University of Zagreb Faculty of Textile Technology

BOOK OF PROCEEDINGS

14th Scientific – Professional Symposium
TEXTILE SCIENCE & ECONOMY

University of Zagreb Faculty of Textile Technology

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Editors:
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Anja Ludaš, mag. ing. techn, text.
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TZG Logo:
Prof. Martinia Ira Glogar, Ph.D.

Contact address:

University of Zagreb
Faculty of Textile Technology
Prilaz baruna Filipovića 28a
HR-10000 Zagreb
Phone: +(385) (1) 3712500
e-mail: tzg@ttf.unizg.hr
http://ttf.unizg.hr

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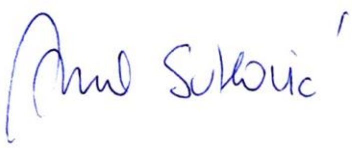
Editor's word

The 14th International Scientific-Professional Symposium "Textile science and economy" - TZG 2022, was organised by the University of Zagreb, Faculty of Textile Technology on January 26, 2022 with the theme "The transfer of innovations to the economy". The TZG 2022 symposium was realised in partnership with the Union of Croatian Innovators and the Zagreb Inventors Association with patrons Ministry of Science and Education, Ministry of Economy and Sustainable Development, University of Zagreb, Croatian Employers Association, Croatian Academy of Engineering, Chamber of Economy, Croatian Chamber of Trades and Crafts, Croatian Association of Textile Engineers and Croatian Leather and Footwear Society. The current topic of TZG 2022, as a basis for sustainable development and increasing the competitiveness of the economy, opened the possibility to submit papers on the latest scientific, artistic and technological achievements with an emphasis on innovation, sustainability, circular economy, advanced processes and technologies, digitalization, ecology in the following thematic areas: textile fibers and advanced materials, textile design, textile refinement and care, dyeing and textile printing, clothing technology, analysis, testing and quality control, design and marketing of textiles and clothing, sustainable textile products and processes, footwear technology, energy, applied fundamental natural and technical sciences and modern educational methods of learning and teaching. At the TZG symposium, 138 participants from the national and international academic community, the economic sector, government institutions, and the field of professional education presented 39 papers in the form of posters and oral presentations. 500 participants followed the meeting online via the official TZG 2022 website and You Tube channel. The international visibility of the TZG 2022 symposium is provides by collaboration and publication of the papers in journals published by MDPI, while a part of the papers will be published in the national journal Textile. Other full papers are available in digital form in the TZG 2022 Book of Proceedings. All papers presented at the TZG 2022 symposium are available in digital form in the TZG 2022 Book of Abstracts. In addition, the proceedings of the symposium "Textile Science and Economy" available in the collection of the German National Library of Science and Technology (TIB), a central comprehensive database for publications in the field of engineering sciences, with the aim of their permanent availability to the scientific community. During the symposium, five plenary lectures were given by distinguished speakers. The head of the Office for Technology Transfer and acting head of the Center for Research, Development and Technology Transfer of the University of Zagreb, Ms. Vlatka Petrović, gave a presentation on "Managing innovation for successful industry-academia collaboration". Linda Kasalo Malić, head of the Project Evaluation and Contracting Sector at HAMAG-BICRO, held a lecture "Possibilities for transformation of the economy through innovation and technology transfer using EU funds". This was followed by Mr. Neven Marković, secretary of the Association of Innovators Zagreb with the presentation "Commercialization of Innovations" and Mr. Matija Žugec from the Association of Croatian Innovators with the topic "Protection of Intellectual Property". The plenary lectures were concluded with a presentation by Prof. Dubravko Rogale Ph.D. "Development and importance of innovations at the Faculty of Textile Technology". There were also six invited presentations: Prof. Ante Jukić Ph.D., dean of

the University of Zagreb, Faculty of Chemical Engineering and Technology "Academic entrepreneurship and transfer of innovations to industry at the Faculty of Chemical Engineering and Technology"; Boris Ćosić, representative of the Centre for Technology Transfer Ltd. of the University of Zagreb, Faculty of Mechanical Engineering and Shipbuilding "The strategic importance of technology transfer for universities / faculties dedicated to the commercialization of academic knowledge - an example of the Center for Technology Transfer at the Faculty of Mechanical Engineering and shipbuilding"; Prof. Nedjeljko Perić Ph.D., from the Nikola Tesla Innovation Centre of the University of Zagreb, Faculty of Electrical Engineering and Computing "Key assumptions and factors for the development of innovations and their transfer to the economy"; representative of the company Čateks dd Nino Kerman "Presentation of the IRI2 project: Development of multifunctional non-combustible fabric for dual purpose"; Tomislav Pokrajčić from the company Jel-Tom doo "Jel-Tom's innovative solutions for the Protection of the marine environment through “Wave Breakers” and “Box Barriers" and others (Croatian patents)”; assoc. prof. Angel Terziev Ph.D., from the Technical University of Sofia "Presentation of the Erasmus + Knowledge Alliance project - ICI-TEX courses-new opportunities for e-learning digital skills for the textile and clothing industry".
Additionally, as part of the consultation, the TTF Gallery organized the exhibition "Three Threads" by assoc. prof. art. Koraljka Kovač, prof. art. Andrea Pavetić and assist. prof. art. Marin Sovar and virtual exhibitions: prof. Snjezana Firšt Rogale Ph.D. "TTF innovations"; assoc. prof. art. Koraljka Kovač Dugandžić and assist. art. Lea Popinjač "Cooperation of the University of Zagreb, Faculty of Textile Technology and Regeneration" and assoc. prof. art. Koraljka Kovač Dugandžić "Textile Design 02 - Cooperation of the University of Zagreb Faculty of Textile Technology, Prostoria and Galleries of the Academy of Fine Arts".
TZG 2022 has once again shown that the Faculty of Textile Technology and the Croatian textile and clothing industry together synergistically create new knowledge and thus advance the development of Croatia.

