069 cm^{-1} (C-O stretching) and N-H amines, In polyamide fabric, antisymmetric and symmetric stresses are 2928-2863 cm^{-1} (CH_2), 1647 cm^{-1} (C=O stretching, amide I), 1539 cm^{-1} (N-H deformation (from amide II) and C-N stretching vibrations), Peaks originating from 1459 cm^{-1} (CH_2 deformation), 1369-1118 cm^{-1} (amide III band indicates the presence of both C-N stretching and N-H bending vibrations) and 678-582 cm^{-1} (N-H amines) can be observed.

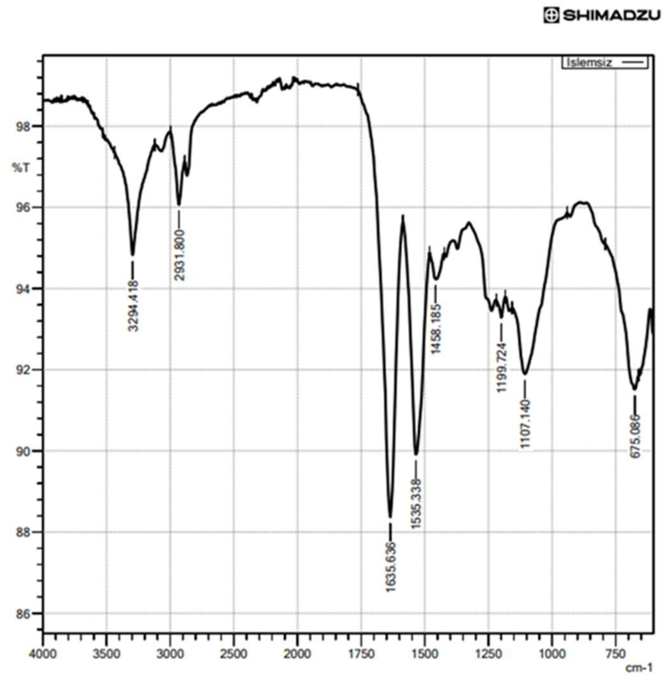

Figure 3. FT-IR graph of wool/polyamide fabric

When the FT-IR analysis taken from the Wool/Polyamide fabric structure used in the study, with pre-treatment and dyeing process applied and no finishing process applied, was evaluated (Figure 3), most of the peaks belonging to the wool/polyamide fabric structure were observed. In Figure 4, FT-IR measurements of fabrics with finishing treatment and untreated fabric are given in the same graph. In structures containing fluorocarbons, C-F bonds can give sharp peaks in the 1200-1300 cm^{-1} band. In the FT-IR graph of recipes number 2 and 3, peaks are evident at 1238-1234 cm^{-1}. In alkyl phosphonate structures, P=O stretching vibrations can peak at 1200 -1300 cm^{-1}. In structures containing organic phosphorus-nitrogen, P-N stretching vibrations can occur in the P-N bond range of 900-1100 cm^{-1}, and P=O stretching vibrations can occur in the range of 1200 - 1300cm^{-1}.

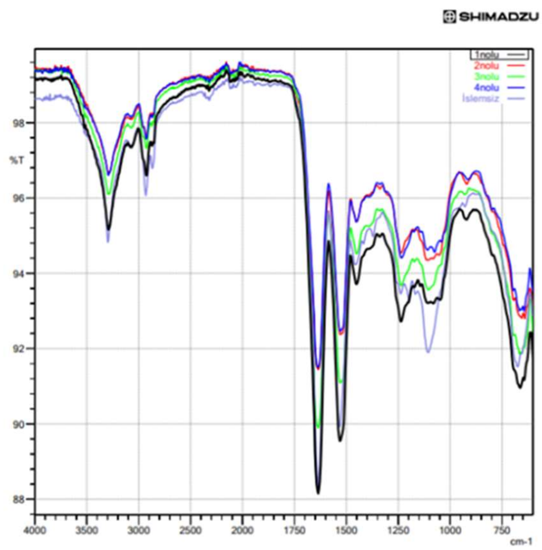

Figure 4. FT-IR graphs of wool/polyamide fabrics treated with four different recipes and untreated fabric.

3.3.Contact Angle Results

Untreated wool/polyamide fabric absorbs water completely. Contact angle values were high in fabrics treated with fluorocarbon polymer. Considering the highest and lowest contact angle values, a contact angle of 133 degrees was measured in the recipe 4 where FC polymer was used at 80 g/L concentration, while the angle value was measured as 106 degrees when 30 g/L FC polymer was used. The most important factor is the concentration of the fluorocarbon polymer applicated.

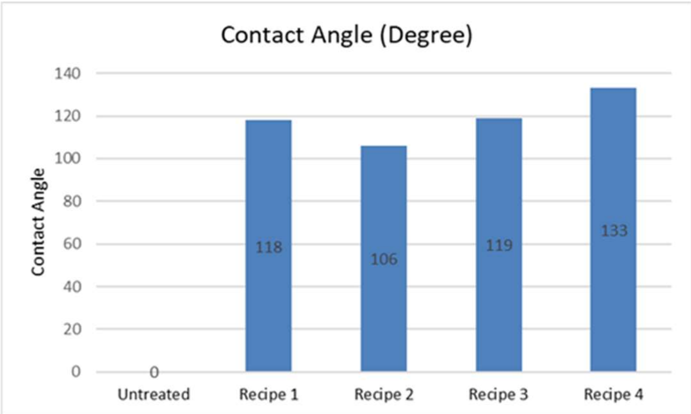

Figure 5. Contact angle results

3.4.Flame Retardent Results

One of the most important properties of the fabric to be used as upholstery is flame retardant. In order to delay the burning behavior of fabrics, organic phosphorus-nitrogen compounds and alkylphosphonate derivative chemicals have been applied. The amounts of chemicals used to delay combustion behavior are generally high. In this study, FR chemical was used at 400 g/L in the first and second recipes, and 100 g/L in the fourth recipe. FR chemical was not used in the second recipe. As a result of the burning test, all fabrics, including the untreated fabric, passed the burning test. The best results on fabrics were obtained by using P-N compound at a concentration of 400 g/L.

Table 3. Flame Retardents Test Results According to Burning Behaviour FMVSS 302

Burning Behaviour FMVSS 302 (Horizontal Test)	Burning Time (s)		Burning Length (mm)		Flame Spread Rate (mm/min)	
Requirements	< 60		< 50.8		< 101,6	
Fabric Direction	Warp	Weft	Warp	Weft	Warp	Weft
Untreated	18	23	20	20	0	0
Recipe 1	6	4	14	12	0	0
Recipe 2	1	1	10	10	0	0
Recipe 3	18	16	17	15	0	0
Recipe 4	3	1	12	10	0	0

*Flame Application Time 15 s

3.5. Thermal Insulation Properties

Thermal insulation properties of the fabrics were measured using the Alambeta device. The thermal conductivity value of fabrics varies between 41.8-45.4 W/mK x10^{-3}. Thermal conductivity value was lower in treated fabrics. In particular, applying water repellent treatment to fabrics may have prevented the fabric from absorbing ambient moisture, causing the conductivity to be lower. Thermal resistance may vary depending on fabric thickness and thermal conductivity ($r(m^2kW^{-1})= h(m)/ \lambda\ W^{-1}Km^2x10^{-3}$).

Table 4. Thermal Insulation Properties

	Thermal Conductivity (λ)	Thermal Absorptivity (b)	Thermal Resistivity (r)	Thickness (h)
Untreated	45,4	154	25,1	1,14
Recipe 1	43	135	33,9	1,46
Recipe 2	43,5	141	32,7	1,42
Recipe 3	42	138	34,2	1,44
Recipe 4	41,8	139	38	1,59

Since the thickness of the untreated fabric was lower than the treated fabrics, the thermal resistance was lower. Absorption value defines the heat perceived at first contact with the fabric. Fabrics with high thermal absorption value give a feeling of cold. Since thermal absorption ($Wm^{-2}s^{1/2}\ K^{-1}$) is a surface property, it can change with textile finishing processes. When the measurement results were evaluated, the thermal absorption value of the untreated fabric was higher than the absorption value of the treated fabrics.

4. CONCLUSIONS

Finishing processes have been applied to improve the structural properties of the wool/polyamide blend fabric and to provide it with multifunctional properties. The main purpose of these processes is to prevent easy contamination of this fabric structure used as upholstery and to increase its resistance to burning. Many recipes have been tried for this purpose. In these studies, chemical concentration, transfer of chemicals in the same bath or in separate process steps, process pH, drying and curing temperatures and time were examined as variables. The results reported here were selected among the recipes that gave the best values for the purpose.

5. REFERENCES

[1] FAİSAL ALLAFİ, & CO., Advancements in Applications of Natural Wool Fiber: Review., Journal Of Natural Fibers 2022, Vol. 19, No. 2, 497–512.
[2] I LENFELDOVA , L HES AND M ANNAYEVA., Thermal comfort of diving dry suit with the use of the warpknitted fabric, 48th Conference of the International Federation of Knitting Technologists (IFKT) IOP Publishing IOP Conf. Series: Materials Science and Engineering 141 (2016) 012009

[3] ELİF KAYNAK, MUSTAFA E. ÜREYEN, A. SAVAS KOPARAL, Halogen free flame retardant finishing of wool and wool rich fabrics for aircraft seats, MaterialsToday Proceedings, Volume 31, Supplement 2, 2020, Pages S258-S262.
[4] ELİF KAYNAK, MUSTAFA ERDEM ÜREYEN, ALİ SAVAŞ KOPARAL., Flammability and Thermal Degradation Behaviour of Wool/Polyamide 6.6 Blends, Journal of Textiles and Engineer, Vol 27, No 117, 2020/1
[5] ŞULE SULTAN UĞUR, NAZLI ÇAĞLAR CİNPERİ, AYŞE MERİH SARIIŞIK, Improving Washable Woolen Fabric by Using Layer-By-Layer Coating, Tekstil Ve Konfeksiyon, Vol: 33(2),2023.
[6]MAŁGORZATA CİEŚLAK https://orcid.org/0000-0001-9867-7789EWA GROMADZİŃSKA, AND KATARZYNA ŚLEDZİŃSKA., The impact of textile relief structures on pressure distribution and heat transport, Textile Research Journal, Volume 91, Issue 9-10, 2020.
[7] J. BACHMANN, R. HORTON, T. REN, AND R. R. VAN DER PLOEG., Comparison Of The Thermal Propertıes Of Four Wettable And Four Water-Repellent Soils, Published in Soil Sci. Soc. Am. J. 65:1675–1679 (2001).
[8] B. L. DEOPURA, R. ALAGİRUSAMY, M. JOSHİ AND B. GUPTA., Polyesters and Polyamides, The Textile Institute, Woodhead Publishing Limited, 2008.

INVESTIGATION OF RAW MATERIAL SOURCES EFFECT ON GREENHOUSE GAS EMISSIONS IN WOVEN FABRIC MANUFACTURING MILL

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ABSTRACT

Increasing greenhouse gas concentration causes environment pollution and global warming. Especially in the textile industry, the developing technology, the acceleration of industrial production, the increase in energy consumption and the greenhouse gases released as a result are undeniable large. Aim of this investigation, calculate and validate the direct and indirect emissions of the existing woven fabric production in an integrated textile operation. Then, the impact of innovative and sustainable raw material alternatives on the greenhouse gas emissions of the facility was investigated.

Key Words: Greenhouse gas, emissions, carbon, carbondioxide, textile emission

1. INTRODUCTION

The climate change we are experiencing globally is caused by human factors, an increase in greenhouse gases and particles in the atmosphere, depletion of the ozone layer, and the reckless destruction of the environment. As a result of the studies carried out under the leadership United Nations and international organizations to reduce the negative impact and pressure of humans on the climate, starting from the late 1980s, the United Nations Framework Convention on Climate Change was established in 1992, followed by the Kyoto Protocol in 1997, and the Paris Agreement in 2015. Comprehensive national development policies should be addressed in line with global goals, integration and the need for economic sustainability [1].

The textile industry is among the industries that contribute significantly to greenhouse gas emissions worldwide. These emissions occur in various stages, ranging from the production of raw materials for the sector to the textile product processes and logistics. The current literature on emission calculations in the textile industry has been reviewed within the scope of this study [2].

In recent years, carbon footprint research and application examples have been carried out for the textile industry. According to the carbon footprint research results of pure cotton shirts in the study conducted in China, the carbon footprint value of the average pure cotton shirt was obtained as 8,771 kgCO2. 0.347 kgCO2 is direct emission. Back the remaining and the majority were observed as indirect emissions [3]. In other study conducted in China, the carbon footprints of fabrics produced from pure wool and wool-polyester mixture were calculated as 14 kg-CO2e/kg-fabric and 13.5 kg-CO2e/kg-fabric [4]. In a study conducted in the USA, the carbon footprint of a polyester t-shirt was calculated as 7.1 kg-CO2e/t-shirt [5]. In the Marmara Region of Türkiye textile company -producing fabric and carpets- the total carbon footprint resulting from production in the company was calculated as 31.2 kg-CO2e/kg-fabric [6]. Herva et al., concluded that if the materials used in a textile factory producing jackets change with changing fashion, carbon footprint values may change over the years. It has been determined that the use of cotton and wool raw materials increases the total carbon footprint by 24.89% and 58.78%, respectively. It is stated that synthetic textile raw materials will have a lower carbon footprint [7]. The use of renewable, recycled and biodegradable materials as resources is of critical importance in the sustainability and efficiency studies of the textile industry. Recent studies indicate that the use of sustainable raw materials reduces greenhouse gas emissions. It is aimed to realize production with low emission values by using alternative sustainable raw materials and recycled raw materials with reduced environmental impact. It is predicted that the use of natural materials such as cotton, bamboo, hemp, pineapple fiber, as well as recycled raw materials, regenerated fibers (viscose, fashion, acrylic, lyocell, etc.) and polyester obtained by polymerization of lactic acid, such as poly lactic acid, will reduce the greenhouse gas emission effect.

The aim of the study is to calculate, validate and investigate the direct and indirect emissions of the existing woven fabric production in an integrated textile operation, as well as explore the impact of innovative and sustainable raw material alternatives on the facility's greenhouse gas emissions.

2. EXPERIMENTAL

The study is based on the following standards: TS EN ISO 14064-1 Greenhouse Gases - Part 1: Specification with Guidance at the Organization Level for Quantification and Reporting of Greenhouse Gas Emissions and Removals, TS EN ISO 14064-2 Greenhouse Gases - Part 2: Specification with Guidance at the Project Level for Quantification, Monitoring, and Reporting of Greenhouse Gas Emission Reductions or Removal Enhancements, and TS EN ISO 14064-3 Greenhouse Gases - Part 3: Specification with Guidance for the Validation and Verification of Greenhouse Gas Assertions [8, 9, 10]. Detailed field research has been conducted for greenhouse gas emission analysis in an integrated facility involved in woven fabric production. Data flow diagrams have been designed for greenhouse gas emission calculations, and greenhouse gas calculation inventories and annaul data have been prepared.

Figure 1. Entegrated Textile Mill

The calculations are based on the reference year 2021 for assessing the impact of emissions from raw materials, and an operational control approach has been followed. The verification process for the calculations has been carried out by the Turkish Standards Institute (TSE) with a reasonable level of confidence. All categories of the standard have been evaluated, except for the ones not applicable within the organizational boundaries, namely Category 1.3: Direct process emissions and removals from industrial processes, Category 1.5: Direct emissions and removals from land use, land-use change, and forestry activities, Category 4.4: Emissions from the use of leased equipment (by the organization), Category 5.4: Emissions from investments and Category 6: Indirect greenhouse gas emissions from other sources.

Carbondioxide emision of woven fabric dyeing and finishing processes are investigated from integrated textile mill in Ergene Region. In contrast to the previous revision of the standard, uncertainty and significance assessments have been completed, and the impact of using different raw materials and alternative sources in the textile industry on greenhouse gas emissions has been examined.

3. RESULTS

According to the study, the largest share in the facility's 2021 emission values is attributed to Category 5: Indirect greenhouse gas emissions from the post-production use of products with 62%; followed by Category 1: Direct greenhouse gas emissions and removals (CO2e) with 17%; Category 2: Indirect greenhouse gas emissions from imported energy with 11%; Category 4: Indirect greenhouse gas emissions from products used by the organization with 6%; and Category 3: Indirect greenhouse gas emissions from transportation with 4%. These calculations have been performed and verified.

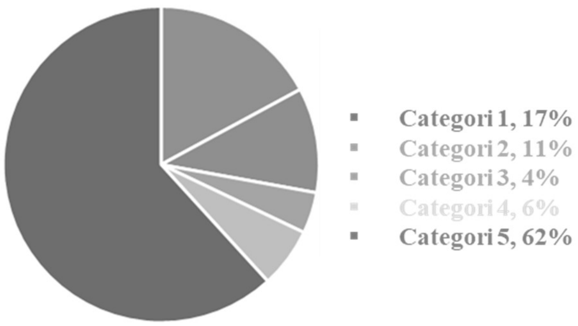

Figure 2. Facility emissions per category

4. CONCLUSION

The use of recycled raw materials in woven fabric production reduces process-related greenhouse gas emissions. Sourcing raw materials from the mentioned sources in the production process will contribute to a circular economy in resource consumption and also reduce greenhouse gas emissions in textile woven fabric production. The study encompasses the evaluation of the impact of alternative raw material usage based on verified facility data in the textile sector. All operations/processes associated with textile production, specifically the raw materials used in the fabric production line at the facility's location, have been examined. The comparison of calculations has been conducted to assess the impact of sustainable and/or recycled raw material usage on greenhouse gas reduction.

5. REFERENCES

[1] T.C. Ticaret Bakanlığı. (2021). Yeşil Mutabakat Eylem Planı 2021 (Green Deal Action Plan 2021). Available on https://ticaret.gov.tr/data/60f1200013b876eb28421b23/MUTABAKAT%20YE%C5%9E%C4%B0L.pdf

[2] Preffered Fiber & Materials Market Report, October 2022. Available on https://textileexchange.org/app/uploads/2022/10/Textile-Exchange_PFMR_2022.pdf

[3] WANG, C., WANG, L., LIU, X., DU, C., DING, D., JIA, J., YAN, Y., & WU, G. (2015). Carbon footprint of textile throughout its life cycle: A case study of Chinese cotton shirts. Journal of Cleaner Production, 108, 464–475. Available on https://doi.org/10.1016/j.jclepro.2015.05.127
[4] YAN, Y., WANG, C., DING, D., ZHANG, Y., WU, G., WANG, L., LIU, X., DU, C., ZHANG, Y., & ZHAO, C. (2016). Industrial carbon footprint of several typical Chinese textile fabrics. Acta Ecologica Sinica, 36(3), 119–125. Available on https://doi.org/10.1016/j.chnaes.2015.09.002
[5] KIRCHAIN, R., OLIVETTI, E., T REED MILLER,T., R., AND GREENE, S., 2015. Sustainable Apparel Materials An overview of what we know and what could be done about the impact of four major apparel materials: Cotton, Polyester, Leather, & Rubber", Materials Systems Laboratory Massachusetts Institute of Technology Cambridge, MA, 7 October 2015.
[6] KESKIN, S. S., ERDIL, M., SENNAROĞLU, B. 2017. Bir Tekstil Fabrikasının Kumaş Üretiminde Enerji ve Karbon Ayak İzlerinin Belirlenmesi. VII. Ulusal Hava Kirliliği ve Kontrolü Sempozyumu, 1-3 Kasım, Antalya, 95-105.
[7] HERVA, M., FRANCO, A., FERREIRO, S., A'LVAREZ, A., ROCA, E. 2011. An approach for the Application of the Ecological Footprint as Environmental Indicator in the Textile Sector. Journal of Hazardous Materials, 156(1–3), 478–487.
[8] TS EN ISO 14064-1 Sera Gazları – Bölüm 1: Sera gazı salımlarının ve uzaklaştırmalarının kuruluş seviyesinde hesaplanmasına ve raporlanmasına dair kılavuz ve özellikler, (2019). Turkish Standardization Institue on https://www.tse.org.tr
[9] TS EN ISO 14064-2 Sera gazları - Bölüm 2: Sera gazı salım azaltımlarının veya uzaklaştırma iyileştirmelerinin proje düzeyinde hesaplanması, izlenmesi ve raporlanmasına dair kılavuz ve özellikler, (2019). Turkish Standardization Institue on https://www.tse.org.tr
[10] TS EN ISO 14064-3 Sera gazları - Bölüm 3: Sera gazı beyanlarının doğrulanması ve geçerli kılınmasına dair özellikler ve kılavuz, (2019). Turkish Standardization Institue on https://www.tse.org.tr

DEVELOPMENT OF SUSTAINABLE CONVEYOR BELT FABRIC ALTERNATIVE TO RUBBER CONVEYOR BELTS

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ABSTRACT

In the project, the design of conveyor belt fabric woven with yarns with high tensile strength has been developed. Conveyor belts, which are widely used in the transportation sector, are aimed to the obtained by using high-strength yarns and different construction techniques. In this context, weaving machine process parameters (warp tension, warp beam tension), pattern design, and construction design studies were carried out. As a result of the studies, the strength tests of the product with optimum parameters were carried out. The breaking strength and elongation properties of the fabrics produced in optimum parameters for the conveyor belt fabric with high strength were tested according to the TS EN ISO 13934-1 standard, and the hot air shrinkage was tested according to the DIN EN 14621 standard.