Proceedings editors:



Prof. **Ana Sutlović** Ph. D.
President of the Organizing Committee

Prof. **Snježana Firšt Rogale** Ph. D.
President of the Scientific Committee

CONTENTS

Original Article

MEASUREMENT OF THERMAL INSULATION OF A PILOT JACKET

Goran MAJSTOROVIĆ

[1] Faculty of Technical Sciences University of Kragujevac, Čačak, Serbia; goran.majstorovic@ftn.kg.ac.rs
***** Corresponding author: goran.majstorovic@ftn.kg.ac.rs

Abstract: *In this paper, a test of the thermal insulation of the so-called pilot jackets was performed. For the needs of the research, the basic construction was made and two jackets of different basic and lining materials were made. All materials used were laboratory tested for properties textile parameters. The thermal insulation of the pilot jacket was measured on a thermal mannequin, that determines the thermal properties of clothing at rest and the simulation of walking. These tests show that the thermal insulation depends on the materials used, on the basis of which all factors relevant to the technical design of a new garment with precisely specified thermal properties can be determined during the technical design of a garment with the required thermal protection.*
Keywords: *thermal insulation, pilot jacket, thermal mannequin, waterproof and airtight fabric*

1. Introduction

Textile and clothing are an integral part of the human being with a primary role in protecting the body from an unsuitable environment while avoiding mechanical, thermal and chemical damage and maintaining thermal equilibrium [1]. The main purpose of clothing is to maintain a normal body temperature and protect the body from various external factors. It is very important that during the development of new fabrics designed for the production of clothing thermal comfort is evaluated at the same time [2]. In the case of new textile materials, new methods of application have been developed, e.g. as a high-grade thermal insulator, which required further research into their thermal insulation properties under various operating conditions. The thermal insulation properties of textile materials depend on their thermal conductivity, density, thickness and heat release [3].
Accurate measurements in the field of thermal insulation of clothing began in the 1940s when the US military developed the first thermal mannequin, and more intensively in the 1980s when international research on cold protective clothing, clothing physiology and clothing thermal functions. Thermal insulation is nowadays expressed in SI-units by m²KW-1. In 1941, Gagge et al. published scientific paper in which a warm business suit provides thermal insulation of approximately 0.155 m²KW-1 for the entire body, which was originally equal to 1 Clo unit, and refers to a person who is thermally comfortable in a ventilated room where the ambient temperature is 21oC, air flow is 0.1 ms-1, and relative humidity is less than 50%.The Clo, defined in J.R. Mather's "Climatology: Fundamentals and Applications" as units measuring the thermal insulation value of clothing, also. To achieve a simpler perception of these units, it should be pointed out that the naked human body has an insulation value of 0.0 Clo, and a value of 1.0 Clo refers to a person wearing a typical business suit. The Clo unit is easier to understand and is more widely used in clothing engineering [4].
In the development of new clothing models, the goal is to achieve, thermal comfort in response environmental conditions, thermal comfort by determining the best combination of textiles in a system that provide protection against natural disasters, is thermally insulated, provide air permeability and vapor permeability, and comfortable to wear [5].
Until now, garments intended for enhanced protection against cold have been designed empirically, and the results achieved could not be accurately assessed in the lack of the availability of suitable measuring equipment and the still insufficient methods [6, 7]. This paper presents the influence of the properties of the materials used and the thermal properties of the clothing. The research was conducted on a thermal mannequin at the Department of Clothing Technology, Faculty of Textile Technology, University of Zagreb.

2. Methodology

The measurement of thermal insulation on the thermal mannequin, Fig. 1, was performed according to the international standard ISO 15831 (ISO15831, 2004). When measuring the thermal insulation of the pilot jacket, the temperature of mannequin was 34.0 °C and the ambient temperature was 20 °C. The air flow velocity was 0. 4 m s-1 and the relative humidity 32%. The total measured resistance in thermal insulation of the unclothed mannequin together with the boundary layer of air along the surface (Rct0) was 0,09116 m² K W-1 [5]. The pilot jacket, Fig. 1, consists of a base and a lining. The model designed with a higher degree of comfort which is very important in special clothing. The length of the jacket to the waist, also allows free movement of the lower

extremities. On the length of the cut and the length of the sleeves, a non-elastic braided band (so-called Putz) is sewn on the length of the cut and the length of the sleeves, which collects the basic material along the body. The model is closed with a zipper on the front outer shells. The closure is protected on the underside by a base material strip to reduce the flow of air through the shutter teeth, thus protect the body from heat loss of the maximum. This model of the outer shell allows air retention between the layers. Depending on the purpose, various combinations of base material and lining are possible. One variant is a textile material of a mixture of cotton polyester fiber, and the other, a material with a coating.
For elaboration of construction dimensions for the basic construction of pilot jackets the standards ISO / TR 10652, (1991) Standard sizing systems for clothes, ISO 8559, (1989) Garment construction and anthropometric surveys-body dimensions and EN 13402-3, (2004) Size designation of clothes-Part3: Measurements and intervals.

Figure 1: Pilot jacket at the thermal mannequin

Size 54 was chosen for the foundation structure. Based on the body measures, all construction measures were calculated and elaborated according to the above standards. Special attention was paid to accessories that increased comfort in all models, due to the specific purpose, so the measures in some positions were extremely increased in order to maintain the functionality of clothing. Further modeling of the basic cut includes all the basic elements and their positions on the garment.

3. Results

Laboratory analyzes of used materials were performed in the two institutions: Cis Institut d.o.o., Belgrade, (Accreditation ATS 01-057, ISO / IEC 17025: 2006) and Jugoinspekt Belgrade A.D. (Accreditation ATS 01-116, ISO / IEC 17025: 2006).
The test sample of the base material marked OM-1 is a material with a polyurethane water-repellent coating whose technical properties are shown in tab. 1. The test sample of the basic material OM-2 is a conventional fabric whose technical properties are shown in tab. 2.
Based on the designed pilot jacket model, two jackets were made (PJ-1 and PJ-2). Two types of basic material (OM-1 and OM-2) and two lining fabrics (PM-1 and PM-2) were used to make the jackets. Since the base material for the PJ-1 jacket is a water-repellent coating material, and for the PJ-2 jacket a conventional material, the aim is to examine whether the coating allows for poorer air exchange with the environment and thus improves thermal insulation. When measuring the pilot jacket, the temperature of the heated surfaces of the mannequin was 34.0oC and the ambient temperature 20oC. The velocity of air flow in the chamber in which the thermal mannequin is located was 0.4 m s-1, and the relative humidity was 32%. The measured total thermal insulation of the undressed mannequin (Rct0) was 0.08535 m² K W-1m².

Table 1: Review of the analyzed technical properties of the sample of base material OM-1 with water-repellent coating

Test elements	Values	Unit of measurement
Raw material composition		
• cotton	67	%
• polyamide	33	%
Surface mass	138	gm^{-2}
Water vapor permeability	2000	$gm^{-2}dan^{-1}$
Air permeability		
• mean value	0,045	$m^3m^{-2}min^{-1}$
• face to face	0,04	$m^3m^{-2}min^{-1}$
• from the back to the face	0,05	$m^3m^{-2}min^{-1}$
Thread density		
• basis	428	yarn/10 cm
• weft	647	yarn/10 cm
The fineness of the yarn		
• basis	66,6	dtex
• weft	21,2	dtex
Interweaving	Plain weave	-

Table 2: Review of the analyzed technical properties of the sample of basic material OM-2 conventional fabrics

Test elements	Values	Unit of measurement
Raw material composition		
• cotton	66	%
• polyamide	34	%
Surface mass	166,2	gm^{-2}
Water vapor permeability	3742,4	$gm^{-2}dan^{-1}$
Air permeability		
• mean value	1,51	$m^3m^{-2}min^{-1}$
• face to face	1,51	$m^3m^{-2}min^{-1}$
• from the back to the face	1,5	$m^3m^{-2}min^{-1}$
Thread density		
• basis	483	yarn/10 cm
• weft	250	yarn/10 cm
The fineness of the yarn		
• basis	21,2	dtex
• weft	20,3	dtex
Interweaving	Plain weave	-

Table 3: Overview of the analyzed technical properties of the PM-1 lining sample

Test elements	Values	Unit of measurement
Raw material composition		
• acetate	62	%
• viscose	38	%
Surface mass	61,1	gm^{-2}
Water vapor permeability	4100,6	$gm^{-2}dan^{-1}$
Air permeability		
• mean value	36,15	$m^3m^{-2}min^{-1}$
• face to face	38,5	$m^3m^{-2}min^{-1}$
• from the back to the face	33,8	$m^3m^{-2}min^{-1}$
Thread density		
• basis	460	yarn/10 cm
• weft	245	yarn/10 cm
Interweaving	Plain weave	-

The test sample of the lining material marked PM-1 is a fabric whose technical properties are shown in tab. 3, and for the lining material PM-2 in tab. 4.

Table 4: Review of the analyzed technical properties of the PM-2 lining sample

Test elements	Values	Unit of measurement
Raw material composition		
• acetate	50	%
• viscose	50	%
Surface mass	62,6	gm^{-2}
Water vapor permeability	4575,75	$gm^{-2}dan^{-1}$
Air permeability		
• mean value	13,99	$m^3m^{-2}min^{-1}$
• face to face	14,08	$m^3m^{-2}min^{-1}$
• from the back to the face	13,91	$m^3m^{-2}min^{-1}$
Thread density		
• basis	417	yarn/10 cm
• weft	263	yarn/10 cm
Interweaving	Plain weave	-

The results of measuring the thermal insulation of the PJ-1 pilot jacket are shown in tab. 5, and for PJ-2 in tab. 6.

Table 5: Results of measuring the thermal insulation of the pilot jacket PJ-1

Power, P	Thermal insulation, R_{ctn}	
W	$m^2 K W^{-1}$	Clo
29,09	0,316	2,04
22,32	0,435	2,81
54,27	0,128	0,83
52,60	0,135	0,87
43,11	0,184	1,19
49,04	0,151	0,97
54,59	0,127	0,82
45,54	0,170	1,10
45,13	0,173	1,12
45,03	0,175	1,13
38,39	0,220	1,42
37,30	0,228	1,47
42,16	0,192	1,24
44,24	0,179	1,15
35,97	0,239	1,54
39,22	0,212	1,37
45,03	0,174	1,12
40,83	0,19	1,28
34,06	0,256	1,65
41,94	0,192	1,24
41,99*	**0,204***	**1,32***

Table 6: Results of measuring the thermal insulation of the pilot jacket PJ-2

Snaga, P	Thermal insulation, R_{ctn}	
W	$m^2 K W^{-1}$	Clo
0,139	0,89	0,89
0,187	1,20	1,20
0,204	1,32	1,32
0,180	1,16	1,16
0,162	1,05	1,05
0,191	1,23	1,23
0,206	1,33	1,33
0,158	1,01	1,01
0,132	0,85	0,85
0,168	1,08	1,08
0,186	1,20	1,20
0,153	0,99	0,99
0,159	1,03	1,03
0,181	1,6	1,60
0,164	1,06	1,06
0,161	1,03	1,03
0,208	1,34	1,34
0,175	1,13	1,13
0,133	0,85	0,85
0,198	1,28	1,28
0,172*	**1,11***	**1,11***

An independent samples Student t-test was used to test the thermal insulation measurement data sets of the PJ-1 and PJ-2 pilot jackets. The statistical parameters of the thermal insulation measurement data sets of the PJ-1 and PJ-2 pilot jackets are shown in tab. 7, and the test results of the thermal insulation measurement data sets are in Tab. 8.

Table 7: Statistical parameters of measured data sets on thermal insulation of pilot jackets PJ-1 and PJ-2

Col(X)	Sum	N	Mean(Y)	σ	CV
A	26,36	20	1,3180	0,45684	0,34684
B	22,19	20	1,1095	0,15185	0,13686
Is there a significant difference between the average thermal insulation of pilot jackets made of materials of different technical characteristics? Hypothesis set: H0: The arithmetic means of a set of measurement data representing the thermal insulation are equal H1: There is a significant difference between the arithmetic means of the measurement data set					

Table 8: Test results of measured data sets of thermal insulation of pilot jackets PJ-1 and PJ-2

Independent t-Test on Data1 col(A) and col(B)
mean variance N

A 1,318 0,20897 20
B 1,1095 0,02306 20
----
t =-1,93574
p = 0,06037
At the 0,05 level The two means are not significantly different
Independent t-Test on Data1 col(A) and col(B)
mean variance N

A 1,318 0,20897 20
B 1,1095 0,02306 20
----
t =-1,93574
p = 0,06037
At the 0,01 level The two means are not significantly different

It is concluded that there is no significant difference between the data sets. In other words, the “null-hypothesis” is accepted - the arithmetic mean values of a measurement data set representing of thermal insulation are the same. With a confidence interval of more than 99%, we claim that there is no statistically significant difference between the measurement data sets.

4. Conclusion

For the productions of a pilot jacket, two outer materials and two lining fabrics were tested and the measurement results and their technical properties were compared, one of which has a waterproof coating. The main purpose of polyurethane coating is to make the waterproof and airtight material. When testing the properties of this material in an authorized laboratory, it was found that the mentioned OM-1 material has a much lower vapor permeability than the other OM-2 sample. The ratio of the obtained values for vapor permeability is 2000: 3742 g m-2 24 h-1. The value for air permeability reached almost zero for both material. For sample PJ-1 made of coated material, thermal insulation of 1.32 Clo was obtained, and for sample PJ-2 made of standard material, thermal insulation of 1.11 Clo was measured. A statistical t-test was performed for these two samples to determine if there was a significant difference in the values of the results between these two measured samples. The test confirmed that adding a coating to the material increases the thermal insulation compared to the standard material. From a professional point of view, it can be concluded that in windy and rainy conditions, a jacket with OM-1 coating provides better protection, as it protects the user from moisture and wind penetration, which is not possible with conventional OM-2 material incorporated the PJ-2 model.