Key Words: Conveyor belt, high strength, construction design

1. INTRODUCTION

Conveyor belt systems are transport equipment used to transport materials from one place to another in any facility [1]. These systems have advantages such as efficiency speed, long transportation distances, low energy consumption, operational safety, and simple operation and maintenance compared to other transportation vehicles [2]. In the research, it is seen that the transportation of materials in a convenient way in terms of energy, time, and money has a direct effect on the economy of the enterprise [3]. Due to the increase in the traffic density of the material flows of the production facilities, conveyor belts are accepted as the most efficient and effective solution preferred by enterprises both in terms of economy and ease of use [4].

Conveyor belts are producing from rubber today. Conveyor belts also can be produced from natural, isoprene, butadiene, styrene, butadiene, and rubber varieties [6]. These rubber materials, which have completed their useful life, bring along a serious waste problem. Today, many studies are carried out on the recycling of waste rubber, which is very difficult and laborious to recycle. In the study of Adhikari et al., cheap, non-toxic chemicals recycled from plant products have been developed for the recycling of waste rubbers [6].

It is noteworthy that the proportion of plastic and rubber wastes in the environmental pollution caused by humans around the world is high, and today, conveyor belts are preferred more in many areas such as loading, unloading, stockpiling, and taking from stock in the material transportation. Thus, usage rates increase, and conveyor belts that have expired cause environmental pollution. As a result of insufficient strength, rupture, puncture, tear, etc. damages can cause the end of their useful life. Damage to conveyor belts for any reason is considered a great risk, because it hinders production in enterprises as well as environmental pollution [7]. For this reason, the main expectance from the conveyor belts are high strength, long working life, and resistance to bending.

The aim of this study is to develop fabrics that can be used in the production of high-strength conveyor belts with different construction design studies. These fabrics will be produced on the weaving machine and will offer a more sustainable alternative to rubber conveyor belt production. In addition, thanks to its high strength, products with a high service life will be developed.

2. MATERIALS AND METHODS
2.1. Materials

Within the scope of the study, multifilament PES yarns with high strength and low dry air shrinkage, supplied by Akan İplik Company, were used. Yarns were woven in Sulzer brand weaving machine. The materials used in the study are given in Table 1.

Table 1. Properties of the yarns used in the study

Filament Type	Features
HTSLS	1000 denier / 192 filament
Bicomponent (carbon+nylon)	1050 denier / 193 filament

2.2. Methods

Within the scope of the study, multifilament polyester yarns with high strength and low dry air shrinkage will be woven in Sulzer brand weaving machines. The work plan created within the scope of the study is given in Table 2.

Table 2. Work Plan

Experiment Number and Name	Experiment
1. Design studies	Determination of pattern design with EAT software
2. Process Parameters	1. Warp Tension
	2. Beam Tension
3. Construction Design Studies	1. Warp Yarn
	2. Weft Yarn
	3. Warp-weft density
	4. Fabric Type

3. RESULTS AND DISCUSSION

In order to develop high-strength and anti-static fabrics produced according to this study plan, it was preferred to use plain weave type, which is a unique construction weave. As a result of the experimental study, the tensile strength, weight determination, hot air, skewness, and bow fabric tests were performed and the sample performances were evaluated. TS EN ISO 13934-1.2013 standards were used to determine the breaking strength and elongation properties of the produced sample. The test results performed according to this standard are shown in Table 3.

Table 3. Tensile Strength Test Results

Sample Number	Tensile Strength (N/S cm) (TS EN 13934-1:2013)		Elongation at Break (%) (TS EN ISO 13934-1:2013)	
	Warp	Weft	Warp	Weft
1	≥4300	≥1500	≥20	≥20
2	≥3900	≥1400	≥20	≥20
3	≥4700	≥3000	≥20	≥20
4	≥5700	≥1000	≥20	≥20

The weights of the produced samples were measured according to the UNI 5114 standard. Test results are shown in Table 4.

Table 4. Weight Measurements

Sample Number	Weight (gsm) (UNI 5114)
1	270 (±5%)
2	270 (±5%)
3	350 (±5%)
4	565 (±5%)

The hot air shrinkage test of the fabric samples produced was measured according to the DIN EN 14621 standard. Test results are given in Table 5.

Table 5. Hot Air Shrinkage Test Results

Hot Air Shrinkage Test (180 C 15 mins) (%) (DIN EN 14621)	
Warp	Weft
2,5	1,5
2,5	1,5
2,5	2,5
2,5	

The skewness and bow fabric tests of the fabric samples produced were measured according to ASTM D 3882-2008 standards. Test results are given in Table 6.

Table 6. Skewness, Bow Fabric Test Results

Skewness (%) (ASTM D 3882:2008)	Bow Fabric (%) (ASTM D 3882:2008)
0± 3	0± 3
0± 3	0± 3
0± 3	0± 3
0± 3	0± 3

According to the test results applied to the fabrics woven in different constructions, trial No. 1 can be used for belts made for conveying systems generally, Trial No. 2 is expected to provide static electricity resistance in the conveying systems, Trial No. 3 is used for bands with the expectation of flexibility in the direction of width in conveying systems, and Trial No. 4 shows that it can be used in power transmission elements in machines.

4. REFERENCES

[1] SOLAK, A. Design of belt conveyor for coal mines and optimization of design parameters. Institute of Science Technology, thesis, 2017.
[2] FICZERE, P., ULTMANN, Z., and TÖRÖK, A., Time-space analysis of transport system using different mapping methods," *Transport*, vol. 29, no. 3, pp. 278–284, 2014.

[3] DEMIR, M. Yüksek sıcaklıkta çalışan bantlı konveyörler. Yıldız Teknik Üniversitesi Fen Bilimleri Fakültesi, 2006.
[4] L., P., ALVIARI, M., F., ANGGAMAWARTI, Y., SANJIWANI, V., Y., RISONARTA, ‘‘Classification of Impact Damage on A Rubber-Textile Conveyor Belt: A Review, International Journal of Mechanical Engineering Technologies and Applications, no. 4, pp. 21-27, 2020.
[5] H., SAVRAN, Elastomer teknolojisi-I, Acar Matbaacılık, İstanbul.
[6] B., De., D., ADHİKARİ, S., MAİTİ, Reclamation, and recycling of waste rubber, Progress in Polymer Science, 25, 909-948.
[7] G. FEDORKO et al. ‘‘Failure analysis of conveyor belt samples under tensile load’’, Journal of Industrial Textiles, vol. 48(8), 1364-1383, 2019. doi: 10.1177/1528083718763776.

SLOW FASHION AND MODULAR DESIGN: IMPROVE SUSTAINABILITY AND VERSATILITY IN TEXTILE PRODUCTS

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ABSTRACT

In recent years, textile design has become a focal point in the textile and apparel industry, with professionals creating designs that prioritize visuality, including fabric, color, pattern, accessory, and more. However, the ever-changing and increasing needs of consumers have also led to the spread of fast fashion. This increase in demand has also caused diversity in textile designs. This study explores textile and garment designs from various perspectives, focusing on visuality and the production of sustainable products that offer alternative options for consumers. Thus, within the scope of sustainable fashion, designers create versatile designs that individuals can wear and use in different ways. Reducing environmental damage, increasing sustainable production, and promoting slow fashion are the objectives of this study.

Key Words: Modular clothes, sustainable fashion, functional clothing, slow fashion

1. INTRODUCTION

Garment production is one of the leading sectors that produce environmental pollution. The increasing population and fast fashion have caused a rapid increase in production and consumption [1]. Short-term or long-term changes in apparel create fashion trends, and these trends have increased consumption and introduced the concept of fast fashion. [2]. The term fast fashion means continuous production, which is carried out to meet the needs of consumers who want to wear new and different products. Consumers always want to wear new garments, along with manufacturers' ambition to produce and profit, which results in rapid resource consumption and environmental damage. [3].

Sustainability is essential for the textile and fashion industry, which is one of the most important consumer industries serving people's clothing, protection, and dressing needs. Various approaches are being developed to mitigate the negative environmental effects of fast consumption and increase awareness of sustainable production, such as pattern designs that do not waste fabric, modular pattern applications, timeless designs, and longer product use [4]. Slow fashion encourages sustainability by emphasizing factors other than material use and production [5]. Although the use of sustainable methods is instructive, the production of sustainable products is costly. To solve this, it aims to design products that allow multi-purpose and long-term use.

Modular design comes into effect when the body measurements used by different companies in different nations do not conform to a single standard [6, 7]. Modular designs allow not only a change in how products are used but also the use of individuals of different ages, genders, and body sizes. With modular designs, it is aimed that individuals with different body sizes living in the same house can use a single outfit in different ways. Thus, it will be possible to produce sustainable products by contributing to the environment and using the products for a long time in different functions.

2. MATERIAL AND METHOD

In this study, 100% cotton fabric with a weight of 420 g/m2 and 5 g metal zippers were used for modular designs. The fabric colors selected for the collections were not based on features such as age, gender, or size. The selected metal accessories were chosen for their suitability with the designs and ability to provide user comfort. Trend analyses for design ideas were performed in the preliminary study, and how they could be employed in product groups within the company was studied. The design process began with sketches based on the research findings. Accessory research was also carried out to ensure suitability with the selected designs. The patterns were created using 2D software, ensuring that they were wearable, suitable for the company's product groups, and not dependent on factors such as age, gender, and size. Since the designs are aimed to be used regardless of gender, age, and size, they have been developed for the use of at least two people. Browzwear V-Stitcher software was used in this study's digital sample production process. The 3D productions used 301-SN and 406 1/8"gg DNTS sewing techniques. Heat maps were used in the design process of the models to ensure user comfort.

3. RESULTS AND DISCUSSION

Modular design 1: Hoodie

The hoodie designed in Figure 1 and Figure 2 consists of a single module. A zipper is used in the hoodie. The hoodie depicted in Figure 1 is designed for both men and women, with a focus on user comfort, as indicated by the heat map.

Figure 1. Model 1 hoodie first alternative usage and heatmap

Figure 2. Model 1 hoodie second alternative usage and heatmap

In Figure 2, the zipper's opening is designed for women's use, offering a different way of wearing the hoodie. The heat map has been used to ensure user comfort.

Modular design 2: Sweatpant

The sweatpant designed in Figure 3 and Figure 4 consists of three modules. A zipper allows the model's pieces to be connected and separated. Additionally, there is a front zipper to adjust the body size. Figure 3 features a model designed for both men and women, with attention to user comfort, as indicated by the heat map.

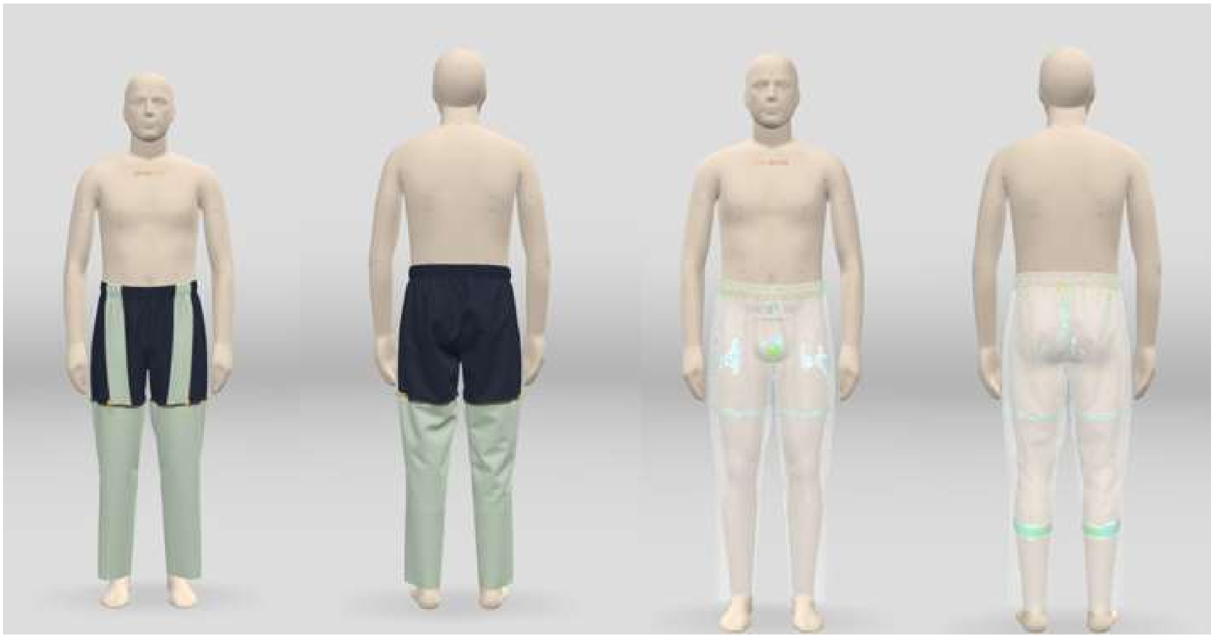

Figure 3. Model 2 sweatpant first alternative usage and heatmap

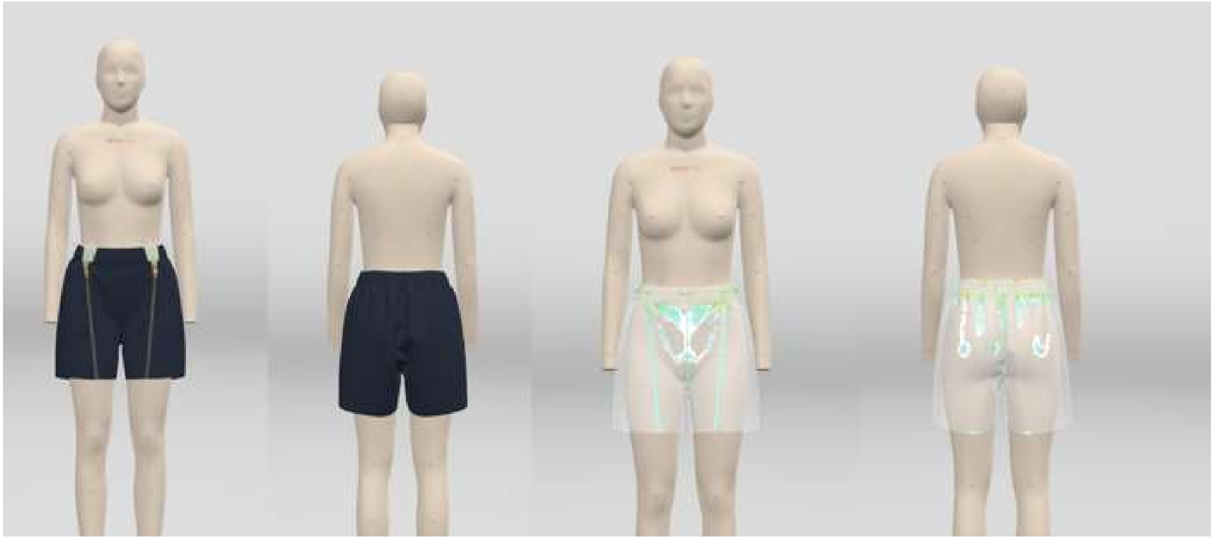

Figure 4. Model 2 sweatpant second alternative usage and heatmap

Figure 3's sweatpants model can also be converted into shorts, making it suitable for use by both men and women. Pulling the front zippers reduces its size. The design also accommodates use by women and children. Considering the heat maps, the designs provide comfort features.

4. CONCLUSIONS

The modular designs produced are innovative and environmentally friendly products suitable for individuals of varying ages, genders, and body sizes. These designs enable a single product to be utilized in various creates and for an extended period. With its modular usage, a range of slow fashion-inspired sustainable clothing goods was obtained, providing at least twice the use of similar products produced using traditional methods.

5. REFERENCES

[1] ALTINBAŞ, G. N., & CAN, D. İ. Sürdürülebilirlik Temelinde Bedensiz ve Dönüşebilen Kıyafetler.
[2] ERTÜRK, N. (2011). Moda kavramı, moda kuramları ve güncel moda eğilimi çalışmaları. Art-e Sanat Dergisi, 4(7), 1-32.
[3] YÜKSEL, B. H. G. C. Moda Sektörünü "Yavaşlatan" Eğilim: Eko Moda ve Moda'da Sürdürülebilirlik. Akdeniz Sanat, 4(8).
[4] ESER, B., ÇELIK, P., ÇAY, A., & AKGÜMÜŞ, D. (2016). Tekstil Ve Konfeksiyon Sektöründe Sürdürülebilirlik Ve Geri Dönüşüm Olanaklari. *Tekstil ve Mühendis*, *23*(101), 43-60.
[5] LANGDOWN, A. (2014). Slow fashion as an alternative to mass production: A fashion practitioner's journey. Social Business, 4(1), 33-43.
[6] CHUN-YOON, J., & JASPER, C. R. (1993). Garment-sizing Systems: An International Comparison. International Journal of Clothing Science and Technology, 5(5), 28-37.
[7] CHUN, J. (2014). International apparel sizing systems and standardization of apparel sizes. In Anthropometry, apparel sizing and design (pp. 274-304). Woodhead Publishing.

HEMP AND COTTON AS NATURAL FIBER

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Abstract

The quantity of production and consumption of synthetic fibers has exceeded the value of natural fibers in recent years. On the other hand, sustainability has also started to gain importance worldwide, and with this concept, the search for sustainable raw materials in textiles has begun. While the issue of recycling has come to the fore for the most consumed polyester fibers in the world, the concept of environmentally friendly fiber has come to the fore in all stages, from production to use in terms of natural fibers. In this respect, hemp fibers have been one of the most emphasized fibers as an environmentally friendly vegetable fiber in recent years. In textile production, cotton fiber is the most used natural fiber globally. Thus, cotton fiber and hemp fiber were compared in this study.

Keywords: Hemp, cotton, sustainability, natural fiber

1. INTRODUCTION

Cotton is a natural fiber that grows well in several climates and can be harvested easily. However, cotton cultivation needs a high amount of water consumption and using pesticides, so it is not sustainable. Organic cotton is generally less environmentally destructive than conventional cotton, primarily since organic cotton does not use any pesticides.

With the concept of sustainability gaining importance worldwide, the textile industry started to attract more attention because the textile industry is one of the most polluting industries in the world. Depending on the increase in environmental problems worldwide, the methods of obtaining textile raw materials have also become important. Accordingly, the search for a more environmentally friendly textile fiber has begun.

Therefore, in this study, among the fibers that are the raw materials of textiles, cotton fibers, which have been considered white gold for many years due to both production and consumption, will be compared with hemp fibers, which have been popular in recent years.

The global hemp fiber market grew from $7.94 billion in 2022 to $10.94 billion in 2023 at a compound annual growth rate of 37.9% and is expected to grow to $36.21 billion in 2027 at a compound annual growth rate of 34.9% according to a last study [8].

Hemp has several environmental benefits, such as carbon storage, breaking the cycle of diseases, soil erosion prevention, biodiversity, and low or no use of pesticides [13].

Cotton and Hemp Cultivation

Cotton is a strategic crop cultivated in nearly all tropical and subtropical regions worldwide. Since cotton salt-tolerant and drought-tolerant, cotton is a tempting crop for arid and semi-arid regions. According to the latest report, Global Cotton Market is expected to reach US$ 46.56 Billion by 2027, with a compound annual growth rate of 2.74% from 2020 to 2027 [9].

An eco-fiber market report mentioned that the global eco-fiber market size was estimated at USD 43.07 billion in 2022. In terms of sustainability, an increase in organic cotton production is expected in the eco-fiber market. The organic fiber market is expected to grow rapidly [11].

China, India, and the United States are expected to lead cotton production in 2023/24, according to a U.S. Department of Agriculture (USDA) report, and the forecast for World cotton production is 115.7 million bales [10].

Industrial hemp can be grown in a wide variety of soil types. Hemp prefers well-drained soil with a pH of 6 or more with good moisture and nutrient-holding capacity. Hemp is best adapted to well-drained soil with a pH between 6.0 and 7.0. In addition, it is not recommended for wet soils or those with a heavy clay content for hemp growing [12].

Although hemp fiber is one of the oldest vegetable fibers, its cultivation has been restricted since the 1950s due to its narcotic features. Therefore, its cultivation has decreased considerably over time. However, flax and hemp cultivation continued to exist in Europe. With the introduction of the concept of sustainability into our lives, the cultivation of eco-friendly industrial hemp has gained importance and started to increase gradually.

Today, hemp is produced in Asia-Pacific, Western Europe, Eastern Europe, North America, South America, the Middle East, and Africa. Asia-Pacific was the largest region in the hemp fiber market in 2022, according to Report [8].

Hemp vs. Cotton Fiber Properties

Hemp and cotton, both vegetable fibers, differ in their cellulose and other substance contents and the region from which the plant is obtained (Table 1) [1].