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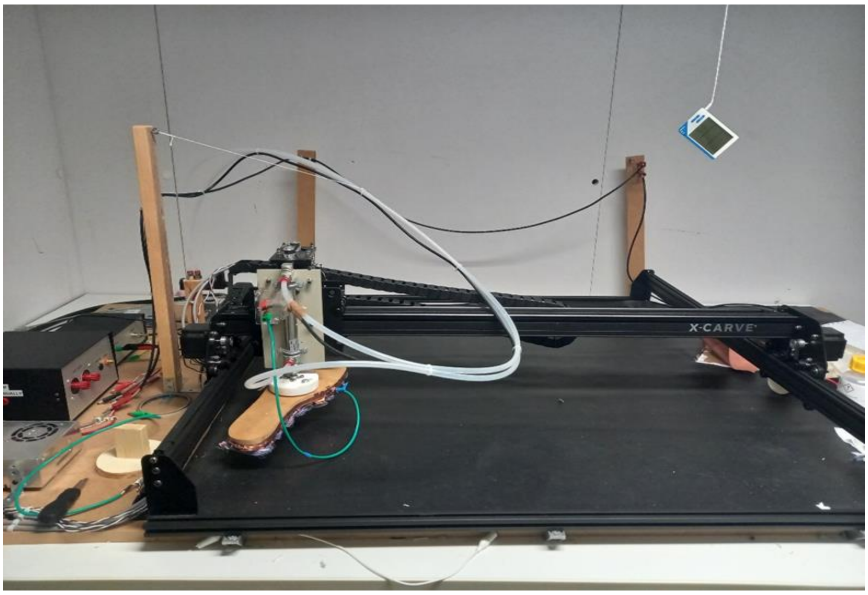
Original Article

SELF-POWERED SMART INSOLE FOR THE DETECTION OF WALKING PATTERN ANOMALIES AND ENERGY HARVESTING APPLICATION

Hasan TAHIR[1]; Benny MALENGIER[1]; Carla HERTLEER [1]; Lieva VAN LANGENHOVE1

[1] Centre for Textile Science and Engineering, Department of Materials, Textiles and Chemical Engineering, Ghent University, 9000-Gent, Belgium
***** Corresponding author: hasan.tahir@ugent.be

Abstract: *Several diseases are characterized by complications with the walking pattern, including Parkinson's disease (PD) causes irregular and asymmetrical walking patterns due to unequal intensity of the neurological signals, which is a disabling pathology affecting millions of people globally. To detect the irregular and asymmetrical in walking patterns, a smart self-powered shoe insole sensor is developed using a flexible triboelectric knitted braid inside a flexible silicon tube. The triboelectric braid was made with PTFE (Polytetrafluoroethylene), Nylon and HC-12 Madera conductive yarns. PTFE (Polytetrafluoroethylene)is highly negative, and Nylon is highly positive triboelectric yarns. Madeira HC12 Conductive Thread with resistance < 100Ω/m was used to collect the signals. A device (walking simulator) with systemic and non-symmetric walking patterns with variable pressure application was used to characterize signals from the smart self-powered shoe insole sensor. The walking simulator motion could be precisely controlled to characterize the signals from the mounted insole. An XY system driven by stepper motors performs a movement in the horizontal direction. A pneumatic cylinder performs vertical movement. G-Code controls the whole system of walking patterns. This is a protocol for CNC machines, offering the possibility to control the system through a serial connection from a PC. The results revealed that using a self-powered shoe insole sensor to detect the walking pattern anomalies is promising. It could have the ability to detect the change in walking pressure and walking patterns.*
Keywords: *walking pattern ; asymmetrical walking; walking simulator; knitted braid*



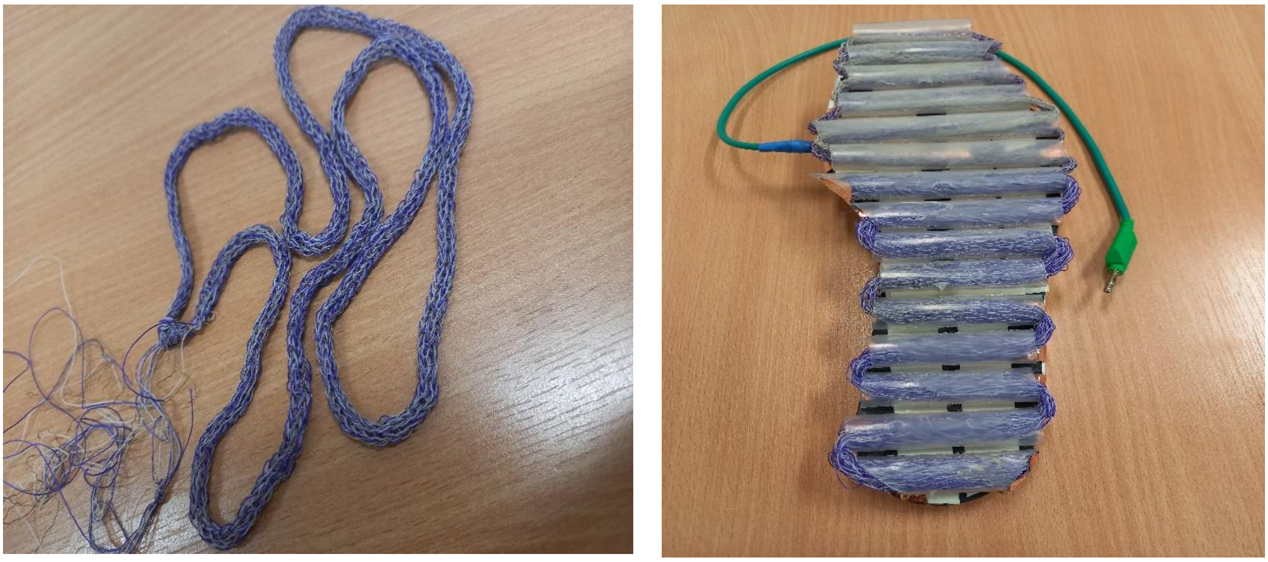
Walking simulator device to detect the walking pattern anomalies.

1. Introduction

Walking is the characterizing phenomenon to detect many diseases. One of them is Parkinson's disease (PD), a neurodegenerative disorder. More than 10 million people worldwide are affected by this disease[1]. It is a neurological disorder characterized by motor and non-motor features of the body. The characteristic features of this disease are irregularity in walking, postural variability, flexed posture, or freezing of gate One of the primary causes of PD is a lack of dopamine that causes irregular or asymmetrical walking. This is because of the unequal distribution of the neurological signal in legs, due to which one leg lags[2, 3]. To detect the irregularity in walking, smart insole was designed[4, 5]. In this work, we developed a smart insole structure that could detect the walking disorder based on the change in pressure or frequency of walking or delay in time (freezing gate disorder).

2. Materials and Method

A triboelectric cord is developed with the highly triboelectric positive (Nylon 66), negative yarns (PTFE), and a conductive thread Madera HC 12 as shown in Fig. 1 a). In triboelectric series, materials are characterized based on their charge generation. Some materials are positively charged, and others are negatively charged. To get the maximum signal generation, the selection of materials is significant. Secondly, in order to collect the signals generated by the compression force and friction force with the outer silicon cover, the yarn should be highly conductive. Figure 1 b) shows the structure of the insole for the detection of walking patterns and also has the possibility to harvest energy.

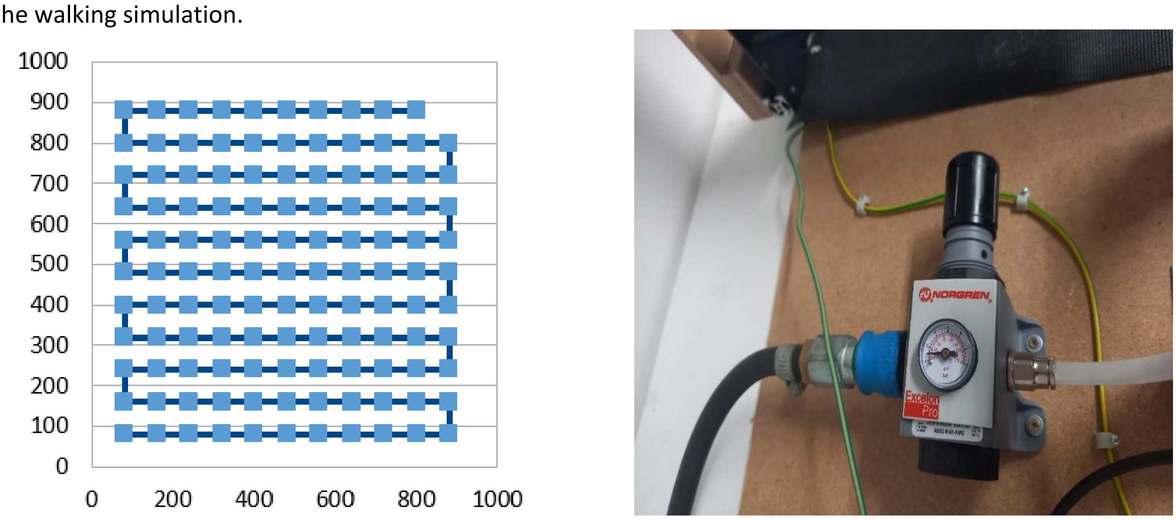


a) b)

Figure 1: shows TENG cord and smart sole structure a) Triboelectric cord made with polyamide, PTFE yarns and conductive Madera HC 12 yarn b) shows the sole structure for detecting the walking frequency, time and irregularity

2.1 G code and pressure changing

The walking simulator is controlled by the G code that controls the motion in XY direction. Figure 3 shows the G code for regular walking and pressure changing switch during waking. Figure 3 a) Regular G code with constant frequency and Figure 3 b) Pressure changing switch of walking simulator corresponding to different human weight. The walking of the automated foot can be precisely controlled to see the effect of variable frequency, time, and pressure during the walking simulation.



a) **b)**

Figure 2 : shows G code for a regular walking and pressure changing switch during waking a) Regular G code with constant frequency b) Pressure changing switch of walking simulator corresponding to different human weight

3. Results and discussion:

Figure. 4 shows the results of the smart insole. The first half of the graph shows the irregular in frequency and pressure. It could also have the ability to detect the freezing gait or delay in stepping time. The freezing gate is one of the major symptoms of Parkinson's disease (PD). The second half of the graph shows when the pressure, time, and walking frequency are constant. The output voltage is also very high 2 KV, pretty high for energy harvesting applications.

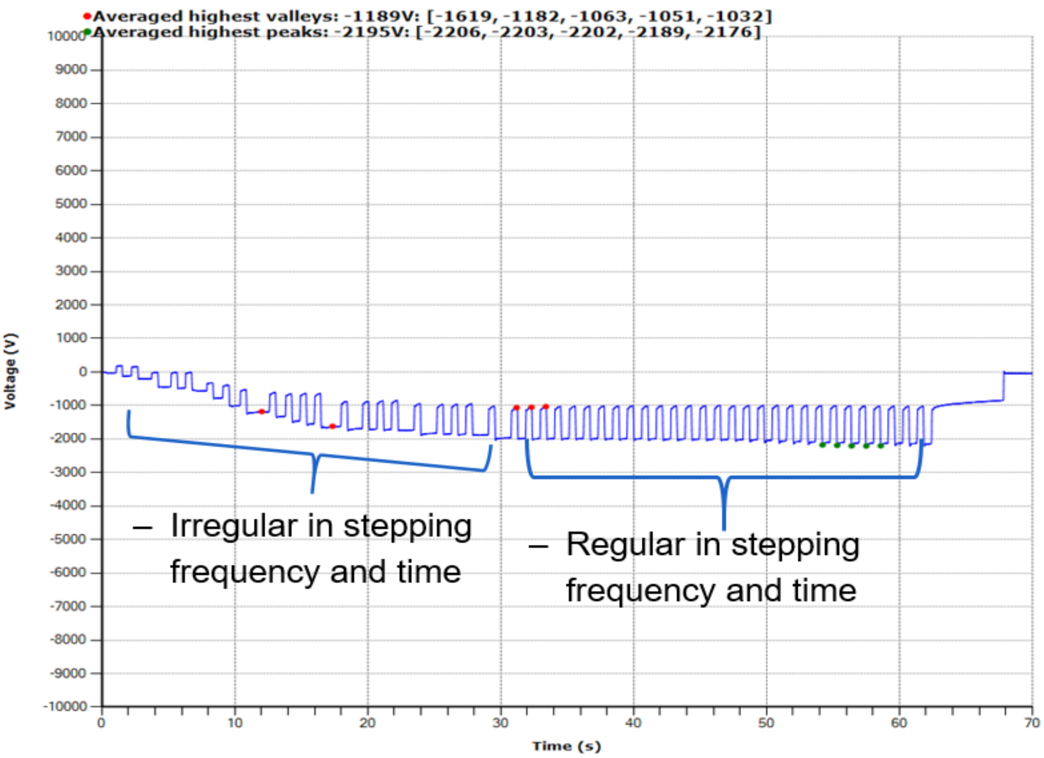


Figure 3 : shows the regular and irregular walking pattern

4. Conclusion

We showed that the insole design, with a triboelectric effect, can detect the walking irregularity. It does detect not only the change in pressure but also the frequency of walking. The time of each step and any delay in stepping frequency could also be detected. The regular walking pattern is characterized by the walking frequency, walking pressure, and contact time. The other application is its very high output voltage that is good for energy harvesting.