Table 1. Chemical composition and mechanical properties of cotton and hemp fibers. [1]

	Cotton fiber	**Hemp fiber**
Origin of plant fibers	Seeds fibres	Bast fibers
Cellulose (%)	82.20-90.00	70.20-74.40
Lignin (%)	-	3.70-5.20
Hemicellulose (%)	3.00	17.90-22.40
Pectin (%)	-	0.90
Wax (%)	0.60	0.80
Moisture (%)	7.85-8.50	6.20-12.00
Ash (%)	-	0.80
Microfibrillar angle (°)	-	2.00-6.20
Density (g/cm^3)	1.48-1.60	1.40-1.50
Elongation at break (%)	2.00-10.00	1.00-4.00
Tensile strength (MPa)	287-800	270-1110
Elastic modulus (GPa)	5.50-13.00	3.00-90.00

Cotton is the highest-produced natural fiber. However, its cultivation needs intensive water consumption and chemicals such as pesticides and fertilizers [2, 3, 4]. The production of fiber must be less harmful to the environment and economical. Duque Schumacher et al. (2020) compared to cotton and hemp fibers. They used four data for comparison: fertilization costs, seed costs, water consumption, and pest control costs. They used these costs and fiber yield to estimate final fiber production in USD per metric ton. According to their result, industrial hemp fiber was better than cotton regarding economic and environmental friendliness.

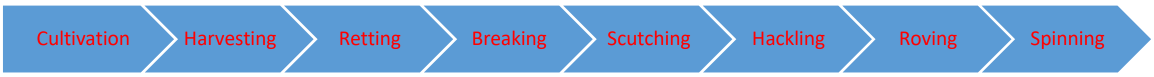
According to cotton, hemp as a crop has some advantages [5]. After 3-4 months from planting, hemp is ready to be harvested [6]. When compared to the ecological footprint of both fibers, hemp fiber has lower values (1.46 - 2.01 gha) than cotton fiber values (2.17 - 3.57 gha) [2, 7].

On the other hand, there are two different types of fibers in hemp, primary and secondary fibers, and primary fiber cells, and the fiber bundles they form are the fibers used in textiles. As the stalk gets thick, the secondary fiber ratio increases. It reduces the spinnability and economic return of hemp fiber.

Usage Areas of Cotton and Hemp Fiber

Cotton is the most used natural fiber in the world. Cotton fiber can be easily blended with other fibers for spinning. The conventional cotton and hemp yarn production steps are given in Figure 1. Compared to hemp fiber, production steps in textiles are easier. The global cotton yarn market is projected to grow from $82.81 billion in 2023 to $100.68 billion by 2028 at a compound annual growth rate of 4.0% during the forecast period [14].

Conventional cotton yarn production steps



Conventional hemp yarn production steps

Figure.1 Conventional cotton yarn production steps and conventional hemp yarn production steps.

All kinds of garments, home textiles, and upholstery fabrics are produced with cotton fiber, hemp fiber, and blend with other fibers. Since hemp fiber is very durable and has less elongation, it has been preferred for rope production throughout history. In addition, since hemp fiber is very durable, it is preferred to be used in producing composite products.

Hemp fiber is attracting attention for producing breathable and biodegradable products for the textile industry. The global industrial hemp market volume was over USD 205 million in 2020 and is forecast to grow at over 6% at a compound annual growth rate between 2021 and 2027 [15].

2. CONCLUSION

The short-fiber spinning method used in spinning cotton fiber is the world's most common and well-known spinning method. Hemp fiber can be processed by long-staple spinning, short-staple spinning, and conventional hemp spinning processes. In addition, both fibers are used in the production of nonwovens. However, cotton is easier to harvest, get fiber, and spin into yarn than hemp.

Both hemp and cotton are our natural raw materials used in textiles. Both have their unique features. The regions where they are grown differ, so it is necessary to work on environmentally friendly production methods for both economic development, utilization of agricultural lands as much as possible, and sustainable natural raw materials.

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3. REFERENCES

[4] CHOKSHI, S., PARMAR, V., GOHIL, P., CHAUDHARY, V. Chemical Composition and Mechanical Properties of Natural Fibers, Journal of Natural Fibers, 2022, 19:10, pp.3942-3953, DOI: 10.1080/15440478.2020.1848738

[5] DUQUE SCHUMACHER, A.G., PEQUITO, S., PAZAOUR, J.SURNAME, N. Industrial hemp fiber: A sustainable and economical alternative to cotton. Journal of Cleaner Production, 2020, 268, 122180, https://doi.org/10.1016/j.jclepro.2020.122180.

[6] FRANCO, M.A., Circular economy at the micro level: a dynamic view of in-cumbents' struggles and challenges in the textile industry. J. Clean. Prod. 2017, 168, 833e845. https://doi.org/10.1016/j.jclepro.2017.09.056SURNAME,

[7] SANDIN, G., PETERS, G.M., Environmental impact of textile reuse and recycling - a review. J. Clean. Prod. 2018, 184, 353e365. https://doi.org/10.1016/ j.jclepro.2018.02.266

[5] https://hempfoundation.net/a-comparative-of-hemp-fiber-and-cotton-fiber/ (online available 25.07.2023)

[6] https://sustainabilityscout.com/hemp-fabric-vs-cotton-and-bamboo-how-sustainable-is-it/ (online available 25.07.2023)

[7] CHERRET, N., BARRET, J., CLEMETT, A., CHADWICK, M., CHADWICK, M.J. Ecological Footprint and Water Analysis of Cotton, Hemp and Polyester. BioRegional Development Group and WWF Cymru, 2005, Stockholm Environment Institute, ISBN 91 975238 2 8.

[8] Hemp Fiber Global Market Report 2023, Report ID: 6317642, Publish Date: March 2023. https://www.reportlinker.com/p06317642/Hemp-Fiber-Global-Market-Report.html (online available 25.08.2023)

[9] Global Cotton Market & Volume by Consumption, Production, Export, Import Countries, Companies, Forecast, Report ID:5265146, February 2021. https://www.researchandmarkets.com/reports/5265146/global-cotton-market-and-volume-by-consumption (online available 25.08.2023)

[10]https://www.ers.usda.gov/webdocs/outlooks/106526/cws-23e.pdf?v=2306.5#:~:text=World%20cotton%20production%20in%202023,are%20projected%20to%20increase%20production. (online available 25.08.2023)

[11] Eco Fiber Market Size, Share & Trends Analysis Report By Product (Organic, Manmade/Regenerated, Recycled) By Application (Textiles/Apparel, Industrial, Medical), By Region, And Segment Forecasts, 2023 – 2030, Report ID: GVR-1-68038-977-7, https://www.grandviewresearch.com/industry-analysis/eco-fiber-market (online available 25.08.2023)

[12]https://rize.tarimorman.gov.tr/Haber/392/Kenevir-Bitkisi#:~:text=TOPRAK%20VE%20%C4%B0KL%C4%B0M%20%C4%B0STE%C4%9E%C4%B0&text=%C4%B0yi%20nem%20ve%20besin%20madde,drenaj%C4%B1%20olan%20topraklar%20tavsiye%20edilmez. (online available 25.08.2023)

[13]https://agriculture.ec.europa.eu/farming/crop-productions-and-plant-based-products/hemp_en (online available 25.08.2023)

[14] https://www.fortunebusinessinsights.com/cotton-yarn-market-107241(online available 25.08.2023)

[15] https://www.gminsights.com/industry-analysis/industrial-hemp-market (online available 25.08.2023)

ANTIBACTERIAL PROPERTIES OF NEEDLE-PUNCHED NONWOVENS FOR MEDICAL APPLICATIONS

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ABSTRACT

Wound healing is a complex and dynamic process that includes biochemical and physiological events, in which harmonious steps continue sequentially for tissue repair to be effective. One of the biggest problems that delay or prevent the healing of the wound is the deterioration of bacteria and microorganisms in wound formation. In this study, nonwoven wound dressings were developed, and their properties were examined to achieve the stated effects. The results of the analysis showed that these structures would be an ideal structure as an absorbent layer in composite wound dressings used for wounds with high exudates.

Key Words: Needle punching, medical textile, chitosan, antibacterial textile

1. INTRODUCTION

The skin, which consists of 3 layers: epidermis, dermis and subcutis, is known as the largest organ of our body after the skeletal system. Skin takes an active role in many issues such as regulating body temperature, protecting the body from physical and chemical effects, preventing water loss, helping respiration and excretion, and removing static electricity from the body [1]. It is defined as the temporary or complete loss of the physiological properties of the tissues because of the disruption or destruction of the integrity of the skin or subcutaneous tissues due to biological, physical, and chemical reasons [2]. Wound healing; is a complex process consisting of four stages: hemostasis, inflammation, proliferation, and remodeling, which begins immediately after injury and can continue for up to 2 years [3,4,5].

It is known that the history of wound care is as old as human history. In the past, it was aimed to absorb the wound exudate, to keep the wound dry, and thus to prevent the growth of bacteria, with linen, gauze and cotton materials used in wound care with herbs and vegetable oils and products. However, today it is known that heat and humidity are directly proportional to wound healing, and that the restructuring of cells in the tissues accelerates when there is sufficient heat, humidity, and oxygen [6,7,8]. For this purpose, although the wound dressings used today can be produced with weaving, knitting and spacer techniques, nonwoven surfaces come to the fore as they are more homogeneous, softer, and more flexible than these structures [9]. Nonwoven surfaces produced with web from combs and mechanical fixation with needles play an important role in wound treatment in terms of their contribution to the healing process by absorbing the exudate from the wound and preventing the risk of infection. Nonwoven wound dressings produced by this method do not contain any additives and, due to their structure, create a soft, bulky, porous, absorbent, and stable environment that can breathe air into the wound and provide comfort to the wearer. This provides a great advantage in medical use. In this research study, nonwoven surface structures were produced by using viscose fibers, known for their absorbent properties, and chitosan fibers due to their absorbent and antibacterial effects, to form an absorbent layer on the wound dressing. Thickness, weight, and air permeability analyzes were performed to evaluate the comfort properties of the produced structures, hydrophilicity analysis to determine the absorbency properties and antimicrobial textile tests were carried out with the AATCC 100 test method to determine the antibacterial properties.

2. EXPERIMENTAL

2.1. Materials and Method

Viscose fibers with water/sweat, exudate absorption, comfort and comfort properties and chitosan fibers with both hydrophilic and bacteriostatic properties used in the study were obtained from Ege University Textile Engineering Nonwovens Department.

Nonwovens were produced by obtaining web from combs and mechanical fixation with needles. Within the scope of the study, chitosan fibers were mixed with viscose fibers at rates of 10%, 20%, 30% by mass. It is also produced on 100% viscose and 100% chitosan nonwovens. The machine parameters worked during this production are given in Table 1 below.

Table 1. Needle-punched Process Parameters

Needle-punched process parameters	Value
Folding tape speed (m/min.)	3
Traction belt speed (m/min.)	5
Feeding belt speed (m/min.)	2
Needle immersion depth (cm.)	0.5-1.0

2.2. Characterization

Weight measurement according to TS 29073-1 standard, thickness measurement in 20 cm^2 area under 200 Pa pressure, according to TS 7128 EN ISO 5084 standard, air permeability from 20 cm^2 area under 100 Pa pressure, according to TS 391 EN ISO 9237 standard, antibacterial analysis Staphylococcus aureus, Escherichia coli, Klebsiella pneumoniae and Vancomycin-Resistant Enterococci bacteria were performed according to the AATCC 100 standard, and hydrophilicity analyzes were performed according to the AATCC 79 standard.

3. RESULTS AND DISCUSSION

3.1. Thickness and Weight Analysis Results

The average thickness and area density of the produced needling nonwovens are given in Figure 1.

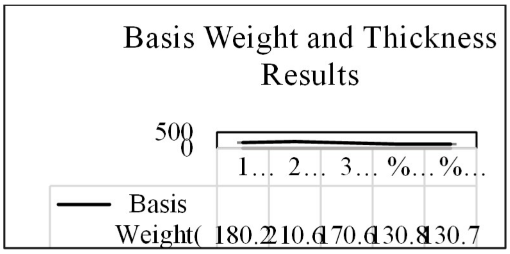

Figure1. Basis Weight and Thickness Results

3.2. Air permeability Analysis Results

There is a directly proportional between air permeability and breathability. Wound dressings with high air permeability accelerate the healing process by allowing gas passage. According to the results given in Table 2, it is seen that the produced 5 surfaces have sufficient air permeability.

Table 2. Air permeability measurement results

Samples	%100 CV	10\90 CHIT\CV	20\80 CHIT\CV	30\70 CHIT\CV	%100 CHIT
Air Permeability (l/m²/s)	1191	1569	1077	1067	1017

3.3. Hydrophility Analysis Results

When the hydrophilicity results given in Table 3 are examined, it can be said that all 5 surfaces produced have hydrophilic properties, but the increase in the amount of chitosan in the structure prolonged the absorption of the liquid dripped onto the surface.

Table 3. Hydrophility measurement results

Samples	%100 CV	10\90 CHIT\CV	20\80 CHIT\CV	30\70 CHIT\CV	%100 CHIT
Time (s)	0	0	0	0,23	1,01

When the literature is examined, it has been reported that chitosan is more hydrophilic than viscose. However, chitosan has a structure containing repetitive functional groups containing two hydroxyls and one amino due to its structure. The presence of surface functional groups made chitosan a pH sensitive material. In addition, chitosan exhibited hydrophobicity at higher pH values, while resulting in a more hydrophilic nature at low pH values, as a function of the protonation intensity of amino groups in the acidic environment [10]. In addition, surface contamination of chitosan may explain its less hydrophilic nature than viscose.

3.4. Antibacterial Analysis Results

Antibacterial analysis was performed with Staphylococcus aureus, Escherichia coli, Klebsiella pneumoniae and Vancomycin-Resistant Enterococci. Samples with 100% viscose content were accepted as control samples. The antibacterial analysis results applied to the needling surfaces at the end of the 24-hour contact period are given in Table 4.

Table 4. Antibacterial analysis results

Samples	S.aureus Decrease (%)	E.coli Decrease (%)	K.pneumoniae Decrease (%)	Vancomycin-Resistant Enterococci Decrease (%)
10/90 CHIT/CV	27,08	28,82	27,85	20,16
20/80 CHIT/CV	99,85	82,37	67,11	68,55
30/70 CHIT/CV	99,98	23,55	28,19	62,10
%100 CHIT	99,98	70,39	86,68	66,45

The use of 20% or more chitosan against S. aureus bacteria resulted in a 99% reduction in bacteria compared to the control sample. 20/80 chitosan/viscose mixture and 100% chitosan samples showed the best results against Escherichia coli, Klebsiella pneumoniae and Vancomycin-Resistant Enterococci bacteria.

4. CONCLUSIONS

Needle-punched nonwoven surfaces can be produced with sufficient thickness and area density, which is important in terms of protecting the injured area from external factors. The air permeability of the produced structures will contribute to the healing process by allowing oxygen and gas to pass to the wound. It has hydrophilic properties on all 5 surfaces produced, which shows that the surfaces have a structure that will allow them to absorb wound exudate. Antibacterial analysis results show that the produced structures prevent bacterial growth. According to the results of all the analyzes carried out, it has been shown that the developed needle-punched nonwoven surfaces will be an ideal structure as an absorbent layer in composite wound dressings used for wounds with high exudates.

ACKNOWLEDGEMENT

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5. REFERENCES

[1] ARAS, S., Yara Nedir? Tipleri, Evrelendirme, [cited 08.04.2020]. Available on http://hmyo.ankara.edu.tr/wp-content/uploads/sites/438/2019/03/Yara-Nedir-Tipleri.pdf.
[2] MUTLU, S. and YILMAZ, E. Yara Yönetiminde Yenilikçi Yaklaşımlar, Gümüşhane Üniversitesi Sağlık Bilimleri Dergisi, 2019, 8(4), 481-494.
[3] NURSAL, T. Z., BAYKAL, A. and HAMALOĞLU, E. Yaşlılarda yara iyileşmesi: Fark var mı, Turk J Geriatr, 1999, 2, 29-32.
[4] PARSAK, C. K., SAKMAN, G., ÇELIK, Ü. Yara iyileşmesi, yara bakımı ve komplikasyonları, Arşiv Kaynak Tarama Dergisi, 2007, 16(2), 145-159.
[5] VARLI, M. Yara iyileşmesinin fizyolojisi ve iyileşme fazları, [cited 08.04.2020]. Available on http://hmyo.ankara.edu.tr/wp-content/uploads/sites/438/2019/03/Yara-iyile%C5%9Fmesi-fizyolojisi-ve-iyile%C5%9Fme-fazlar%C4%B1.pdf.
[6] DAUNTON C., KOTHARI S., SMITH L. and STEELE D. A history materials and practices for wound management, Wound Practice and Research, 2012, 20(4), 174- 185.
[7] DHIVYA S., PADMA VIJAYA V. and SANTHINI E. Wound dressing-a review, Biomedicine, 2015, 5(4), 24-28.
[8] MIRANDA O.J. and SRINIVASAN G. Advanced trends in treatment of wounds, Current Science, 2016, 111(4), 641-647.
[9] ERDEM, R. Advances in fabric structures for wound care, In Advanced Textiles for Wound Care, Woodhead Publishing, 2019, 509-540.
[10] de ALVARENGA, E. S. Characterization and properties of chitosan, Biotechnology of biopolymers, 2011, 91, 48-53.

DESIGN AND DEVELOPMENT OF A JACQUARD FABRIC FOR ZERO-WASTE GARMENTS

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ABSTRACT

We live in a time when waste is increasing and becoming a growing problem. Zero-waste is becoming an increasingly important issue in the fashion world, as the fashion industry is one of the top three polluters in the world. The goal of the research was to combine jacquard weaving techniques and zero-waste design. By analyzing the garment cut, we determined the layout of the jacquard pattern and defined the areas with elastane yarns. We produced a garment with minimal waste according to the zero-waste principle of garment production, which considers sustainable principles in addition to the digitalization of the process.

Key Words: zero-waste, jacquard weaving, fabrics, cad system, PBT yarn

1. INTRODUCTION

There are various sustainability movements to improve the current environmental problem, including the zero-waste movement that contribute to the conservation of natural resources through responsible production [1]. The biggest financial burden for manufacturers is the production processes and textile material. Costs can also be reduced by optimizing the production process, including garment pattern optimization towards toward zero waste [2], with the goal of generating as little textile waste as possible. There are several techniques to reduce textile waste, one of which is to combine weaving techniques with garment pattern development. By using CAD systems that allow rapid design, modification, and simulation of jacquard fabrics, and by developing jacquard patterns in a way that allows the best possible match of the fabric pattern along the seams when it is made into a garment, waste in garment manufacturing can be reduced. By using yarns with elastane-polybutylene terephthalate (PBT) in the weft direction in specific areas corresponding to the garment cut, the fabric was given a 3D shape that conforms to the body after heat treatment [3]. We have managed to design and produced a garment with minimal waste.

2. EXPERIMENTAL

We started with the design of the pattern and laid it out on the surface in a way that would best suit a jacquard fabric. Using an oriental motif, we arranged the motifs on the surface according to the principle of pattern matching on all diagonals and according to the shape of the of the garment cut (Figure 1, left). In the next step, we simulated the appearance of the jacquard pattern on the shape of the garment. To achieve an aesthetic effect, we placed the smaller pattern for the upper, lighter part and the larger pattern for the lower, darker part (Figure 1, right). Arahne CAD software was used for the fabric design and simulation. The jacquard fabrics were woven on the same warp (CO, 2 x 8 tex; 1 black, 1 white) and three different wefts were combined in the non-elastic area (1 blue PES, 39 tex and 1 white CO, 2 x 8 tex) and elastic area (1 blue PET, 39 tex and 1 white PBT multifilament 2 x 7,8 tex).

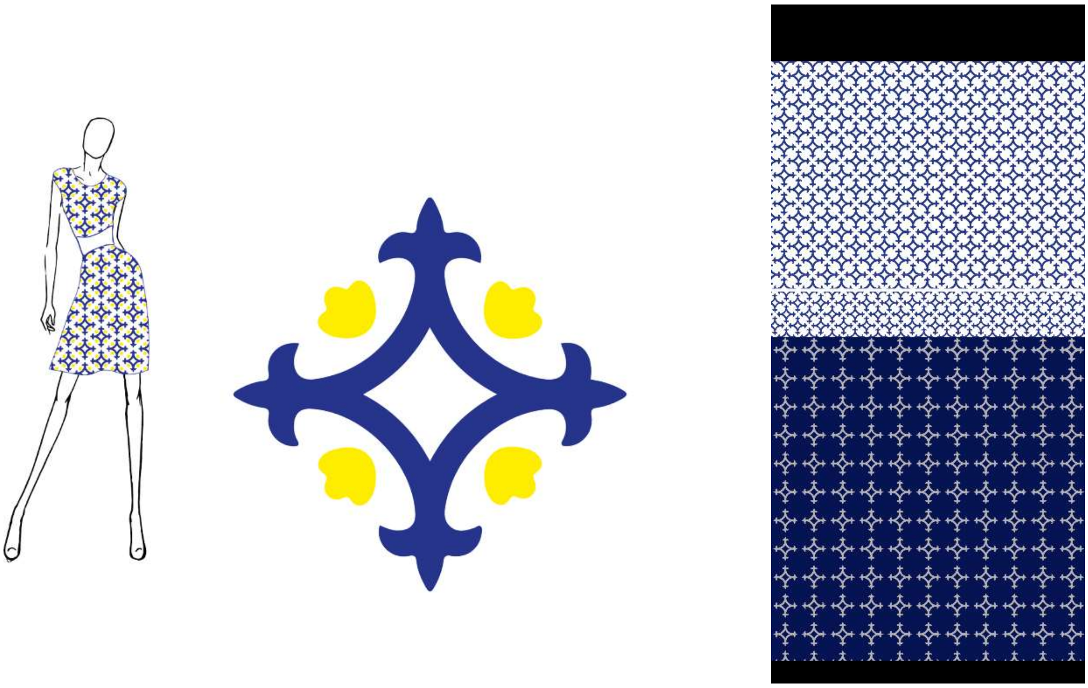
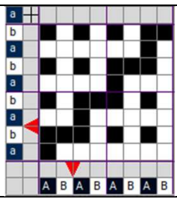
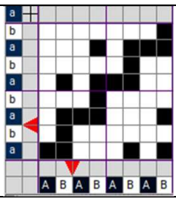
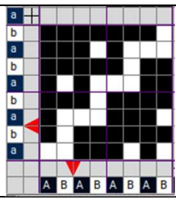
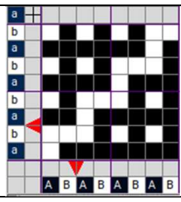


Figure 1. Development of the pattern for the jacquard fabric (left), patterns of the jacquard fabric arranged across the surface according to the garment shape (right)

Two different twill double weaves were used in the jacquard structure (self-stitched for the background and interchanging for the motif), Table 1.