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Professional Paper

CURRENT SITUATION ON ENERGY MARKET AND ITS IMPACT ON TEXTILE INDUSTRY

Igor SUTLOVIĆ[1]; Veljko FILIPAN[2]; Karlo FILIPAN[3]

[1] University of Zagreb, Faculty of Chemical Engineering and Technology, Zagreb, Croatia; isutlo@fkit.hr
[2] University of Zagreb, Faculty of Chemical Engineering and Technology, Zagreb, Croatia; vfilipan@fkit.hr
[3] Catholic University of Croatia, Zagreb, Croatia; karlo.filipan@unicath.hr
* Corresponding author: isutlo@fkit.hr

Abstract: *After period of stable prices of all forms of energy, in last few months we are encountering fast growing prices of energy. Trend is the same for natural gas, electricity and crude oil. This affects our life in financial manner. Cost of energy is part of every industrial product as well as those from textile industry. Textile industry is energy intensive one meaning that share of energy in textile products is highly influencing their cost. Review on correlation between energy prices and textile industry is analysed.*
Keywords: *energy prices; spot market; textile industry*

1. Introduction

Role of energy in modern world is out of question. We cannot conceive our everyday life without various forms of energy wherever we are or whatever we do. The same is when we talk about commercial activities including industry. Cost of energy is incorporated in our house expenses as well as in all industrial products, whether it is consumer goods or any specific product. There are three forms of transformed energy derived from primary energy sources such as fossil fuels, hydropower, nuclear, or renewables. These are electricity, heat and mechanical energy where first two are of major importance.

2. Short history of energy market

Not so far in past energy prices were predictable and more or less stable, even crude oil prices after oil shocks during seventies of last century followed same pattern. Imposing new energy market concept in the beginning of this century made things much more uncertain. Cost of energy was strongly split in controlled or regulated and free forming parts. Controlled or regulated part was put under national energy regulatory authority jurisdiction relating to use of grid. Second part is related to energy, kWh of electricity or natural gas for instance, which is now considered as good following market rules especially supply/demand logic. Beside this, energy market is very much global category where each energy market region affects another i.e., any disturbance in one part of World will have consequences far away from place where occurred. Disturbance can be caused by any natural disaster like tsunami in Fukushima, political disputes, war games etc. Let this put in context of lack of indigenous energy sources, confusion or as already said uncertainty is here. It is very easy to recognize European Union (EU) here with 27 member countries with various level of development measured in gross domestic product, various standard of their citizens, but what they have in common is shortage of crude oil and natural gas sources with strong dependence on their import. Expressed in numbers that means that EU has 0,1% of total World oil reserves and 0,2% of total World natural gas reserves while OECD countries have 15% of total World oil reserves and 10,8% of total World natural gas reserves [1].

Some relaxing facts could be found in adopted energy and climatic goals tending to low carbon society in order to achieve climate change mitigation through decreasing of CO_2 emissions. This can be realised by abandoning fossil fuels, higher share of renewables and nuclear, but that will not happen so fast so we can conclude that in ongoing years we shall still live in fossil fuel era.

3. Current trends on energy market in European Union

In last few months we are facing up with fast growth of natural gas prices followed by growth of crude oil and electricity prices. This is trend in EU as well as in rest of World. There are few reasons for that, growing demand for liquefied natural gas (LNG) in Far East, as global reason. Additional reason, according to media, for natural gas prices growth in EU is dispute between Russians and EU and German authorities over putting into operation Nord Stream 2 pipeline. That was preceded by low reserves in underground gas storages owned by Russian Gazprom during summer, while they should be full before heating season, at that moment they were up to 75% full. We can speculate about reasons but fact is that high prices are here and question is how long they will last and will they ever go down to level before they started to rise. Figure 1. shows trend in natural gas prices from end of March 2021 until end of November 2021 on spot market Central European Gas Hub in Austria [2]. Prices (CEGHIX) are expressed in EUR/MWh representing day ahead prices. That means buying today and taking bought volume tomorrow. This is the most expensive, but usual way of trade. Grey columns show traded volume in MWh where 10MWh roughly equals 1000m^3 of natural gas under standard conditions (pressure 101325Pa and temperature 273,15K=0°C). At the end of March 2021 price was a little bit over 19EUR/MWh with traded volume of 993888MWh while at November 23rd it ended near 92EUR/MWh with traded volume of 459072MWh. Peak was reached in first days of October with price of almost 115EUR/MWh and traded volume of 418896MWh. Generally, increasing of prices is driven by growing demand and vice versa higher prices do not slowing down traded volumes. Simply, who needs gas must buy that gas despite financial terms.

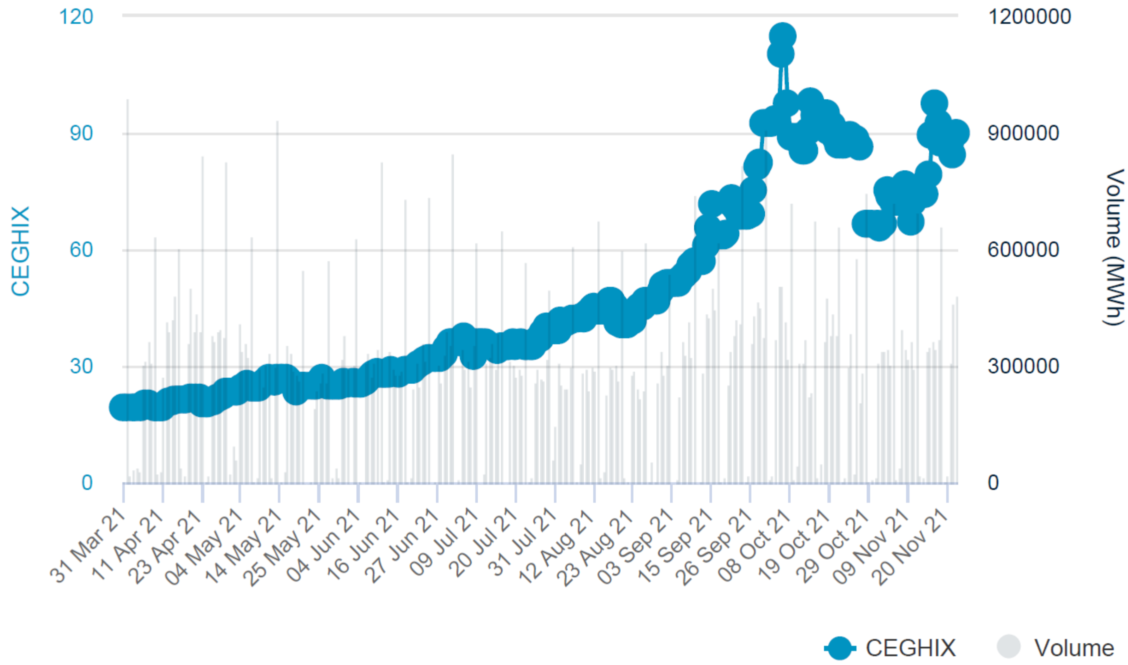

Figure 1: Natural gas prices on CEGH spot market from March 31st to November 25th 2021