Table 1. Weaves for two colours effect in jacquard patterns

Weaves for the upper part of the fabric		Weaves for the lower part of the fabric	
			
Blue effect	White effect	Blue effect	White effect

Two versions of the fabrics were produced, one with elastic upper part (Figure 2-3) and non-elastic lower part (Figure 2-5), and the second with additional elastic yarns woven over the entire fabric (Figure 2-3 and 4). The fabrics with PBT yarn in the weft were steamed for about 5 minutes to gain the elasticity.

Figure 2. Simulation of fabrics (left), the woven fabric (centre) and the appearance of the fabric with the PBT yarn after heat treatment (right)

3. RESULTS AND DISCUSSION

By combining different textile techniques, it is possible to design and produce fabrics that comply with the zero-waste principle. We have managed to design and determine the size and distribution of the pattern in such a way as to allow an optimal matching along the seams of the garment, minimizing fabric waste. By using yarns with elastane (PBT) in the weft direction, the fabric was given a 3D shape after heat treatment, which not only supports the shape of the garment, but also adds aesthetic value to the garment. From an economic point of view, we would have chosen a fabric with a partially elastic area that tapers in the upper part of the waist, while remaining flat in the skirt area. However, from an aesthetic point of view, a dress made of a fabric with a continuous elastic area is much better because it fits the body better.

Two dresses were made according to the zero-waste principle, the first from a fabric with an elastic top and a non-elastic bottom (Figure 3, left), the second with a continuous elastic area (Figure 3, right).

Figure 3: Dress made of fabric with elastic upper part and non-elastic lower part (left), dress made of fabric with continuous elastic area (right)

4. CONCLUSIONS

Modern technologies and digitisation in the field of weaving, weaving preparation and garment production preparation make it possible to quickly and efficiently design garments that are produced according to sustainable principles and with minimal waste. Although designing a jacquard pattern based on the shape of a dress may seem unrealistic in mass production, the digitisation of the processes makes this possible and the process can be used to produce sustainable garments on a small scale. The aim of the research has been achieved; we have produced a garment completely waste free with the appropriate jacquard fabric pattern. Sustainable fashion is a holistic process that encompasses sustainable product design from raw material to manufacturing to recyclability after use.

5. REFERENCES

[1] RISSANEN, T. Zero-waste fashion design: a study at the intersection of cloth, fashion design and pattern cutting [online], 2023 [cited 22.04.2023]. Available on <https://www.academia.edu/64612126/Zero_waste_fashion_design_a_study_at_the_intersection_of_cloth_fashion_design_and_pattern_cutting>.

[2] MCQUILLAN, H. Hybrid zero waste design practices. Zero waste pattern cutting for composite garment weaving and its implications. The Design Journal, 2019, vol. 22, no. 1, pp 803-819.

[3] KOSTAJNŠEK, K., BAJRIČ, Š., BIZJAK, M. Technological design of jacquard fabric and their functionalization. In Passion for Innovation: AUTEX conference proceedings. Edited by TOKARSKA, N. Lodz: University of Technology Press, June 2022. pp. 55–9.

SUBLIMATION FASTNESS INVESTIGATION OF POLYESTER FABRICS TREATED WITH HYDROPHILIC SILICONE EMULSION

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ABSTRACT

Sublimation fastness is classically tested with ISO 105x11 standard. In this study, we developed a new sublimation fastness test method and compared the results with the sublimation fastness test method as per the ISO 105x11 standard. The applicability of the test method has been proven with the results of the two test methods having the same results. Also, after finishing application is done on the polyester fabrics, there is a decrease in the sublimation fastness of the fabric.

Keywords: Fabric, fastness, sublimation fastness, polyester fabric

1. INTRODUCTION

The use of polyester fabric is increasing due to its many beneficial properties. It is used in every field from innerwear to outerwear due to its slippery and soft structure, low wrinkling rate, eye-catchy colors. Contrary to the benefits in its use, it is difficult to dye polyester fabric. No chemical reaction occurs during polyester dyeing because there is no functional group to react in polyester fibers. The crystalline region of the polyester fiber is higher than the amorphous region. Polyester fibers are difficult to dye because the dye penetrates the fibers from the amorphous region.

Disperse dyestuffs are used to dye polyester fabric. Disperse dyes have a very high affinity for polyester fiber. In order to dye polyester fibers, the tight fiber structure of polyester fibers must be opened, and the dye needs to penetrate through the pores. At high temperatures, the pores of the polyester fibers open up and the disperse dye penetrates the pores. However, in order for the dye to enter the pores in a balanced and even manner, it is necessary to use a leveling agent. Disperse dyeing starts at 80 °C and gradually increases to 130 °C (1,5-2 m/dk). Dyeing continues for one hour at 130°C and is cooled to 80°C. Reductive cleaning is required to remove any of the residual dead dye.

In textile industry, after dyeing, there are a lot of fastness methods tested such as color fastness, light fastness, water fastness, sublimation fastness. Sublimation fastness is important for polyester dyes. When disperse dye is heated to high temperatures, it gasifies from its solid state. The sublimation property is connected to the polarity of the substituting group. The polyester and acetate fibres that are dyed by disperse dyes may have fastness problems in the heat setting process or other after-finish processes, which is because of the poor sublimation fastness or dry heat fastness. Polyester fiber or acetate fiber fabrics dyed by disperse dyes may have the phenomena of the original shade being changed or stained because of the poor sublimation fastness. (1)

For the sublimation test, the ISO 105x11 standard is classically applied. The logic of the test is to place the treated dyed fabric and the untreated fabric together between the heating plate and pollute the untreated fabric as a result the dye becomes gaseous at a certain temperature and time. Tests are given for hot pressing when the textile is dry, when it is wet, and when it is damp. The end-use of the textile usually determines which test should be done. In this test method, dye contamination of the fabric is achieved by temperature. In the sublimated test fastness method we have developed, we carry out this contamination by means of chemical named perchloroethylene. Additionally, with this method, sublimation fastness can be conveniently tested without the need for a device.

In this study, perchloroethylene is used to evaluate the sublimation fastness. Since perchloroethylene is a very good organic solvent, its success in stain removal and its low toxicity compared to other chlorinated solvents results in perchloroethylene to be widely used in this field. Paint removers and some other stain removers also contain perchloroethylene. (2)

2.EXPERIMENTAL

2.1. Materials

In the study, woven fabrics of various colors were used, all made from 100% polyester. The dyeing recipes for blue and red colors from different fabrics used in the study are given in Table 1. Following the dyeing process, various softeners with varying levels of silicone content were applied to the fabric. Details regarding the utilized softener are presented in Table 2. In addition to these, for the sublimation fastness test method 2, perchloroethylene was used. The specifics are outlined in the Table 3.

Table 1. Pes fabric dye repice

COLOR	DYE REPICE
RED	RUBINE S-2GFL %200: 0.556
	RAPEZOL BRILL YELLOW: 0.458
	RED EN-F 01: 3.782
BLUE	BLUE E-2BL %100: 1.024
	TURQ. BLUE %200: 0,243

Table 2. Softeners used in the study

SAMPLE NAME	SOLID CONTENT	pH	IONIC CHARACTER
Sample 1	14	6,2	Weak Cationic
Sample 2	19	6,3	Weak Cationic
Sample 3	37	8	Weak Cationic
Sample 4	43	6	Cationic

Table 3. The chemical used in method 2 for sublimation fixation

Cas no	127-18-4
Molecular weight	165,82 g/mol
Density	1,622 g/cm3
Solubility (aq)	0,15 g/L

2.2. Method

2.2.1. Dye Method

The dyeing process took place in a Forlab-branded dyeing machine at 130°C for 90 minutes. A 40°C rinsing process was carried out, followed by drying in a Forlab drying machine at 130°C.

2.2.2. Padding Method

The fabric was padded using 1-dip 1 nip in a hydrophilic silicone solution finishing bath with 80–85% wet pickup. Then the padded fabric was dried at 180 °C for 180 s.

2.2.3. Sublimation Fastness Method

2.2.3.1. Method 1

The sample fabric size was 50x100mm. The size of the accompanying fabric is the same as the sample. It is placed in the sublimation fastness device with the treated fabric at the bottom and the untreated fabric at the top then kept on the device for 30 seconds at 180 degrees under the pressure of 4kPa. Color change was evaluated according to the grayscale.

Figure 1. Scorch brand sublimation fastness device

2.2.3.2. Method 2

The treated fabric is cut to 50x50 mm. The fabric is placed on the petri dish. Filter paper is placed on it. A glass plate with a 1 cm hole is placed on it. 0.5 ml of perchlorethylene is dropped through the hole and held for 5 minutes to get the final results.

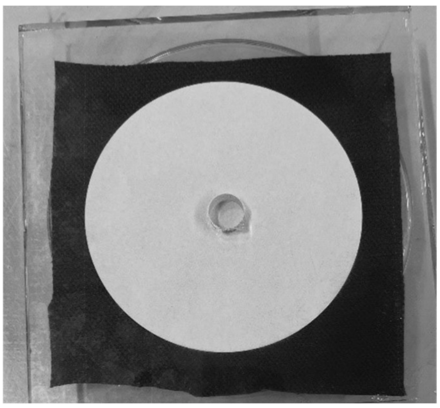

Figure 2. Method 2

3. RESULTS

In this study, we compared the ISO standard with the sublimation fastness and the newly developed sublimation fastness test method. We evaluated the results according to the gray scale.

In the study, fabrics in different color tones including yellow, red, blue, navy, and black were utilized. Additionally, finishing chemicals containing various types and levels of silicone were applied. A total of 100 distinct experiments were conducted. According to the obtained results, Method 2 yielded parallel outcomes with Method 1, with a concurrence rate of 98%.

Table 4. Sublimation fastness test results according to method 1 and method 2

Fabric Color	Sample Name	Sublimation fastness method 1	Sublimation fastness method 2
Red	**Blank**	2/3	2/3
	Sample 1	2/3	2/3
	Sample 2	2/3-	2/3-
	Sample 3	2	2
	Sample 4	2-	2-
Blue	**Blank**	2/3	2/3
	Sample 1	2	2
	Sample 2	2	2
	Sample 3	1/2	1/2
	Sample 4	1	1

İt was found that the sublimation fastness decreased the results with the increase of silicon content in the finishing agent, while the fabric that was not treated with the finishing agent had the least contamination.

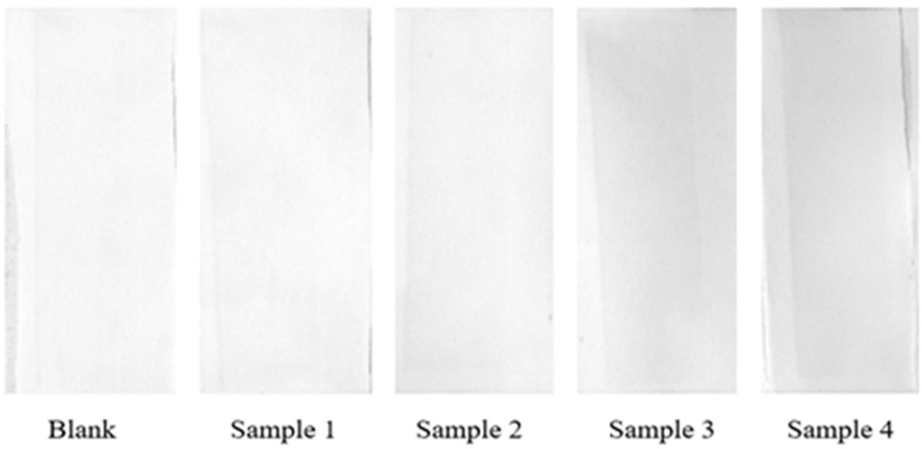

Figure 3. Sublimation fastness results of red polyester fabric according to method 1

When the sublimation fastness test was performed with method 2 on the same fabric used in method 1, the results were analogous. The finishing agents applied to the fabrics decreased the sublimation fastness. However, the results of sample 1 and sample 2 were close to the untreated fabric. (Figure 4)

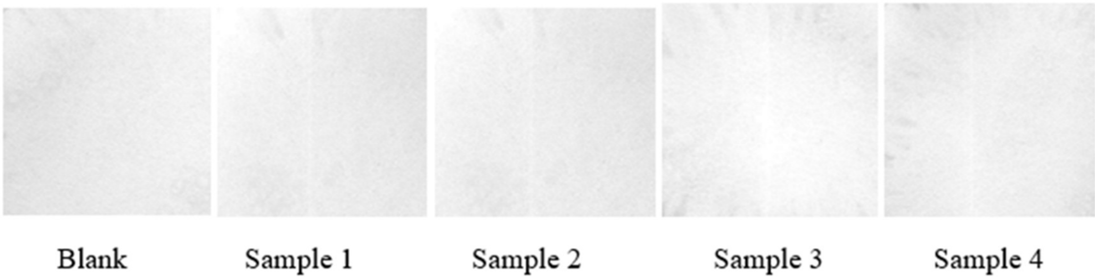

Figure 4. Sublimation fastness results of red polyester fabric according to method 2

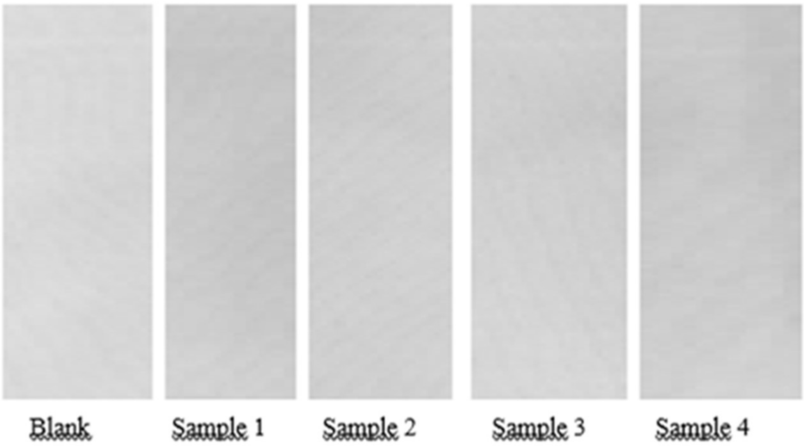

Figure 5. Sublimation fastness results of blue polyester fabric according to method 1

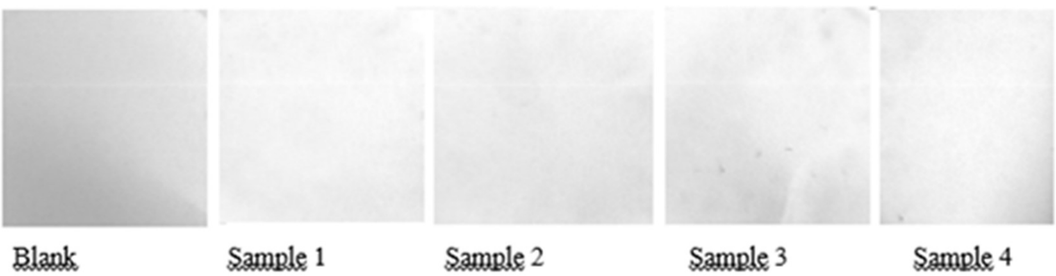

Figure 6. Sublimation fastness results of blue polyester fabric according to method 1

4. DISCUSSION

The developed novel method enables the assessment of sublimation fastness in polyester fabrics without the necessity of any device utilization. Consequently, it is a cost-effective testing approach, and it is feasible without incurring device expenses. Nonetheless, the drawbacks associated with the new method is the longer time consumed compared to the shorter timeframe when it is conducted on a device. Within the existing literature, no analogous testing methodology pertaining to sublimation fastness has been identified.

5. CONCLUSIONS

Examination of sublimation fastness in polyester fabrics is an important criterion. This method, which is examined as the dye passing from the gas phase to the solid phase at high temperatures, contaminating the fabric, is examined with the help of a device. In this study, a new method for sublimation fastness is developed and examined. In this method, we used a chemical that dissolves the dye, perchlorethylene. We tested the accuracy by comparing the results with the classical method.

In our study, we compared fabrics that did not contain a finishing agent and fabrics treated with a finishing agent. It is a known fact that the sublimation fastness of the fabric decreases as a result of the finishing process. Some finishing agents reduce sublimation fastness more, while others give results close to untreated fabric. This actually depends on the silicon content of the finishing material. As the silicon ratio increases, sublimation fastness is expected to decrease. In our study, we used 2 finishing materials with a lower silicon ratio and 2 silicone materials with a higher silicon ratio. When we examined the results, we saw that the finishing materials with high silicon content pollute more.

6. REFERENCES

[1] https://www.tib.eu/en/search/id/tema:TEMA20060501388/The-sublimation-fastness-of-disperse-dye/

[2] http://www.mikroteknik.com.tr/urunler/perkloretilen/

PROTECTIVE CLOTHING: STANDARDIZATION AND CERTIFICATION

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ABSTRACT

Protective clothing guards the wearer from environmental and working conditions hazards. The production and certification of protective clothing in according to the standards is very important for the health and safety of the wearer. In this paper detailed information about the standardization of protective clothes and certification procedures are given.

Keywords: Protective clothing, standardization, certification, Personal Protective Equipment Regulation, conformity

1. INTRODUCTION

Technical textiles are manufactured and used essentially for their functional properties and technical performance rather than their aesthetic or decorative characteristics [1]. Protective textiles are one of the very important application areas of technical textiles used against a variety of hazards. Protective clothing refers to garments and other fabric-related items designed, fabricated, or treated to protect the wearer from extreme environmental and dangerous working conditions, safeguard the user against possible risks that may result in injuries or death. It is a part of the personal protective equipment (PPE) suite. Protective textiles are classified according to the end-use functions such as chemical- biological protection, mechanical impact protection, thermal (cold) protection, flame protection, radiation protection, wearer visibility and electrical protection. While developing the specialised protective textiles it should be considered that, each hazard has its own functional behaviour. Therefore, all protective clothes should be specifically designed and produced to meet the basic requirements against possible risks. In some cases, there may be need to protection against more than one threat, such as, protection to cutting or chemicals in addition to the protection from fire could be require for firefighter clothing [2-6].

Standards have become the common language of international trade in today's world, where a rapid globalization process is experienced with the development in production technologies. Standardization is the establishment and application of certain rules with the assistance and cooperation of all parties involved, so standardization of specifications or test methods facilitate trade and reduce costs. According to the contents, standards can be divided into different categories such as product requirements, test methods, requirements for quality management in testing, production and certification. In terms of protective clothing, standardization is a key factor for users' safety [5,7]. Various national and international standardization associations have developed standard test methods and performance specifications since the early 1990s to assess the performance properties of protective clothing. The standards for PPE contain safety requirements and, as far as this is necessary, descriptions of the test methods to be used. These standard test methods and performance specifications ensure that the performance data on protective clothing are useable, comparable and meaningful [6,8,9].

2. STANDARDIZATION AND CERTIFICATION OF PROTECTIVE CLOTHING

In many countries protective textiles fall under the framework of legal regulations. Legal authorities on occupational safety and health in all developed industries accept Personal Protective Equipment (PPE) safety as an essential social factor. If employees used the proper PPE, the majority of workplace injuries can be avoided. Employers have to guarantee a series of requirements to protect the worker. The level of protection of protective garments can be ensured by standards based on advances in the materials used, technical progress in the world, the development of legislation about vocational safety and health, and the consciousness of the user [5].

The product standardization of PPE in Europe is based on the Council directive 89/686/EEC (EC-European Community, 1989a) which lays down the basic safety requirements. The provisions of this directive concern the design and manufacture of PPE to ensure a safer working environment. More than 300 of European standards for PPE have been developed for equipment conformity to the directives. There is a clear difference between the use of PPE products and the manufacture of PPE in Europe. The use of PPE is under authority of EC directive 89/656/EEC (called `users directive') relevant to the minimum safety and health requirements for using of PPE at the workplace (EC, 1989b). In North America the standardization is mainly implemented by US Department of Labor, Occupational Safety and Health Administration (OSHA). Under a regulation of OSHA, employees must use the proper PPE to avoid workplace hazards and an employer must meet specific requirements about that [5,6,8].

CEN (European Committee for Standardisation) carries out standardization in the field of PPE, as in other fields. Seven technical committees (TC) from CEN are involved in establishing the standards. These committees include working groups (WG) or subcommittees (SC). The TC 162 with 12 working groups is the responsible committee for protective clothing, hand and arm protection and lifejackets.

Standardization of International PPE over the worldwide is accomplished by ISO (International Standardisation Organisation). Technical Committee (TC) ISO/TC 94 and a series of subcommittees (SC) takes place standardisation of different types of PPE. IEC (International Electrotechnic Commission) carries out the standardisation of protective clothing especially against electric risks (arcing heat, shock, electromagnetic radiation etc.) [5,6].

In Turkey, within the scope of Personal Protective Equipment Regulation, there are provisions on Conformity of Personal Protective Equipment, Conformity Evaluation and Use of Personal Protective Equipment. TSE (Turkish Standard Institution) executes the conformity assessment activities within the scope of the Personal Protective Equipment Regulation. It has been prepared within the framework of harmonization with the European Union legislation [10].

Although standards are very important tools providing a common language about protective clothing, conformity assessment to a standard is required to show minimum level of protection from hazards. This shows the customer that the product meets the requirements and helps with the purchasing decision. Also, provide confidence to the producer about the product [11]. PPE products are classified in four categories in terms of on the importance of hazard (simple, medium, complex) they protect against (Table 1). According to these categories, the required set of tests and certifications of a product are different [12].

Table 1. Categorization of personal protective equipment according to protection against the hazards [5,12]

Risk Categories of PPE	Type of PPE
III	PPE models of complex design intended to protect against life-threatening hazards or serious harm to health (harmful biological agents, fire-fighters' clothing etc.)
II	All PPE includes other than those listed in categories I and III (high-visibility warning clothing, welders clothing etc.)
I	PPE models of simple design, user can himself assess the level of protection (simple gardening gloves etc.)
0	PPE excluded from the scope of the PPE directive 89/686/EEC (PPE for use by the police and armed forces)

This classification is very important for the required set of tests and certifications (conformity assessment) of a product. For the category I (simple protective clothing for minimal risks), a self-conformity statement by the manufacturer is sufficient. The manufacturer has to apply for an EC type examination to a notified body for the products of category II (middle hazard potential). EC type examination is the procedure whereby the approved notified body establishes and certifies that the PPE model satisfies the relevant provisions of the directive. The EC type examination alone is not sufficient for PPE of category III (includes serious life-threatening risks). Additional measures for quality assurance during the serial manufacturing process of the product are required. These measures are obligatory and must be controlled by a responsible authority.

According to the European regulation, before placing a PPE on the market, the manufacturer has to carry out a `EC declaration of production conformity'. The CE (European conformity label) mark is affixed on each personal protective equipment. This is a schematic declaration of conformity with the relevant health and safety requirements of the PPE directives. In EC type quality system, manufacturer applies all requirements to ensure that the manufacturing process, including the final inspection of PPE and tests, the homogeneity of production and the conformity of PPE with the type described in the EC type certification and PPE directive. Following the "CE" mark, the standard identification number of the notified body performing the execution of the certification procedures should be included. In addition to the CE marking, business name and full address of the manufacturer, the European standard fulfilled, type, name of the product, size, pictogram for the risk that the product should protect against, including performance classes, and care labels must be presented on the PPE product [5, 10, 12].

3. CONCLUSION

Protective clothing is used to protect wearer from serious workplace injuries or illnesses resulting from contact with chemical, radiological, physical, electrical, mechanical, or other environmental hazards.

The production and certification of protective clothing in according to the standards is very important necessity for the health and safety of the wearer. The standardization of personal protective clothing is carried out on international (ISO), European and national levels by different technical committees. There are a lot of ISO and European Standards, relevant test methods for protective textiles. According to the European regulation, before placing a PPE on the market, the manufacturer should carry out a `EC declaration of production conformity'. CE mark is a conformity label to guarantee correspondence to the requirements of the safety and health. PPE products are classified in four categories depending on the hazard potential they protect against. This classification is very important for the required set of tests and certifications. According to these categories, different situations from manufacturer conformity statement to EC type certification by notified body could be required.

4. REFERENCES

[1] The Textile Institute, Textile Terms and Definitions, 1991, 9th edition, Textile Institute.
[2] ADANUR, S., Wellington sears handbook of industrial textiles, Lancaster, Pennsylvania, Technomic Publishing Company, Inc.1995.
[3] POTLURI, P. and NEEDHAM, P. Chapter 6: Technical textiles for protection. In Textiles for protection, Edited by SCOTT R. A. England: Woodhead Publishing, 2005, pp 151-175.
[4] ZHOU, W., REDDY, N. and YANG Y., Chapter 1: Overview of protective clothing, In Textiles for protection, Edited by SCOTT R. A. England: Woodhead Publishing, 2005, pp 3-5.
[5] HAASE J., Chapter 2: Standards for protective textiles. In Textiles for protection, Edited by SCOTT R. A. England: Woodhead Publishing, 2005, pp 34-48.
[6] DOLEZ P.I., IZQUIERDO V., Chapter 11: Specific testing of protective clothing. In Advanced characterization and testing of textiles, Edited by Dolez P, Vermeersch O, Izquierdo V. England: The Textile Institute Book Series, Woodhead Publishing, 2018, pp 318 [7] ÖZDIL, N., Tekstilde standardizasyon ve önemi. Tekstil ve Konfeksiyon, 1, 2001, pp: 3-7 [8] JUNG K., CEN Standards for testing and certifying personal protective equipment—status quo and deficiencies: Examples. International Journal of Occupational Safety and Ergonomics, 1995, 1:2, pp 108-117, DOI: 10.1080/10803548.1995.1107630
[9] MÄKINEN, H. Protective clothing—nowadays and vision. In 3rd European Conference on Protective Clothing and Nokobetef: book of proceedings, Vol 8. Gdynia, Poland: 10-12 May 2006, pp 3.
[10] http://mevzuat.basbakanlik.gov.tr/Yonetmelikler.aspx- Kişisel Koruyucu Donanım Yönetmeliği
[11] COHEN, H.J., LIVERMAN, C.T. Certifying Personal Protective Technologies: Improving Worker Safety, Institute of Medicine (US) Committee on the Certification of Personal Protective Technologies, 2011 National Academic Press, Avaible on https://nap.nationalacademies.org/catalog/12962/certifying-personal-protective-technologies-improving-worker-safety
[12] https://www.cencenelec.eu/areas-of-work/cen-cenelec-topics/personal-protective-equipment/[cited 04.09.2023].

BRIDGING CREATIVITY AND TECHNOLOGY: STITCHING IMAGINARY IZMIR FROM ANCIENT TIMES TO AI

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ABSTRACT

Artificial intelligence applications have proliferated across diverse sectors including technology, healthcare, finance, retail, transportation, and even within artistic and cultural domains. The year 2022 witnessed a significant surge in the prominence of AI-powered tools such as MidJourney, Stable Diffusion, DALL·E, and ChatGPT. This paper intends to present the potential impact of AI on the creation of art. The visuals of the textile art piece titled 'Imaginary Izmir: From Ancient Times to Artificial Intelligence' were collaboratively generated employing MidJourney. The artwork indicates the historical and cultural essence of Izmir from different periods by combining a traditional technique with a modern approach.

Key Words: Artificial intelligence, AI art, midJourney, textile art

1. INTRODUCTION

The idea of creating systems that "think like humans" first emerged in the 1950s, and John McCarthy conceptualized this idea as "artificial intelligence" in 1956. Artificial intelligence studies have come to a halt from time to time due to economic conditions and high expectations [1]. Nevertheless, at present AI applications continue to develop at full speed and used in many sectors such as technology and computer, health and medicine, finance and banking, retail and e-commerce, transportation and automotive, textile and fashion, as well as in the field of art and culture.

Throughout 2022, a remarkable surge in AI-powered tools such as MidJourney, Stable Diffusion, DALL·E, and ChatGPT has captured widespread attention. These models manifest the capability to generate distinct images or textual content through a synthesis of human- supplied text prompts, specified parameters, or imagery. In the wake of DALL·E and MidJourney gaining considerable traction within the mainstream, a fervent discourse has ensued at the confluence of artistic and technological domains. This discourse primarily orbits the adverse ramifications of AI-generated imagery upon the professional cadre of artists. Notably, this deliberation exhibits a pronounced polarization, characterized by vociferous assertions from disparate factions, often marked by a lack of constructive dialogue and meaningful engagement [2]

Indeed, considering the humanistic dimension of art, distinct from the conventional advancement of human intelligence within the realms of science and technology, the emergence of AI constitutes a paradigm shift, offering novel dimensions to the domain of art. Central to this discourse is an exploration of how AI engenders shifts and alterations in our perceptual understanding of art, thereby illuminating a vital area for scholarly deliberation and contemplation [3].

2. CREATING ART WITH ARTIFICIAL INTELLIGENCE

Generative Adversarial Networks (GAN) accelerated the use of AI among the artists due to their ability to create high quality realistic images. However, GAN have some disadvantages including instability, training requirements, evaluation, and lack of diversity in the images [4]. Eva Cetinic and James She classify the activities and researches related to “AI and Art” into two categories. The first category focuses on the process of analyzing existing art through the instrument of AI, while the second category focuses on AI created art [5]. This new art form, called hybrid art, is based on the principle of obtaining art products through human-machine collaboration with technological opportunities such as graphic design programs, 3D printers and artificial intelligence [6]. According to Burnett, “Artificial intelligence is a metaphor for information processing and modeling. The assumption is that as new information is introduced to the computer, it will be capable of processing new information into the existing models that have been part of its operations. To some degree, the hope is that the computer will be able to use enough of its “intelligence” to move beyond the limitations of the information it has received and to develop predictable as well as unpredictable outcomes. To some degree, the more autonomous the computer, the more it “feels” as if there is intelligence, especially if the programming process allows the computer to effectively work on its own” [7].

Harold Cohen, who was an academician at the University of California, is widely acknowledged as a pioneering figure in AI art. In 1973, he started working on an art creation program called AARON. He worked as a guest lecturer at Stanford University's Artificial Intelligence Laboratory and managed to create an algorithm that implemented his own painting technique [8]. In 2018, a collective named “Obvious” uploaded approximately 15,000 portrait paintings produced between the 14th and 20th centuries to GAN's database [9]. The network tried to create its own portrait named the "Portrait of Edmond Belamy”, and this is the first AI art portrait sold for $432.500 at Christie’s [10].

3. IMAGINARY IZMIR: FROM ANCIENT TIMES TO ARTIFICIAL INTELLIGENCE SERIES

The visuals of the textile artwork titled "Imaginary Izmir: From Ancient Times to Artificial Intelligence" were created with the collaboration of MidJourney and textile artist Elvan Özkavruk Adanır in 2023. The artwork aims to reflect the history and cultural values of Izmir by blending the traditional with the modern. The historical and cultural heritage of Izmir is reinterpreted through an imaginary perspective. Using artificial intelligence, 40 images of Izmir from different periods have been created and 15 of them were selected by the artist. Each period is represented by three visuals (Figure 1-5). The color and size adjustments of these images were made by using Adobe Photoshop program. The images were transferred onto leftover polyester fabrics through digital printing. Traditional quilting technique was used to give dimension by using metallic and cotton threads where all the stitching was done by hand. Finally, each artwork combines the texture of the past with a modern approach, showcasing the harmony of art and technology. “Imaginary Izmir: From Ancient Times to Artificial Intelligence” was exhibited in Turkish Textile Biennial in İzmir in 2023.

4. CONCLUSION

Artistic works carried out in collaboration with artificial intelligence will undoubtedly increase in the coming years. Although there are various discussions about ethics, imitation, and ownership after each AI artwork, it is thought that this developing technology will take artists and art lovers on an exciting journey.

Figure 1: "Imaginary Izmir from Ancient Times to Artificial Intelligence" Series, Ancient Times

Figure 2: "Imaginary Izmir from Ancient Times to Artificial Intelligence" Series, 15th Century Izmir Bay from Kadifekale

Figure 3: "Imaginary Izmir from Ancient Times to Artificial Intelligence" Series, 18th Century Izmir Inner Bay

Figure 4: "Imaginary Izmir from Ancient Times to Artificial Intelligence" Series, 19th Century Izmir: Carpet Merchants and Izmir Streets

Figure 5: "Imaginary Izmir from Ancient Times to Artificial Intelligence" Series, 21st Century Izmir: Suburbs and the City

5. REFERENCES

[1] UNAL, E. Yapay Zekadan Sanatçıya. Tübitak Bilim ve Teknik Dergisi, Aralık, 2018, pp 58- 66.
[2] DENNIS, S. The AI Art Debate: Excitement, Fear and Ethics, Towards Data Science[online], updated 22.12.2022 [cited 21.08.2023]. Available on https://towardsdatascience.com/the-ai-art-debate-excitement-fear-and-ethics-c04d30f338da
[3] ASLAN, E. Yapay Zekâ Resimleri ve Sanatın Başkalaşan Mecrası Üzerine, Güzel Sanatlar Enstitüsü Dergisi , 2019, 42, pp 231-242.
[4] LIU, M. Overview of artificial Intelligence Painting Development and Some Related Model Application [online], updated 18.05.2023[cited 21.08.2023]. Available on https://www.shs-conferences.org/articles/shsconf/abs/2023/16/shsconf_cacc2023_01004/shsconf_cacc2023_01004.html
[5] CETINIC, E. and SHE, J. Understanding and creating art with AI:Review and Outlook [online], updated 18.02.2021[cited 21.08.2023]. Available on https://arxiv.org/abs/2102.09109
[6] ASLAN, E. Yapay Zekâ Resimleri ve Sanatın Başkalaşan Mecrası Üzerine, Güzel Sanatlar Enstitüsü Dergisi , 2019, 42, pp 231-242.
[7] BURNETT, R. How Images Think. 1st edition. Cambridge, Mass: MIT Press, 2004, p. 253.
[8] BALLI, Ö. Yapay Zekâ ve Sanat Uygulamaları Üzerine Güncel Bir Değerlendirme [online], Sanat ve Tasarım Dergisi, updated 28.12.2020 [cited 22.08.2023]. Available on https://dergipark.org.tr/tr/pub/sanatvetasarim/issue/58750/848330, pp 277-306.
[9] ASLAN, E. Yapay Zekâ Resimleri ve Sanatın Başkalaşan Mecrası Üzerine, Güzel Sanatlar Enstitüsü Dergisi , 2019, 42, pp 231-242.
[10] VINCENT, J. Christie's sells its first AI portrait for $432,500, beating estimates of $10,000[online], updated 25.10.2018 [cited 22.08.2023]. Available on https://www.theverge.com/2018/10/25/18023266/ai-art-portrait-christies-obvious-sold

MULTI-PURPOSE KNITTED BABY WRAP

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ABSTRACT

Baby/child carriers are support devices used by adults to carry children in close contact with their bodies. They are made from a variety of raw materials and fabrics with varying degrees of stiffness to provide adequate support. Modern textile baby carriers are ergonomic and support the child's natural posture, promote physical development, are safe, allow freedom of movement and are comfortable. Knitted baby wraps are simple in shape and are suitable for waste-free production on a flat knitting machine. As part of the research, we have designed a multipurpose baby wrap made of single jacquard knit and interior textiles for the nursery.

Key Words: Knitting, knitted fabric, baby carrier, wrap, ring sling

1. INTRODUCTION

Baby and child carriers are support devices used by adults to carry children in close contact with their bodies. They help carry or hold the child for long periods of time during walks, outings, errands, etc. Adults can carry the baby in contact with their abdomen and chest, at the hip, or on their back. The babies can face the adults to interact with them, or they can face away from them to observe their surroundings while being carried close to the chest or at the hip. Baby carriers are made from a variety of raw materials and fabrics that vary in stiffness to provide adequate support. Modern textile baby carriers are ergonomic and support the child's natural posture, promote physical development, are safe, allow freedom of movement, and are comfortable [1].

There is a lot of information, reviews and advice about baby/child carriers on the websites of manufacturers and sellers of these products, as well as on parenting blogs. Many scientific studies have also been conducted, e.g. from the area of measuring loads during baby carrying [2, 3, 4], on the physiological response of wearers in terms of muscle load, etc., during the use of different carriers [5, 6], on the impact of carrying newborns in baby carriers on the duration of breastfeeding [7], etc. All this proves that baby carriers are a marketable product that requires comprehensive planning.

For over a decade, baby carriers have (re)enjoyed popularity; they are especially useful for carrying babies and children when the stroller is too rigid and in the way. Baby carriers increase the comfort of the wearer when carrying children and free up the hands, but at the same time must provide the baby/child with adequate position and support for the head and spine. The child must not be shrink-wrapped in the carrier, as such a position may impede his/her breathing. When using carriers, the baby's/child's age and stage of development must be considered; experts do not recommend the use of carriers until the child is 3 months old. Parents who choose and use an unsuitable baby carrier that is not adapted to the age and developmental stage of the child unintentionally influence its development and risk spinal damage [8].

Carrying children is strenuous work that consumes a lot of energy. The weight of a child increases rapidly with growth: from about 3 kg at birth to about 10 kg at the age of one year.

Energy consumption when carrying a baby in a carrier is lower than when carrying a baby in the arms, but higher than when carrying a baby on the back [2]. Babywearing has many advantages at the same time:

- allows freedom of movement for the wearer,
- calms the child as he/she feels the touch, rhythm and heartbeat,
- facilitates communication and helps to identify the child's needs,
- allows the father to participate more actively in the care and upbringing of the child,
- facilitates play and care for siblings
- helps in the occurrence of colic [9].

Children in baby carriers can suck and bite, drool and sweat on the material, so they must be made of materials that do not contain harmful substances [8].

We know different types of baby carriers: wraps, soft structured carriers, ring slings, pouch slings, and Asian style baby carriers (Figure 1).

https://www.primamici.si/pregled-priporocenih-nosilk-in-trakov/	https://www.primamici.si/pregled-priporocenih-nosilk-in-trakov/	https://www.primamici.si/pregled-priporocenih-nosilk-in-trakov/	https://www.pupsikstudio.com/pupsik-pouch-bekko.htm	https://www.primamici.si/pregled-priporocenih-nosilk-in-trakov
(a)	(b)	(c)	(d)	(e)

Figure 1. Different types of baby carriers: (a) wraps, (b) soft structured carriers, (c) ring slings, (d) pouch slings and (e) Asyan style baby carriers

2. EXPERIMENTAL

Knitted baby wraps are simple in shape and suitable for waste-free production on a flat knitting machine. In the research work we investigated baby wraps and their possible multifunctionality. In the theoretical part, we studied baby carriers over time and in different cultures, as well as traditional concepts in the development of children's clothing and equipment. Based on the theoretical research and literature review, we designed a multipurpose baby wrap made of single jacquard knit and interior textiles for the nursery.

The inspiration for the structured jacquard knit was a pattern with a swallow motif (Figure 2), which is a symbol of spring and freedom of movement, as well as happiness, prosperity, loyalty and progress. Since the knitted baby carrier is wrapped around the wearer's body in several layers when carrying a baby, which can cause discomfort, especially in warm climates, we chose a single jersey structure combined with a porous structure (swallow motif).

The jacquard pattern was designed using Shima Seiki software at the pattern station SDS. The knitted baby wraps were made on a flat knitting machine SHIMA SEIKI SES 122 RT with gauge 12E. A 100% organic cotton (Bio Ethic, Alpes) 20x3 tex yarn was used for knitting, as organic cotton yarns are often used for making elastic knitted baby wraps. The yarn has Oeko-Tex Standard 100 and GOTS certificates. According to the manufacturer, products made of Bio Ethic yarn can be machine washed at 30°C, ironed at up to 110°C and dry cleaned with perchloroethylene.

Figure 2. Single jersey with swallow mesh motif made of 100% organic cotton yarn

A 460 cm long and 55 cm wide fully fashioned strip was knitted for the baby wrap. The beginning and the end of the strip were knitted diagonally. A rib structure was incorporated along the long edges to reduce the tendency to curl. In addition, holes were made along the longitudinal edges at a distance of 1.5 cm to allow the assembly of the strip and its transformation into other products by folding, collapsing and sewing.

The functional properties of the fabric from which the baby wrap was made were tested using standard methods: elasticity, heat transfer, pilling and abrasion resistance.

3. RESULTS AND DISCUSSION

The fully fashioned knitted strip was designed to encourage creativity and transformation into a range of other products based on DIY hand textile techniques. With the personal involvement of the user, the industrially produced baby wrap can become an individualized, sustainable, multipurpose product with an extended life span. Figure 3 shows different ways of transforming the knitted strip by folding, sewing, decorating with a satin ribbon, adding tassels, etc.

(a)	(b)	(c)	(d)

Figure 3. Various functions of the fully fashioned knitted strip: (a) baby wrap, (b) baby ring sling, (c) nursing mother cape and (d) decorative pillow

The elasticity test (SIST EN 14704-2: 2007) showed that both the plain single jersey and the porous jacquard knit have good elastic recovery. The abrasion resistance test (SIST EN ISO 12947-1: 1999.) showed that both knits begin to tear at 5000 cycles. The pilling resistance test (SIST EN ISO 12945-2: 1999.) gave both structures a value of 3 at 5000 rubbing cycles. The thermal conductivity (DIN 52 612) is almost the same for both knits (0.08 W/mK).