While natural gas prices were at their peak fivefold higher than at the beginning of period, crude oil prices on Brent spot in London were "only" doubled from beginning 2021 as shown on Figure 2 [3].

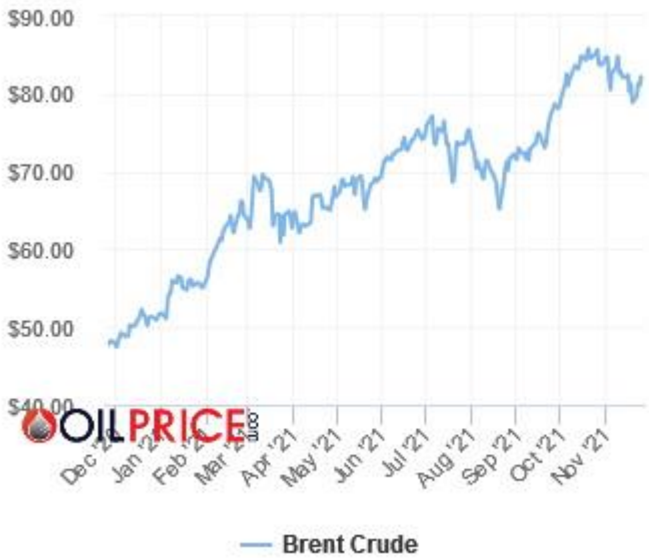

Figure 2: Brent crude oil prices (USD/bbl) from end of 2020 until now

Oil prices follow similar trend as that of natural gas as result of growing demand in global market. Trend is similar for other trading spots in world but Brent is taken as most relevant trading spot for Europe as well as another World.

Finally, let us what is going on with electricity price. Figure 3. shows day ahead electricity prices in October 2021 in Hungarian (HUPX) trading spot [4] which is relevant also for Croatian electricity market. Strong oscillations of prices can be remarked starting from under 50 EUR/MWh then jumping over 300EUR/MWh. Also, trends are not same for all markets, while all markets reached their minimum under 50EUR/MWh, as can be reckoned in October 10th, Croatia reached maximum with round 180EUR/MWh. It is difficult to comment why that happened.

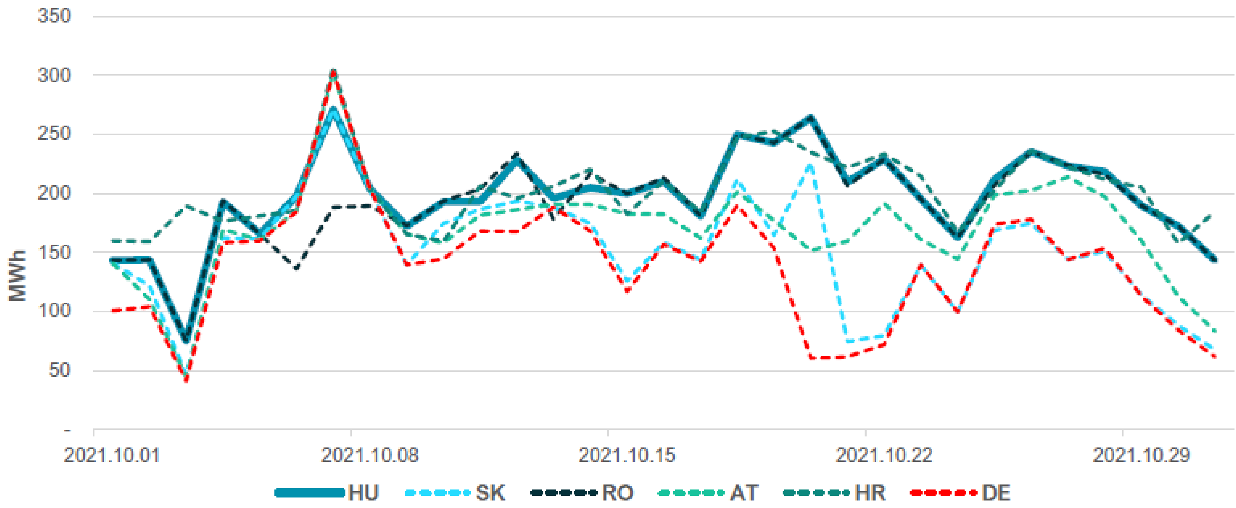

Figure 3: Regional electricity prices on HUPX spot in 2021 (different lines indicates prices for each country)

Second interesting point is peak reached around October 20th in all markets except Germany (DE) and Slovakia (SK). Since there is no historical data for this trading spot presented in one diagram, looking at monthly reports [4] significantly lower average prices can be observed, until May up to 80EUR/MWh, sometimes much lower, in June started to rise reaching at the end of month 105EUR/MWh then keeping that level through July, ending August with 120 EUR/MWh. In September maximal level of 160EUR/MWh was reached and went up in October as already described.

Previous discussion showed constant growth of energy prices, oscillating more or less but reaching new higher levels expected or unexpected, difficult to say. Future prices are unpredictable, will they go down? Maybe. Will they reach levels from half a year ago or year ago? Hardly.