4. CONCLUSIONS

The study showed that fully-fashion flat knitting using eco-cotton is a suitable technology to produce sustainable knitted multipurpose baby wraps without waste. The research results also showed that the combination of plain and mesh single weft knitting ensures suitable performance characteristics for making a knitted baby wrap. Knitted baby carrier wraps can be designed and manufactured as multipurpose products. By folding and sewing, they can be transformed into a product with a different functionality. This versatility increases their sustainability value. In addition, mass-produced knitted baby wraps can be customised using creative DIY textile techniques.

5. REFERENCES

[1] Baby Carrier Market: Global Industry Trends, share, size, growth, opportunity and forecast 2022-2027 (2022) Global Information, Inc. (GII) - Premium market research reports. Available at: https://www.giiresearch.com/report/imarc1077777-baby-carrier-market-global-industry-trends-share.html (Accessed: 24 May 2023).
[2] INUKAI, H.I. (1998) Physical Load of Carrying Baby in Arms or in Baby-Carrier, Journal of Home Economics of Japan, 49(11), pp. 1233–1239. doi:https://doi.org/10.11428/jhej1987.49.1233.
[3] WALL-SCHEFFLER, C.M., GEIGER, K. AND STEUDEL-NUMBERS, K.L. (2007) Infant carrying: The role of increased locomotory costs in early tool development, American Journal of Physical Anthropology, 133(2), pp. 841–846. doi:10.1002/ajpa.20603.
[4] WILLIAMS, L., STANDIFIRD, T. AND MADSEN, M. (2019) Effects of infant transportation on lower extremity joint moments: Baby Carrier versus carrying in-arms, Gait & Posture, 70, pp. 168–174. doi:10.1016/j.gaitpost.2019.02.004.
[5] WU, C.Y., HUANG, H.R. AND WANG, M.J. (2016) Baby carriers: A comparison of traditional sling and front-worn, rear-facing harness carriers, Ergonomics, 60(1), pp. 111–117. doi:10.1080/00140139.2016.1168871.
[6] LEE, H. AND HONG, K.H. (2018) Type and wearing method-dependent cop and muscle fatigue measurement of baby carriers for the development of Smart Baby Carriers, International Journal of Clothing Science and Technology, 30(5), pp. 610–627. doi:10.1108/ijcst-11-2017-0178.
[7] PISACANE, A. et al. (2012) Use of baby carriers to increase breastfeeding duration among term infants: The effects of an educational intervention in Italy, Acta Paediatrica, 101(10). doi:10.1111/j.1651-2227.2012.02758.x.
[8] BEVC BAHAR, J. (no date) Otrok in Družina, ZPS - Zveza potrošnikov Slovenije. Available at: https://www.zps.si/otrok-topmenu-258/oprema-in-tekstil-topmenu-260/10454-zdrav-razvoj-otroka-naj-bo-pred-udobjem-starsev (Accessed: 25 May 2023).
[9] Nosilke in vse o nošenju: MojŠkratek, trgovina z nosilkami (2019) MojŠkratek. Available at: https://mojskratek.si/nosilke (Accessed: 25 May 2023).

FASHION, TECHNOLOGY AND SUSTAINABILITY IN CONTEMPORARY KNITTING

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ABSTRACT

Both fashion and technology are described as interdisciplinary processes that combine different disciplines and tools to create user experiences. Throughout history, they have found points of contact and strongly influenced each other. Fashion, design, natural sciences, engineering, and economics and management combine in a field also known as "fashion-tech". Major knitting machine manufacturers have joined the fashion-tech stream, showcasing the capabilities of their machines at textile machinery shows such as ITMA, as well as fashion yarn trade shows such as Pitti Filati, technical textiles trade shows such as Techtextil, and functional textiles trade shows such as ISPO sports trade show.

Key Words: knitting, fashion, technology, sustainability, internet of things

1. INTRODUCTION

With the development of science and technology, as well as society and daily needs in general, both professional and personal life is becoming more and more »technical« in every aspect. Modern life encompasses a large amount of very different information. The increasing fast pace of life and the pursuit of a higher standard of living are accompanied by ever-increasing demands, as well as the need to use engineering devices and assistive technologies that facilitate manual labor, shorten work processes, and provide greater safety, accuracy, and repeatability in every aspect of life and work. Science and technology have transformed our lives and impacted important areas of society such as education, health, communications, transportation, business, and more. However, efforts must be made to ensure that inventions and discoveries in these areas are always used in the interest of all humanity and make the world a better place [1]. In addition to improved communication, better access to information, more flexible working, smarter health monitoring, reduced privacy, and virtual social life, shopping has also become more accessible. It's convenient to shop online, and what's more, it's become a necessity during the lockdown caused by the Covid 19 pandemic. Instead of being physically present to open a shop, you can now do it online, and the ease of creating professional-looking websites further helps sell products or services [2].

2. HIGH-TECH, FASHION-TECH, ECO-TECH AND INTERNET OF THINGS

High-tech textiles and clothing take advantage of advances in science and technology to design contemporary, high-performance products. The methods used in the production of high-tech textiles and clothing borrow ideas and concepts from chemistry, computer science, aerospace engineering, automotive engineering, architecture, industrial textiles, high-performance sportswear, etc. High-tech textiles occupy a special position. Part of their production has become more and more merged with everyday life, as the once specific and extravagant needs of consumers that could only be met by special or technical textiles and clothing have gradually become conventional needs [3].

Both fashion and technology are described as interdisciplinary processes that combine different disciplines and tools to create user experiences. Throughout history, they have found points of contact and strongly influenced each other. As the fashion world embraces technological advancements, the industry has changed on both the production and consumption sides [4].
Fashion-tech products and/or services can be developed for their functionality, to create communication opportunities, and for greater sustainability [4], as well as to improve the way we produce and consume fashion [5]. Fashion-tech designers are designing wearables that give new functions to the human body and interact with the environment. Tools such as 3D printing, artificial intelligence, augmented reality, and digital fabrication are among the recent technological advances that enable the design of these smart textiles [6]. Major knitting machine manufacturers have also joined the fashion tech stream, showcasing the capabilities of their machines at textile machinery trade shows such as ITMA, as well as fashion yarn trade shows such as Pitti Filati, technical textiles trade shows such as Techtextil, and functional textiles trade shows such as ISPO sports and Performance days trade shows.

Figure 1. Shima Seiki self-foldable fashion accessories at Itma 2023 in Milan

Eco-tech fashion was first introduced by Sarah Scaturro in a 2008 article titled "Eco-Tech Fashion: Rationalizing Technology in Sustainable Fashion" in the journal Fashion Theory. The term "eco-tech" originated in the field of architecture and refers to the belief that technology is a necessary component of a truly sustainable system [7]. Nowadays, attention to issues such as sustainability, environmental protection and health is growing both in public opinion and among policy makers. In this context, the textile and clothing industry as a whole, as well as individual sectors such as the knitting industry, are considering adopting sustainable development as a business model that pays more attention to environmental issues and human well-being. However, the path to sustainability as a means of promoting growth requires both technological and cultural innovation [8].
Textile and clothing trade shows such as Techtextil, ITMA and ISPO have shown that more and more companies are adopting approaches to greater sustainability based on the "cradle-to-cradle" concept. In knitting, the main focus is on using recycled, reused or even waste materials and increasing production efficiency. Shortening the manufacturing process of a knitted product can be achieved in three ways: by increasing production speed/efficiency, by introducing new technology that allows certain process steps to be skipped, such as seamless knitting, or by merging two or more processes into one, such as hybrid spinning- knitting and sock toe-closing directly on the knitting machine.
In the last decade of the 20th century, knitting seamless clothing accessories evolved into knitting seamless garments. The manufacture of pantyhose led to the development of body-size seamless circular knitting machines, while the manufacture of gloves inspired the development of the so-called »Wholegarment« and »Knit&Wear« flat knitting machines. This was followed

by the development of seamless warp knitting machines. All this led to a commercially successful, low-waste or even waste-free seamless knitting industry of the 21st century. Yet there seems to be a dilemma as to whether seamless knitting is really as sustainable as it is made out to be.
German flat knitting machine manufacturer STOLL recently presented its contribution to low-waste production in the form of a suit knitted almost entirely in one piece. In addition to greater sustainability, the suit offers the look of conventional woven counterparts and the typical stretch comfort of knitwear. It was developed in collaboration between The Woolmark Company, Südwollgroup, Hugo Boss AG and STOLL [9].

Figure 2. Woolen knitted suit, produced on a STOLL machine [9]

Knitting is a constantly evolving process technology that, when combined with digital modeling and design, offers remarkable potential for unlocking opportunities by connecting to the Internet. Knitted fabric manufacturers are increasingly using Inetrnet of Things technology in the manufacturing process to improve production efficiency. Knitting machines equipped with IoT sensors are connected to the Internet, enabling real-time monitoring of production equipment. IoT technology is also used for predictive maintenance of machinery in fabric manufacturing facilities. The data collected from knitting machines in real time helps optimize production planning. For example, knitting machines from knitting and cutting machine manufacturer Shima Seiki can be connected to the company's own product lifecycle management software for efficient production management.

3. SUSTAINABILITY

As part of the recent trend toward sustainability in modern society in general, the knitting sector has also been emphasizing social responsibility and the careful use of resources in the knitting sector as well. Focus has been placed on reusing, recycling and upcycling raw materials and reducing or even eliminating knitting waste. Manufacturers and users were encouraged to rethink processes and volume of production and consumption. Knitting machines that offer environmentally friendly manufacturing techniques with less impact on people and the environment, and production processes that significantly reduce time losses or unproductive time gaps between manufacturing phases were favoured. Increasing knitting speed has also become a major issue, with recent evidence that some manufacturers have reached the peak. In short, sustainability is not just a new approach or trend that is fashionable right now, but a must, a mandatory concept for the survival of businesses in the future [10].
On the other hand, in the field of knitting, there is an antithesis to industrial mass knitting - hand knitting, which has recently been revived as a »do-it-yourself« activity, especially during the

Covid-19 pandemic. Hand knitting is primarily important as a leisure activity with relaxing and therapeutic effects, rather than as an economic activity, although the entry of hand knitting into street and high fashion is not entirely negligible. Discussing the importance of hand knitting in the highly technical environment of the 21st century seems like a step backwards. However, DIY fashion trends in knitting raise awareness of unnecessary consumerism and the recyclability of textiles and clothing, and influence awareness of the crucial importance and inevitability of sustainability in modern society.

4. CONCLUSIONS

Hi-tech, fashion tech and eco-tech concepts play an important role in the knitting industry. Knits and knitwear represent an important sector in the field of fashion and technical textiles, even though they are often still seen in people's minds as simple, traditional everyday items. With sustainable, multifunctional, high-tech and high-performance knitted products designed through material, mechanical and chemical functionalization, a new awareness of the potential of knits and knitwear has emerged. Although the development of sustainable knitting materials and knitting equipment is enabling a slow but steady transition to a sustainable society, the current growth and expectations for further growth of the knitted fabrics and knitwear market indicate that consumerism is still strongly entrenched and awareness of the importance of rational production and consumption in knitting is still far off.

5. REFERENCES

[1] SCI-TECH SOCIETY (2021) Importance of Science and Technology in Contemporary Society. Available at: https://www.scitechsociety.com/importance-of-science-and-technology-in-contemporary-society/ (Accessed: 25 August 2023)
[2] TURNER, J. (2022) The 7 Main Ways Technology Impacts Your Daily Life. In: Tech.Co. Available at: https://tech.co/vpn/main-ways-technology-impacts-daily-life (Accessed: 15 April 2023)
[3] SEAMLESS SOURCING PLATFORM (2019) The Future of Tech Fashion. Available at: https://seamlesssource.com/the-future-of-tech-fashion/. (Acessed: 2 September 2023)
[4] TEAM YOUCAM (2022) AI fashion technology - the complete guide 2023, PERFECT. Available at: https://www.perfectcorp.com/business/blog/general/the-complete-guide-to-fashion-tech (Accessed: 25 May 2023).
[5] KNOX, B. (2021) What is Fashion Technology in 2022 - expert definition & examples, The VOU. Available at: https://thevou.com/fashion/what-is-fashion-technology/ (Accessed: 25 May 2023).
[6] SHAKERI, S. (2022) 10 fashion-tech designers revolutionizing the fashion industry -, Parametric Architecture. Available at: https://parametric-architecture.com/10-fashion-tech-designers-revolutionizing-the-fashion-industry/ (Accessed: 8 June 2022).
[7] SCATURRO, S. (2008) Eco-tech fashion: Rationalizing technology in sustainable fashion, Fashion Theory, 12(4), pp. 469–488. doi:10.2752/175174108x346940.
[8] The ACIMIT Green Guide 2015 (2015). Normanton, West Yorkshire: MCL Global, pp. 4-6.
[9] MY TEXTILE NEWS (2023) Sustainability gallery shows new ways. Available at: https://my-textile-news.com/news-events/karl-mayer-news/sustainability-gallery-shows-new-ways (Accessed: 1 September 2023)
[10] SINHA, R. (2022) What Is Sustainability? And Why Does It Matter? Available at: https://www.greenqueen.com.hk/what-is-sustainability-definition/ (Accessed 5 January 2023)

ECO-FRIENDLY, SUSTAINABLE APPROACH TO DENIM WASHING PROCESS

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ABSTRACT

In this study, we focus on one of the significant process of denim producing: Denim Washing. Dry treatments or nearly water-free treatments are slowly becoming a sustainable trend for replacing traditional wet treatments in denim washing, such as laser and ozone treatment. In coming years, denim washings may involve only such dry or water-free treatments. We are trying to support such a clean applications' performances with our eco-friendly products. We improved ozone treatment's performances with chemical's special penetration properties.

Key Words: Ozone, booster, washing treatment, oxidation, auxiliary chemical.

1. INTRODUCTION

Denim, a cotton woven fabric, may be the most considered article of style today. It is an icon and one of the most familiar products within the textile industry that attracts all age groups. Today design is deficient without denim. [1] The most well-known denim is indigo denim, in which the twist string is coloured whereas the weft string is left white.

The use of denim items in the world has expanded in past years. The global denim jeans market size was valued at $56,204.8 million in 2020 and is estimated to reach $88,138.0 million by 2030, registering a CAGR of 4.2% from 2021 to 2030. (CAGR: Compound Annual Growth Rate)

The resources consumed by such a large industry throughout the process is high. Although denim and jeans have a prominent role in the fashion trade, it is time to think about jeans' impact on the environment. The American Chemical Society mentioned that the production of a pair of jeans consumes more than 10000 L of water (including cotton growing, dyeing and processing of denim), about a half kg of chemicals (in the form of dyes, auxiliaries and finishing agents) and a vast amount of energy (including the irrigation of cotton and subsequent processes such as spinning, weaving etc.) [2].

Denim washing stands out as a part of the essential production processes needed to meet the rapidly rising and changing fashion market's demands. Denim washing is an aesthetic finish that is imparted to fabric to improve the softness and comfort of the fabric. In addition, the fabric achieves a different look such as a faded or worn-out appearance.

Sandblasting, Microsanding are like a mechanical finish which uses sand containing silica. Silica dust spreads in air and poses serious respiratory disease such as silicosis.

Chemical washing like bleaching employs chemicals such as sodium hypochlorite or potassium permanganate. It is harmful to human health and corrodes the stainless-steel drum of the bleaching machine. The effluent contains chlorinated organic substances which cause severe pollution to the environment.

Dry treatments or nearly water-free treatments are slowly becoming a sustainable trend for replacing traditional wet treatments in denim washing, such as laser and ozone treatment. Laser treatment is a water-free, colour fading treatment of denim and is an ecological and economical process. Lasers can create local abrasion, fabric breaks and a 'used' look effect with excellent reproducibility and higher productivity [3].

In ozone treatment, the ozone generated in the equipment can provide a bleaching effect. Commercially available ozone equipment is operated like a washing machine but without much use of water for the colour fading process. In coming years, denim washings may involve only such dry or water-free treatments.

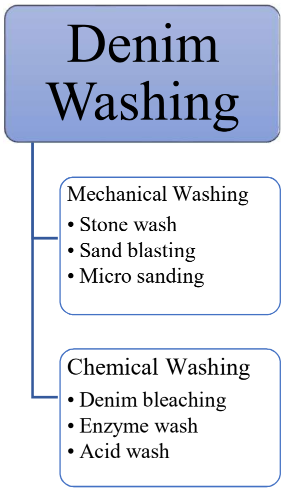

Figure 1: Denim Washing Techniques

2. EXPERIMENTAL

Ozone bleaching process is extremely important to eliminate toxic chemicals and to use them instead of potassium permanganate and similar chemicals in the denim industry.

Ozone washing is based on a natural process that ensures the enrichment of oxygen. In order to bleaching at desired level and homogeneous, it is preferred to use auxiliary chemicals in dry and wet method.

With the developed product; -completely ecological OXYBOOST DRY-, the clean production ozone bleaching process is supported and the performance of treatment is increased. In this study, the fading effect of chemicals on denim fabrics and the chemical's effects on human health, also the consumption of water and chemical compared to the traditional method.

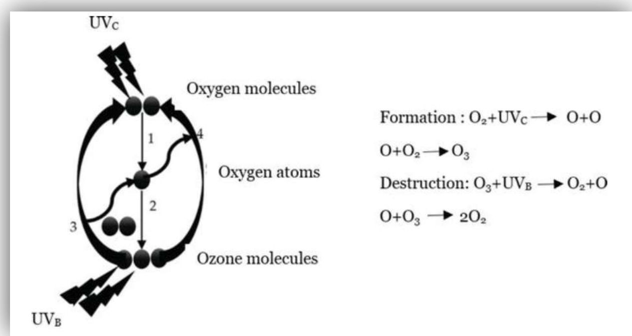

Figure 2: Cycle of formation and destruction of ozone

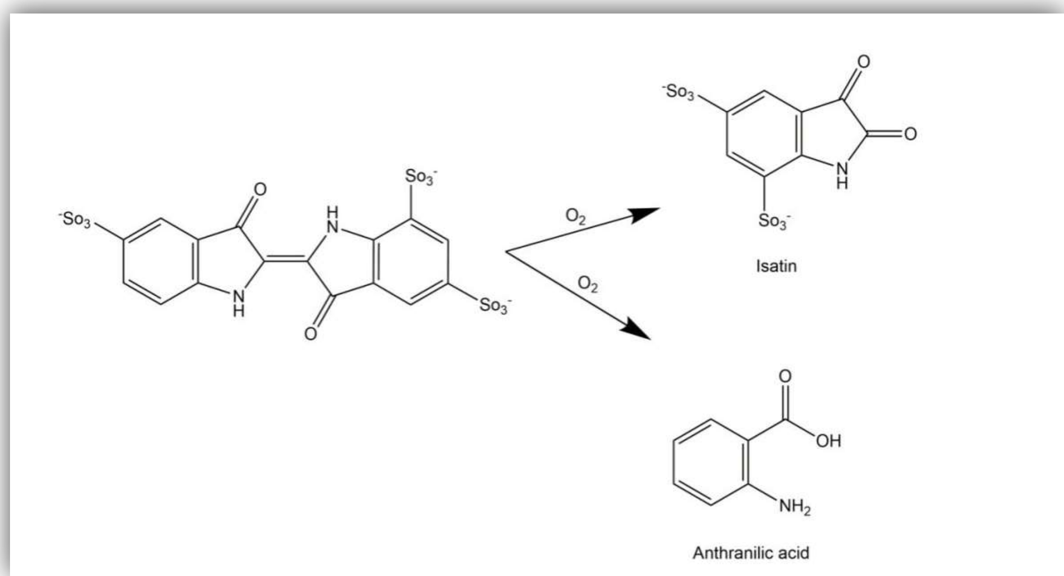

Figure 3: Schematic meachanism of denim bleaching with ozone

3. RESULTS

For determining the fading effect of chemicals to the denim fabric, the surface color is measured with Optical Spectrometer.

The strength properties of treated denim fabric also studied and compared with untreated one.

Table 1: Tearing Strength of treated denim fabric

	Tearing Strength(N, Newton)		
	OZONE ITSELF	WET PROCESS	OXYBOOST DRY

Parallel to the warp (Weft length)	17,27	13,67	18,11
	17,86	12,92	18,91
	17,50	13,60	17,99
	18,13	13,67	17,75
	16,07	15,05	17,66
Avg.	17,37	13,79	18,08

GSM (g/m^2)	
OZONE ITSELF	280
WET PROCESS	263
OXYBOOST DRY	277

Table 2: Fading Properties with optical Spectrometer

	The colour difference		
Samples	L*	a*	b*
OZONE ITSELF	26,80	-0,31	-9,52
WITH WATER	33,57	-1,44	-14,86
OXYBOOST DRY	37,30	-1,89	-13,03

4. CONCLUSIONS

It is obvious that ozone treatment has a significant impact on the mechanical and color properties of denim. Due to Ozone's high oxidation potential (E = 2.07 eV) denim should be treated with a medium concentration of ozone for a short period of time. Aspecially for protecting the strength properties of denim fabric the process of ozone should activate with an additive. With Oxyboost Dry the tearing strength and the GSM properties of the denim fabric are developed. With the comparison studies, ıt is clear that; Water isn't enough to improve penetration properties. If the pick up amount cannot be adjusted correctly, water entering the cellulose spaces will delay bleaching. For an advance appearance with more sustainable way, DRY behave like an activator so desired results can obtain with less application time. With the development of like these products and technologies, the number of studies that will focus on more ecofriendly sustainable textile production will increase.

5. REFERENCES

[1] PAUL R. Denim and jeans: an overview. Denim: manufacture, finishing and applications. 2015.p 1.
[2] SARRA BEN HMİDA, AND NEJİ LADHAR., Ozone: Scıence & Engıneerıng 2015, p, 15.
[3] AYSEGUL E. KORLU., The Journal of the International Ozone Association, 2006,p,24.

AN INVESTIGATION OF ELECTROMAGNETIC SHIELDING EFFECTIVENESS PROPERTIES OF POROUS STRUCTURE IN NON-WOVEN FABRICS

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ABCTRACT

In the study, electromagnetic shielding efficiency (EMSE) absorption and reflectivity properties of fabric produced from staple stainless-steel fibers and recycled staple polyester fibers by carding and needling technologies were investigated. As the conductive fibres were very expensive, the aim of the study was to obtain optimum shielding effectiveness with usage of minimum conductive fibres. The fibre webs were formed at wool type carding machine and then the folded webs were bonded mechanically with needle punching machines. As shown in the figure below, fabric structures with 4 different pore sizes of the conductive structure were produced. It was aimed to investigate the effect of the pore size formed by the conductive structures on the electromagnetic shielding efficiency. Electromagnetic shielding properties, absorption and reflection characteristics of needle punched nonwoven fabrics were performed by coaxial transmission line method according to ASTM-D4935-10 in the frequency range of 15MHz to 3000MHz. It is a known fact that electromagnetic shielding effectiveness increases with the increase of the pore size and the amount of conductive fibre. The developed EMSE nonwoven fabrics have potential applications in defence applications such as military tent, military secret room, protective cover, missile cover and building as an EMI shielding material.

Keywords: Electromagnetic shielding (EM) effectiveness, Electromagnetic radiation, Stainless steel fibre, recycled polyester fibre, Needle punching, Nonwoven fabric

1. INTRODUCTION

With the rapid growth of the electrical and electronic devices and accessories, which emit electromagnetic energy in the different frequency bands used in the markets, it becomes essential to limit and shield electronic equipment against all sources of interference due to all these electromagnetic energies [1-3]. Among the various solutions offered, textile products and textile-based composite materials have caught the attention of researchers for the versatility and conformability these textile structures provide. Increased awareness of EMI has led to the formulation of new regulations around the globe for the manufacturers of electrical and electronic equipment to comply with the electromagnetic compatibility requirements [3-7]. If an electromagnetic wave gets into an organism, it vibrates molecules to give out heat. In the same way, when an electromagnetic wave enters the human body, it will obstruct a cell's regeneration of DNA and RNA. Furthermore, it brings on abnormal chemical activities to produce cancer cells and increases the possibility of leukemia and other cancers. Injuries by electromagnetic waves to the human body are the top priority of professionals and scholars, and we are most concerned with solving this problem [7-13].

2. EXPERIMENTAL

In this study, conductive fibers were used to produce non-woven textile fabrics with conductive properties. Polyester (PES) fibers were produced as cheesecloth in the sample screening machine. The conductive fibers were placed on the cheesecloth by following the determined geometric placement between the produced cheesecloths. Non-woven textile surfaces were produced by needling the created cheesecloths in the needling machine. Structural and electromagnetic shielding efficiency measurements of the produced non-woven textile surface structures with conductive fiber addition were made. The results obtained were evaluated.

2.1. Conductive Fibers and Polyester (PES) Fibers Used

Stainless steel fibers were used as conductive fibers. Stainless steel fibers were supplied from BEKAERTS company. Polyester (PES) was used as insulating fiber. The properties of the fibers used are given in table 1 and table 2 below.

Thin Yarn	Thick Yarn	Tape	PES Fibres

Figure 1 Appearance of Textile Fiber Forms Used

Table 1 Polyester (PES)

Fiber Fineness (denier)	3
Staple Fiber Length (mm)	51
Number of Folds (Curls/inch)	3.73
Breaking Strength (gf/denier)	12-16
Fiber Diameter (micron)	18-19

Table 2 Stainless Steel Fiber Properties

Fiber Fineness (dtex)	6.7
Staple Fiber Length (mm)	60
Fiber Diameter (micron)	26-27
Fiber Composition (Ag-wt%)	12-15

2.2. Non-Woven Fabric Surface Production

Figure 2 Sample Carding Machine

Figure 3 Non-Woven Textile Needling Machine

Table 2 Machine Production Parameters

Number of Needles (Pieces)	3200
Needle Table Width (cm)	23x106
Entry Speed (m)	1.70
Ascent Speed (m)	2.63
Machine Speed (rpm)	397
Needle Type	15x18x38x3.5x R-222-G3037

Table 3 Properties of Produced non-woven textile fabrics

Sample Code	Conductive Structure Pore Shape (cmxcm)	Grammage (g/m^2)	Thickness (mm)
3x3 (TAPE)	3x3	330	1.92
5x5 (TAPE)	5x5	310	2.12
8x8 (TAPE)	8x8	290	1.75
10x10 (TAPE)	10x10	280	1.82
3x3 (THICK-YARN)	3x3	346	2.21
5x5 (THICK-YARN)	5x5	308	1.95
8x8 (THICK-YARN)	8x8	280	2.15
10x10 (THICK-YARN)	10x10	270	2.05

3x3 (THIN-YARN)	3x3	275	1.95
5x5 (THIN-YARN)	5x5	260	2.21
8x8 (THIN-YARN)	8x8	245	2.12
10x10 (THIN-YARN)	10x10	230	1.95

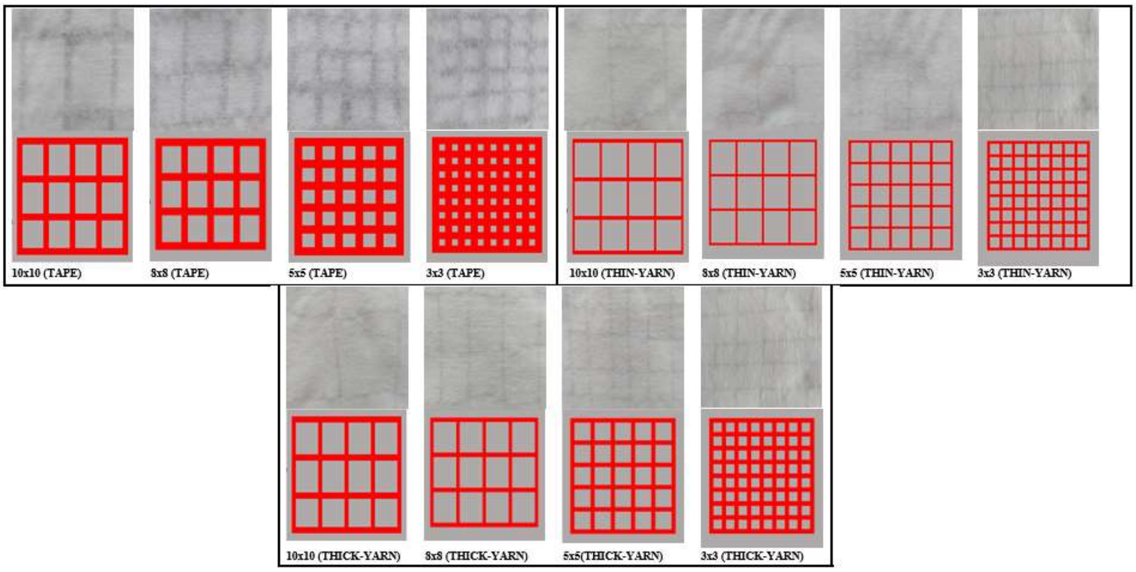

Figure 4 Structural Views of the Distribution of Conductive Surfaces on Produced Non-Woven Textile Surfaces

Figure 5 Electromagnetic Shielding Effectiveness Measurement Test Device

Figure 6 Conductivity Measurement Device with Four Point Technique

3. RESULTS

Comparisons regarding the effects of porosity density, one of the important fabric parameters of the produced textile structures, on the electromagnetic wave shielding effectiveness and the effects on the absorption-reflection amounts that form the shielding are given in graphs.

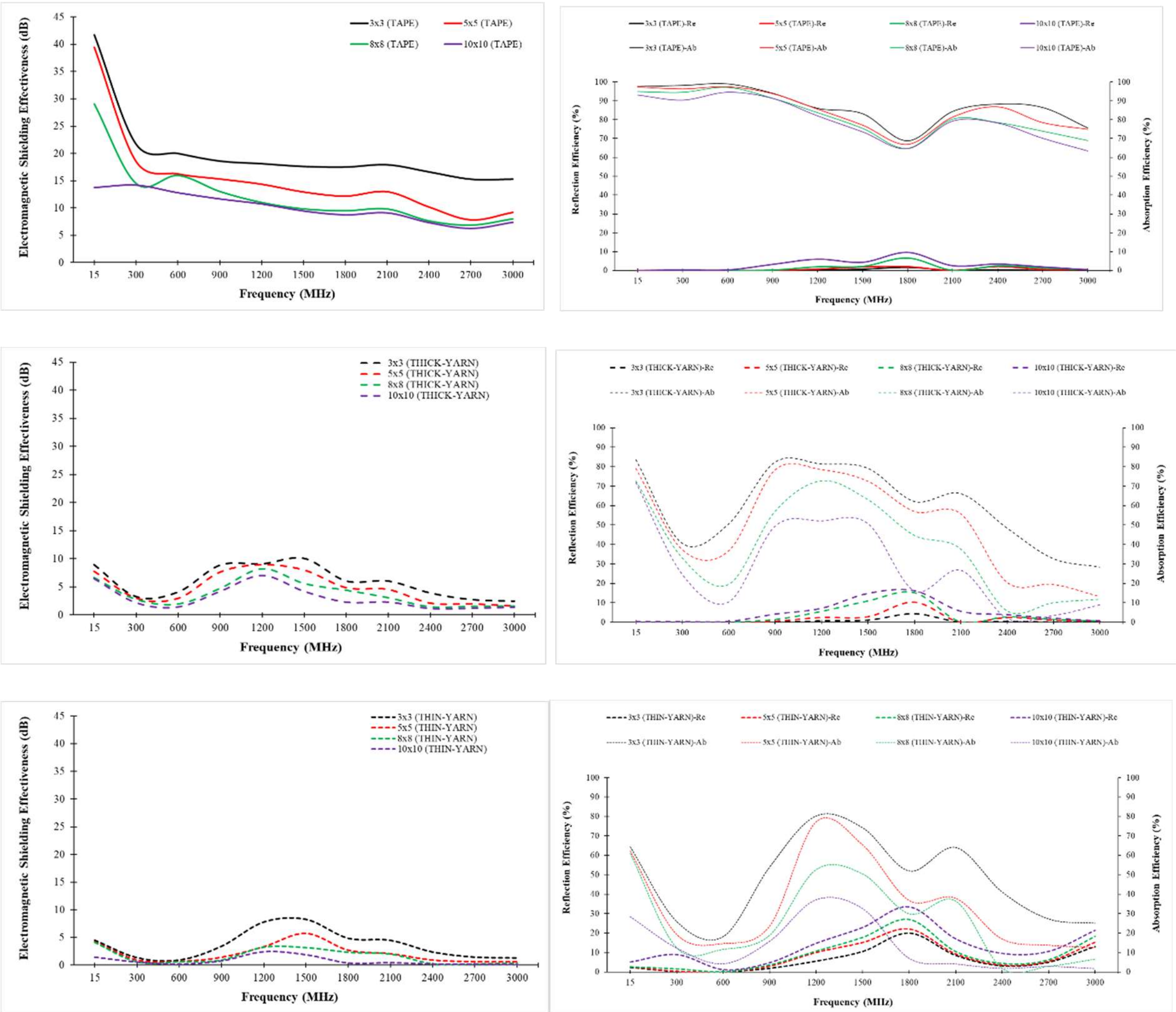

Figure 7 Effects of Conductive (Form) Porous Structure Size on Electrical Conductivity and Electromagnetic Shielding Effectiveness (EMSE)

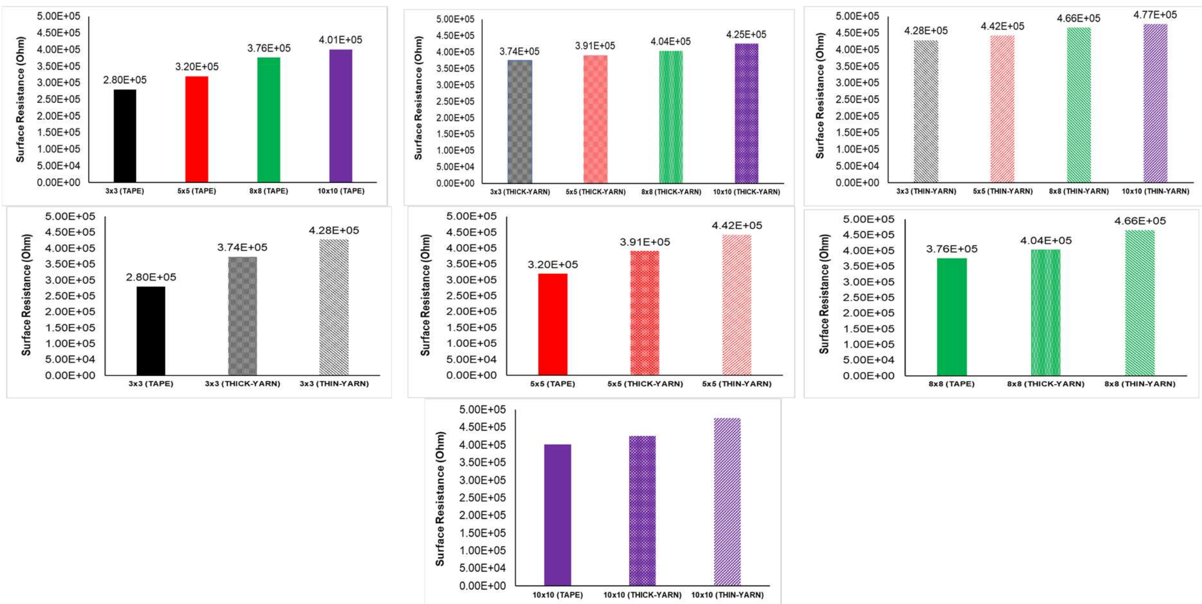

Figure 8 Electrical Conductivity of Conductive Structure Form in Porous Structure Dimension

4. CONCLUSIONS

According to the results obtained, textile surfaces were produced by using conductive fibers and conductors with different pore sizes and different form properties. An evaluation was made by comparing the results obtained. In the evaluation made without taking into account the differences in pore size and conductive form; Conductive textile structures The amount of electromagnetic shielding effectiveness increases with increasing frequency in the 15-3000 MHz frequency range. When 3x3 pore size conductive fiber form is used in tape form; It shows higher electromagnetic shielding efficiency than other structure forms in the frequency range of 15-3000 MHz. When 3x3 pore size conductive fiber form is used in tape form; In the frequency range of 15-3000 MHz, the average is around 25 dB, which means a shielding percentage of 99.99%. The reason for such a result is; The amount of conductive material per unit area is high. An increase in the surface resistance of textile surfaces indicates that their conductivity decreases, and conversely, a decrease in surface resistance indicates an increase in their conductivity. The results obtained from the measurements show that as the porosity size increases, the surface resistance increases and accordingly the conductivity decreases. As a result of the measurements, the textile surfaces with porosity of conductive fibers in the form of 3x3 bands show the lowest surface resistance and therefore the highest conductivity. As a result of the measurements, the textile surfaces with porosity of conductive fibers in the form of 10x10 bands show the highest surface resistance and therefore the lowest conductivity. The reason for such a result is; It is the change in the amount of conductive material per unit area and the isolation of the conductive layer by the insulating layer.

5. REFERENCES

[1] CHENG, K.B.: Production and electromagnetic shielding effectiveness of the knitted stainless steel/polyester fabrics, *Journal Textile Enginering,* Vol. (46) No.2, pp. 42–52, (2000), ISSN: 1880-1986
[2] CHENG, K.B. ET AL: Electromagnetic Shielding Effectiveness of the Twill Copper Woven Fabrics, *Journal of Reinforced Plastics and Composites*, Vol. (25) No.7, pp. 699–709, (2006), ISSN: 0731-6844
[3] CHING-LUAN, S. & JIN-TSAIR, C.: Effect of Stainless Steel-Containing Fabrics on Electromagnetic Shielding Effectiveness, *Textile Research Journal*, Vol. (74) No.51, pp.51-54, (2004), DOI: 10.1177/004051750407400109
[4] ŞEKER, S. & ÇEREZCI, O.: C*evremizdeki Radyasyon ve Korunma Yontemleri*, Bogazici Universitesi Yayinlari, ISBN: 975-518-089-3, pp.22-30, Istanbul, (1997)
[5] BRZEZINSKI, S., RYBICKI, T., MALINOWSKA, G., KARBOWNIK, I., RYBICKI, E., SZUGAJEW, L. (2009) Effectiveness of Shielding Electromagnetic Radiation, and Assumptions for Designing the Multi-layer Structures of Textile Shielding Materials. Fiber & Textiles in Eastern Europe, 17(1), 60-65.
[6] BRZEZINSKI, S., RYBICKI, T., KARBOWNIK, I., MALINOWSKA, G., RYBICKI, E., SZUGAJEW, L., LAO, M., SLEDZINSKA, K. (2009) Textile Multi-layer Systems for Protection against Electromagnetic Radiation. Fiber & Textiles in Eastern Europe, 17(2), 66-71.
[7] PALAMUTÇU, S., ÖZBEK, A., KARPUZ, C., DAĞ, N., ÖZTÜRK, P. Elektromanyetik Kalkanlama Özelliği Olan Tekstil Yüzeylerinin Üretimi ve Yüzeylerin Kalkanlama Etkinlik Alanının Araştırılması.Tübitak Projesi, 107M454, 2010. (092)
[8] PARK, K. Y., LEE, S. E., KIM, C. G., HAN, J. H. (2006) Fabrication and Electromagnetic Characteristics of Electromagnetic Wave Absorbing Sandwich Structures. Composites Science Technology, 66, 576-584.

[9] ÖZEN M.S., SANCAK E., BEYIT A., USTA İ., AKALIN M. (2013) Investigation of Electromagnetic Shielding Properties of Needle-Punched Nonwoven Fabrics With Stainless Steel and Polyester Fiber. Textile Research Journal, 83(8), 849-858.
[10] ÖZEN M.S., SANCAK E. (2016) Investigation of Electromagnetic Shielding Effectiveness of Needle-Punched Nonwoven Fabrics with Staple Polypropylene and Carbon Fibres. The Journal of The Textile Institute, 107(2), 249-257.
[11] HUA Z., PING C., RUIXIN W., HUI Z. (2007) Microwave Absorption Properties of Carbon Fiber Containing Nonwovens. Indian Journal of Fibre &Textile Research, 32, 391-398.
[12] ÖZEN M.S., SANCAK E., AKALIN M. (2015) The Effect of Needle-Punched Nonwoven Fabric Thickness on Electromagnetic Shielding Effectiveness. Textile Research Journal, 85(8), 804-815.
[13] ÖZEN M.S., SANCAK E., SOIN N., SHAH T.H., SIORES E. (2016) Investigation of Electromagnetic Shielding Effectiveness of Needle Punched Nonwoven Fabric Produced from Conductive Silver Coated Staple Polyamide Fibre. The Journal of The Textile Institute, 107(7), 912-922.

DENIM ART

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ABSTRACT

Reducing the harm of chemicals to the environment and efficient use of natural resources various researches and studies have been carried out to reduce the water used in conventional warp dyeing processes. For this purpose, a machine design that will make a difference in denim warp dyeing has been made. Except for dye groups such as indigo, sulphur, reactive and indanthrene used in warp dyeing, dyeing is planned with pigment dyestuffs not used in warp dyeing.
It is not possible to complete the dyeing process without using water in standard warp dyeing processes. After dyeing, water contaminated with chemicals accumulates as waste. In order to perform warp dyeing without using water with the newly proposed dyeing process, modification processes have been carried out in the existing processes.

Keywords: Colour denim, ecological dyeing

1.INTRODUCTION

Natural indigo dye is obtained from the plant called Indigofera. It was used in India about 5000 years ago. Synthesis of indigo by synthetic means was carried out by Adolf von Bayer in 1850. Synthetic (leuco) indigo is used today.

Since indigo dye has no affinity for cellulose fiber, it is made soluble in water (reduced) with caustic (NaOH: Sodium hydroxide) and Hydrosulfite (reducing aid) in alkaline medium and bonded to cotton with physical bonds.

Dyeing is done in rope form or in warp form (Slasher). In these dyeing methods, different methods are used to obtain different tones.

Pure Indigo: It is the dyeing made by using only indigo as a dyestuff. Suitable for all kinds of industrial washing.

Sulphur Bottom: There is a pre-treatment vessel before the indigo vessels in dyeing. Color and appearance differences can be obtained by applying pre-treatments such as mercerizing process and sulphur bottom in this box. In the pre-treatment of sulfur bottom colors, a preliminary coloring is made with sulfur-based paint. In sulfur bottom colors, there is indigo on the upper part of the yarn and sulfur dye on the inside. As the colour wash down, the indigo disappears and the sulphur dye emerges from below.

Sulphur Top: It is a type of dyeing that is mercerized at different concentrations in the pre-treatment, indigo is applied in different bases and amounts, and sulphur dyeing is applied on the indigo in the desired colors. The product turns into a darker indigo depending on the upper sulphur, and as the sulphur on it moves away, it turns into a clean indigo during the washing process.

Sandwich Dyeing: It is a type of dyeing in which a single bottom sulfur dye is applied in the desired colors in the pre-treatment and after indigo is applied in different bases and weights, sulfur dyeing is applied on the indigo as the requested shade. Since its dyeing consists of 3 steps, it provides a wide variety of color wash downs.

The completion of the dyeing process without using water in standard warp dyeing processes and the absence of waste water after dyeing has led to the search for innovative and ecological solutions. For this reason, investigation of dyes and chemicals that can replace chemicals that are toxic and create a waste water load in the textile industry, it is aimed to research the machine design and dye group that will make a difference in denim warp dyeing, to create more environmentally friendly new products, and to create a new, colourful warp dyeing process for the denim world.

The dyeing process developed for water consumption in the enterprise is carried out together with sizing. Rope dyeing and slasher (open width) dyeing processes are carried out conventionally in warp dyeing of denim fabric production. In this study, the new dyeing method was compared with rope dyeing and slasher dyeing in terms of water consumption.

2. MATERIAL AND METHOD
2.1. Material

One of the existing machines, which is not a warp dyeing machine, has been modified and turned into a warp dyeing machine. Studies have been carried out on the behavior and reproducibility of the dye group, which is not used in warp dyeing in conventional dyeing, in single, double-triple combinations.100% cotton open end yarn was used in the scope of the study. Test values of fiber and yarn are given in the tables (table 1. and table 2.) below.

Table 1. HVI values of 100% cotton fiber used in the study

HVI Test Parameters	Average Values
SCI (Spinning Consistency Index)	129,67
Mic (Mikroner)	4,49
Mat (Maturity)	0,87
Len (Length) (mm)	29,26
Unf (Uniformity) (%)	82,28
SFI (Short Fiber Index-fiber content shorter than 12,7 mm) (%)	7,45
Str (Strength) (cN/tex)	32,2
Elg (Elongation) (%)	6,56
Moist (Moisture) (%)	7,3
Rd (Reflectance Degree)	68,54
+b (Yellowness Degree)	9,06

2.2. Metod

2.2.1.Rope Dyeing Process

In the conventionally applied rope dyeing process, the warps that come in the form of rope go through rope opening and sizing processes after indigo dyeing.

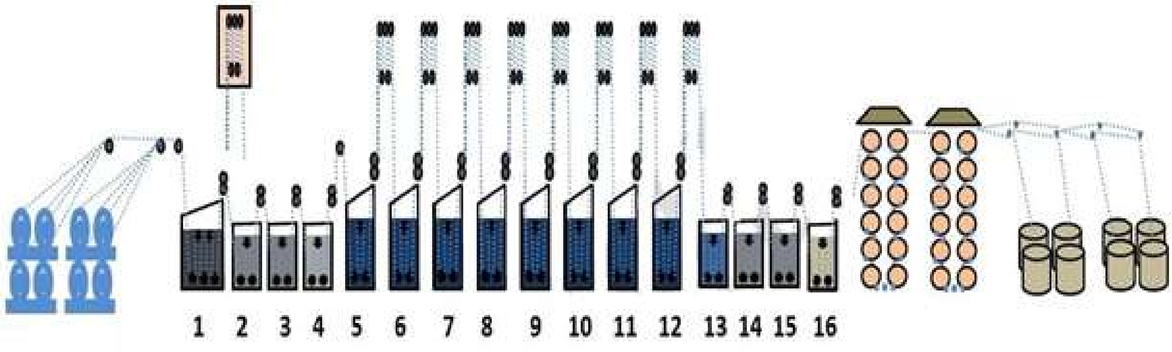

Figure 1. Rope dyeing machine

The first four tubs (1-4) shown in the figure are pre-treatment (pre-wash) vats with a capacity of 1500 litres, the next eight boats (5-12) are indigo dyeing vats with a capacity of 4000 litre, and the four at the rear (13-16) are 1500 litres. Capacity after treatment (backwash) troughs. Machine and yarn parameters for dyeing are given below.

Table 3. Rope dyeing process

		Rope Dyeing	
Tub No		**Tub function**	**Solution/Water Volume (L)**
1	Prewash tubs	Mercerized	1500
2		Wash	1500
3		Wash	1500
4		Wash	1500
5		Wash	4000
6	Indigo dyeing tubs	Indigo dyeing	4000
7		Indigo dyeing	4000
8		Indigo dyeing	4000
9		Indigo dyeing	4000
10		Indigo dyeing	4000
11	Rear wash tubs	Wash	4000
12		Wash	4000
13		Wash	1500
14		Wash	1500
15		Wash	1500
16		Wash	1500

As can be seen from the table, mercerization process was applied in the tub no 1. 5 g/l wetting agent and 4 Be caustic (50% NaOH) were used for the mercerization process.In rope dyeing, the washing process was carried out in the 2, 3, 4 and 5 numbered prewash tubs, while the dyeing process was carried out between the 6th and 10th tubs.In the rope dyeing process, backwashing was carried out on the last six tubs (boats 11-16).In rope dyeing, 250 liters of water per minute was fed to the front and rear washing trays.

2.2.2 Slasher (open width) Dyeing Process

Warp in the slasher dyeing process, which is conventionally applied in the enterprise
The warps coming from the beams are in open width form, first indigo dyeing and then sizing.

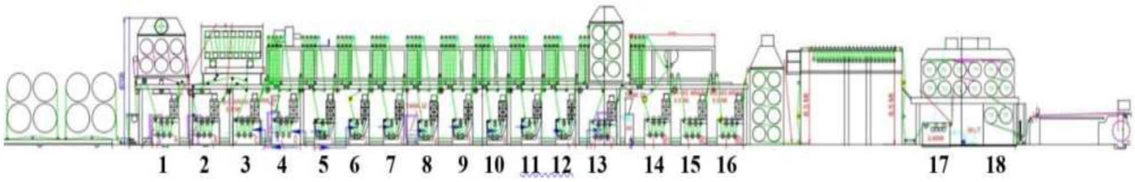

Figure 2. Slasher (open width) dyeing machine

The first tub shown in the figure is mercerizing, the next three tubs are (2-4) wash tubs, the next six tubs (5-10) are indigo dyeing tubs, and six tubs at the back (11-16) are washing tubs. In the last two tubs (17-18), sizing is done.

Table 4. Slasher dyeing process

		Slasher Dyeing	
Tub No		Tub function	Solution/Water Volume (L)
1	Prewash tubs	Mercerized	500
2		Wash	1500
3		Wash	1500
4		Wash	1000
5	Indigo dyeing tubs	Indigo dyeing	1000
6		Indigo dyeing	1000
7		Indigo dyeing	1000
8		Indigo dyeing	1000
9		Indigo dyeing	1000
10		Indigo dyeing	1000
11	Rear wash tubs	Wash	1000
12		Wash	1000
13		Wash	1500
14		Wash	1200
15		Wash	1200
16		Wash	1200
17	Sizing tubs	Sizing	400
18		Sizing	400

2.2.3 Sizing Warp Dyeing Process

Sizing warp dyeing developed to reduce water consumption in the enterprise.

The pigment dyestuff used in the process is transferred to the sizing solution taken in a separate boiler after cooking.

The total amount of solution in this boiler is 400 liters and this amount is sizing. Schematic of the sizing machine with the machine and yarn parameters of this process is given below. As seen in the figure 3, the machine has 2 sizing chambers and the application is only one.

Table 5. Sizing warp dyeing process information

	Sizing Warp Dyeing
Warp wire count (pcs)	3744
Warp length (m)	500
Warp (Ne)	8,25
Machine speed (m/min)	25
Staining concentration (%)	1,50

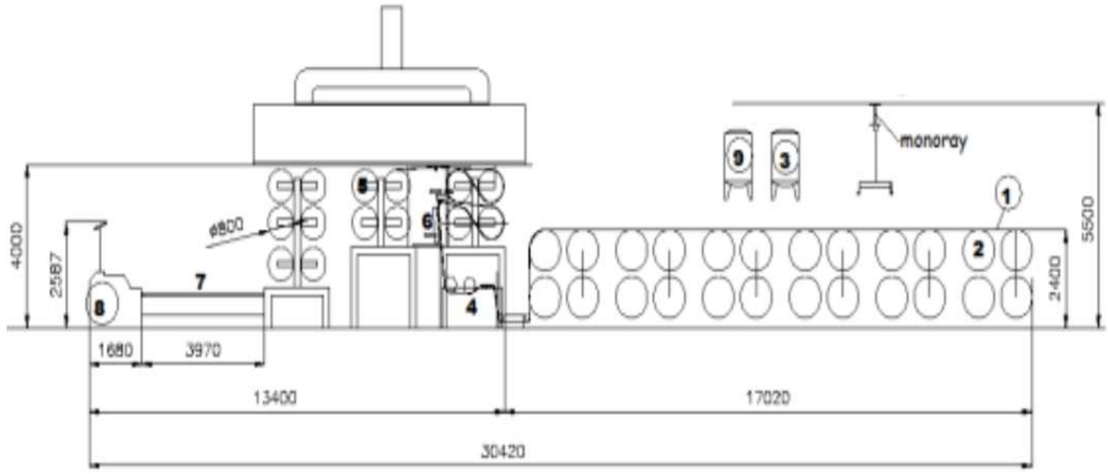

Figure 3. Modıfied machine

3. RESULTS AND DISCISSION

3.1.Rope Dyeing Process Water Consumption

Water consumption in rope dyeing is given below. The amount of water spent for dyeing and then sizing 20,000 meters of warp in a rope dyeing machine was calculated as 551.56 tons.

*Calculated at 20 m/min working speed for 20,000 meters of warp yarn. Since 20 meters of warp yarn is dyed per minute, 1000 minutes will be processed for 20,000 meters of warp, and therefore, water will be fed to the front and rear washing troughs for 800 minutes. Since the water feed rate is 500 lt/min (total of front and rear boats), 500 tons of water will be fed to the boats in 800 minutes.

**8000 lt sizing solution was used for sizing 20,000 meters of warp yarn. Since 94.5% of the solution is water according to the sizing recipe, the amount of water consumed for this process was calculated as 7.56 tons. Calculated at a working speed of 20 m/min.

Table 6. Rope dyeing process water consumption

Water Consumption	Rope dyeing
Amount of water fed to indigo tubs at first filling (tonnes)	20 (Capacities of tubs 7-12)
The amount of water fed to the wash tubs at the first filling (tonnes)	24 (tubs 1-5 and 11-16 capacities)
Amount of water fed to wash tubs during dyeing (tonnes)	500*
Amount of water consumed in sizing	7,56**
Total (tonnes)	551,56

3.2. Slasher Dyeing Process Water Consumption

The slasher of the 20,000 meters warp the amount of water consumed in the dyeing and sizing process in the machine is 157.8 tons.

Table 7. Slasher dyeing process water consumption

Water Consumption	Slasher Dyeing
Amount of water fed to indigo tubs at first filling (tonnes)	6 (Capacities of tubs 5-10)
The amount of water fed to the wash tubs at the first filling (tons)	12,1 (tubs 1-4 and 11-16 capacities)
Amount of water fed to wash tubs during dyeing (tons)	133*
Amount of water consumed in sizing	6,7**
Total (tonnes)	157,8

*Calculated at 20 m/min working speed for 20,000 meters of warp yarn. 20 meters of warp yarn per minute since it is dyed, 1000 minutes will be processed for 20.000 meters of warp and therefore 1000 minutes of front and back washing. Water will be supplied to the boats. Since the water feed rate is 8 tons/hour (to the front and rear boats total) 133 tons of water will be supplied to the boats in 1000 minutes.

**7050 lt of solution was used for sizing 20,000 meters of warp yarn. % of solution according to sizing recipe since 94.5 of it is water, the amount of water consumed for this process was calculated as 6.7 tons. for 20 m/min operating speed calculated.

3.3. Sizing Warp Dyeing Process Water Consumption

After sizing 500 meters of warp, the amount of solution remaining in the sizing vessel is 240 liters and it has been observed that 160 liters of solution are used for this process. According to the recipe used; of the solution since 78.4% is water, 125 liters of 160 liters of solution is calculated as the amount of water consumed in this dyeing process, and the amount of water consumed for dyeing and sizing 500 meters of warp in the same solution at the same time is 125 liters. Accordingly, the amount of water spent for dyeing and sizing 20,000 meters of warp will be 5000 liters.

4. CONCLUSIONS

There was no significant difference between the fastness (washing, water, sweat and rubbing) test results of denim fabrics in which yarns dyed with warp dyeing and rope/slasher dyeing processes are used in the warp.

When the recipes are examined, caustic is not used in the water-saving dyeing process, unlike the rope dyeing, and this is considered as a positive approach in terms of environmental pollution.

In the warp dyeing process, it is about approx. It has been determined that 99.1% of water saving is achieved.

In the rope dyeing process, a total of 544 tons of water, of which 500 tons is fed to the front and rear washing tubs during the process, and 44 tons of water is fed to the washing tubs and indigo tubs at the first filling, is given to the environment as waste after the water dyeing process. Considering that the remaining 240 liters of solution in the sizing dyeing process is waste, it is thought that 0.2 tons of water can be considered as waste since the amount of water in the solution is 78.4%. Thus, it was determined that the amount of waste water decreased by approximately 99.8% with the size dyeing process. However, as in conventional sizing, the remaining sizing solution can be recovered and reused in the enterprise.

LOW TEMPERATURE BLEACHING OF COTTON FIBER BY NOVEL CATALYST

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ABSTRACT

Peroxide bleaching is commonly carried at high temperature (normally ~98 °C) and high pH, which causes significant fiber loss and therefor poor strength properties[2]. There is some catalyst which has been developed for mild bleaching of cotton by controlling H_2O_2 decomposition speed such as; Copper (Cu), Ferrum (Fe) and Titanium (Ti). In this work, we designed a bleaching method at low temperature (~80 °C) stain removing by using special catalyst which can activate and control H_2O_2 decomposition under alkaline conditions for improving traditional bleaching method.

Key Words: Bleaching, Cotton, Peroxide, Catalyst, Sustainability

1. INTRODUCTION

Cotton has been grown for fiber, food and even fuel for over 6.000 years. The cotton is one of the most important fiber and play dominant role in textile industry. It is a natural fiber, grown from the earth and spun into a soft yarn. The cotton fabrics are favoured among natural cellulose fabrics because of their comfort, breathability, and softness [1].

The cotton that has been harvested from the plants will have seeds embedded inside it, pectin, ash, organic acid, wax, sugars and others which need to be mechanically and chemically cleaned before further processes. From field to fabric, the process of making cotton transforms the raw fibers into threads, yarn and fabric in three steps: Purification, Spinning, and Weaving.

One of the chemical purification steps of the cotton is bleaching. Main goals of the bleaching process are to obtain a white, ultimately cleaned substrate in the shortest time (highest productivity) possible with minimum fiber damage.

The most widely used bleaching agent is hydrogen peroxide (H_2O_2). This agent uses a form of oxygen as the oxidizing agent in the process. Decoloration can occur by breaking up the chromophore groups, most likely destroying one or more double bonds within the conjugated system. H_2O_2 is easily decomposed (Figure 1) due to its instability and the catalytic effects from metal ions present in bleaching solution, which leads to increase in running cost and damaging the cotton fiber. To improve the bleaching efficiency, many catalysts and methods have been developed to control of the H_2O_2 decomposition.

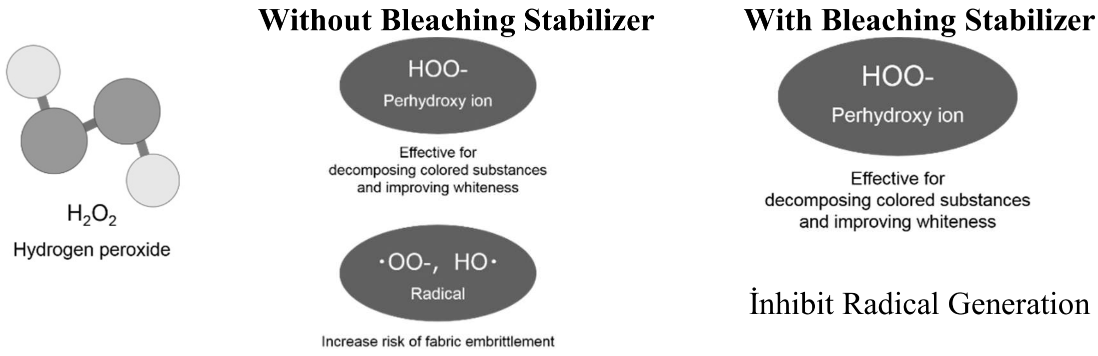

Figure 1. H_2O_2 radical generation and inhibition.

In this work, we designed a bleaching method at low temperature (~80 °C) stain removing by using special catalyst (Figure 2) which can activate and control H_2O_2 decomposition under alkaline conditions for improving traditional bleaching method. Key advantage of the developed product novel bleaching process is energy cost saving due to lower bleaching temperature, 50% shorter bleaching cycle by improving production capacity, milder processing conditions such as higher cotton yields, softer feeling cotton, less creasing in final fabric.

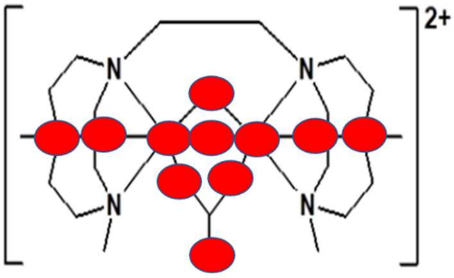

Figure 2: Structure of Special Catalyst.

2. EXPERIMENTAL

In this work, we applied two different solution recipes with and without developed product included at different temperatures as summarized in Table 1.

3. RESULTS AND DISCUSSION

In the same bleaching application duration, whiteness index (berger) value of the cotton sample reached higher values in the presence of activator. While we were comparing different temperature, we can reach the optimum accepted whiteness result at 80°C. Even though 98 °C gives higher whiteness in cotton fabric, application temperature is too high for the sustainability aspects.

Table 1. Bleaching of Cotton Fabric with and without Catalyst

Application Temperature (°C) and Time (min)		70°C- 45 min.		80°C- 45 min.		98°C- 45 min	
Sample Name		RECIPE-1	RECIPE-2	RECIPE-1	RECIPE-2	RECIPE-1	RECIPE-2
Mn Based Bleaching	g/L	1	-	1	-	1	-
Traditional Bleaching	g/L	-	1	-	1	-	1
Capillarity	min /sec	>5 min	>5 min	15sec.82 sl. 14sec.44 sl.	>5 min	5 sec. 88 sl. 5 sec. 35 sl.	5 sec. 92 sl. 5 sec. 65 sl.
Berger Value		67,80	61,19	71,73	67,12	76,05	74,08

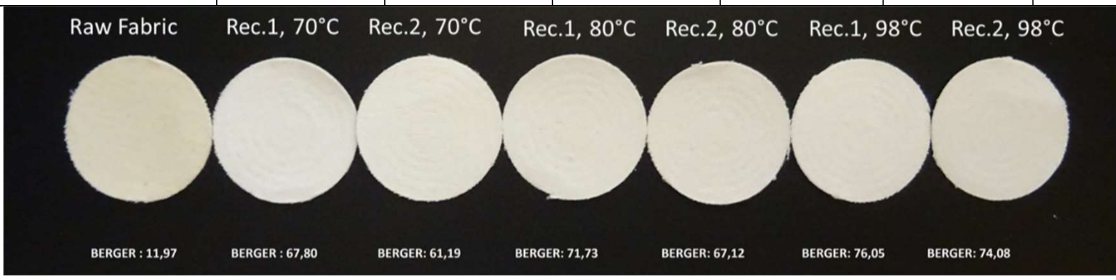

Figure 3. The whiteness comparision of knitted cotton fabric at different solution and application temperatures.

4. CONCLUSIONS

Concern over the environmental impact from the industrial processing of cotton and its blends has increased in recent years. Bleaching of cellulosic materials is commonly performed at the boiling point.

To reduce the ecological footprint of the bleaching process, we developed special catalyst based product, a bleaching booster that works as low as 80°C in discontinuous processes on natural fibers and their blends. It drastically reduces energy consumption during the process and delivers an exceptional degree of whiteness and absorbency without strength loss.

5. REFERENCES

[1] KHATRI, A. A review on developments in dyeing cotton fabrics with reactive dyes for reducing effluent pollution. Journal of Cleaner Production, 2015, vol. 87, pp 50-57.
[2] FONTANA, G. Effect of the Bleaching on Physical and Mechanical Properties of Different Fabrics. Fibers and Polymers, 2018, vol. 19, No.12 pp 2590-2596.

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