4. Energy consumption in textile industry

To define energy consumption in textile industry is very difficult because of many reasons. It is hard to collect data and more important is that there are many technological operations in textile industry. So, this issue is far beyond the scope of this paper. For purpose of this paper data from two sources will be shortly discussed [5, 6]. Textile industry processes from energy consumption point of view are energy intensive. World final energy use in textile industry has doubled in 2004 compared to 1971 from 47EJ/year to 90EJ/year. Electric energy is one of the most used energy types in the textile and clothing plants, used to supply energy for textile machinery, heating and cooling control systems, lighting, and office equipment. Electricity consumption in the total consumed energy participate with share of 93% for spinning, 85% for weaving, 43% for wet processing, and 65% for clothing manufacturing. Energy sources, such as natural gas and coal, serves for rest of energy supply in the textile processing plants [5]. Also, as result of various energy mixes in different countries share of energy used in textile industry is not the same. For instance, comparing energy consumption in German and Columbian textile industry, in Germany prevails use of gas roughly 50%, electricity 23% and other from 30% to 15% with decreasing trend in total energy consumption in considered period from 1998 to 2005. At the same time in Columbian textile sector prevails other fuels (Columbia is one of World major coal producers), with 30% share of electricity and few percent of gas. At the same time energy intensity (MJ/EUR 1998) German textile industry is very much lower than in Columbia [6]. Data for energy consumption in this sector in Croatia is also difficult to find. For in statistics of energy consumption in industry [7] by sectors textile industry is not presented as itself, but is in category "rest".

5. Conclusion

Emphasis of paper is put on energy prices trends especially those of natural gas, crude oil and electricity. Patterns seen in last few years are now disrupted without warning and could be said for irrational reason. Supply lines weren't interrupted, but growing demand in market and political tensions based on strong dependence of EU on natural gas import caused growing trends. It is also seen that growing trend follow all forms of energy. It can be concluded that predicting future of prices is impossible especially in light of growing demand for energy. As energy is part of our lives, we cannot leave without electricity, natural gas, gasoline etc. it affects our lives from financial point of view. We pay energy in every product we buy, including cloth we wear, and any kind of textile in our every day and professional life. Short analysis showed that processes in textile industry are energy intensive ones so growth of energy prices will cause prices of textile products go up as well.

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Professional Paper

COMPARATIVE ANALYSIS OF COTTON PRODUCTION AMONG LEADING PRODUCERS ON THE INTERNATIONAL MARKET

Robert MATAŠIĆ; Patricija DUVNJAK; Ivana SALOPEK ČUBRIĆ & Željka PAVLOVIĆ

University of Zagreb Faculty of Textile Technology, Zagreb, Croatia; rmatasic@ttf.hr, pduvnjak@ttf.hr, ivana.salopek@ttf.unizg.hr, zeljka.pavlovic@ttf.unizg.hr
* Corresponding author: zeljka.pavlovic@ttf.unizg.hr

Abstract: *Cotton is one of the world's leading agricultural cultures and makes up about 2.5% of the world's arable land. According to the available sources, the leading producers of cotton in the world in the last decade are China, India, USA, Brazil and Pakistan. This paper presents a comparative analysis of cotton production for the two leading countries - China (24.76% of total production) and India (19.43% of total production) in terms of geographical predispositions, population, economy, production rate, prices, import and export.*
Keywords: *cotton, international market, production, China, India*

1. Introduction

Cotton is one of the most important agricultural crops in the world. It is a white, fluffy cut fibre composed almost entirely of cellulose (about 87-90%). Because the harvest is abundant and economical, cotton products are relatively cheap. Cotton is very versatile, as its fibres can be used to make clothing, bedding, and towels, as well as paper, cooking oil, rope, U.S. currency, and biofuels. Cotton occupies about 2.5% of the world's cultivated land. The list of 20 of the world's leading cotton producers for 2018 and production for the selected years (1964, 1975, 1986, 1977, 2008, and 2012) is presented in Table 1.

Table 1: World cotton production in selected years and 20 most important countries [1]

Country	Production (t/year)							
	1964	1975	1986	1997	2008	2012	2018	Percentage in total production
China	1662700 (3)	2381000 (2)	3540000 (1)	4603000 (1)	7491881 (1)	6835975 (1)	6102800 (1)	24.76 %
India	1067000 (4)	1160000 (4)	1173900 (5)	1844670 (3)	3787000 (2)	5817400 (2)	4767140 (2)	19.34 %
USA	3297408 (1)	1807451 (3)	2119000 (3)	4091700 (2)	2790200 (3)	3770000 (3)	4003950 (3)	16.24 %
Brazil	504596 (6)	576900 (5)	764000 (6)	271000 (12)	1314450 (5)	1639791 (5)	1932889 (4)	7.84 %
Pakistan	377600 (8)	513868 (6)	1319500 (4)	1563000 (4)	1923264 (4)	2215000 (4)	1677287 (5)	6.80 %
Turkey	326000 (9)	480000 (7)	518000 (7)	831672 (7)	673000 (7)	858400 (8)	976600 (6)	3.96 %
Australia	2500 (55)	32900 (32)	267300 (9)	610100 (14)	132800 (14)	1224600 (6)	950395 (7)	3.86 %
Uzbekistan	-	-	-	1080000 (5)	1226200 (6)	1126000 (7)	756700 (8)	3.07 %
Mexico	565349 (5)	205796 (10)	143513 (13)	208322 (14)	125000 (15)	231000 (11)	400000 (9)	1.62 %
Greece	73100 (18)	118900 (16)	205000 (16)	370000 (8)	240000 (8)	251000 (9)	314000 (10)	1.27 %
Argentina	99200 (14)	171700	120000 (14)	300000 (14)	166265 (13)	234000 (10)	300000 (11)	1.22 %
Mali	7846 (38)	39077 (27)	78574 (22)	217681 (13)	67500 (23)	143000 (15)	275757 (12)	1.12 %
Benin	2300 (60)	8600 (50)	48000 (28)	155000 (16)	75000 (22)	84000 (25)	205000 (13)	0.83 %
Turkmenistan	-	-	-	190000 (15)	330300 (8)	198000 (14)	204000 (14)	0.83 %
Sudan	100179 (13)	229287 (9)	145000 (12)	71000 (26)	37450 (31)	97920 (23)	187340 (15)	0.76 %
Burkina Faso	2983 (52)	18168 (37)	65970 (25)	144104 (17)	266000 (9)	206000 (13)	175700 (16)	0.71 %
Tanzania	53206 (22)	41903 (26)	73030 (23)	69636 (27)	123600 (16)	74500 (27)	116967 (17)	0.47 %
Kazakhstan	-	-	-	66747 (28)	113348 (19)	131200 (19)	113000 (18)	0.46 %
Cameroon	16000 (28)	19100 (36)	46500 (29)	73067 (25)	61500 (26)	84000 (26)	100000 (19)	0.41 %
Myanmar	17711 (27)	14305 (40)	32805 (33)	56023 (30)	66000 (24)	133500 (17)	97000 (20)	0.39 %
Remaining	3547128	4576480	4558314	2219871	1448045	1577164	995162	4.04 %
Total registered	**11,722,806**	**12,395,435**	**15,218.406**	**19,036,593**	**22,458,803**	**26,932,450**	**24,651,687**	

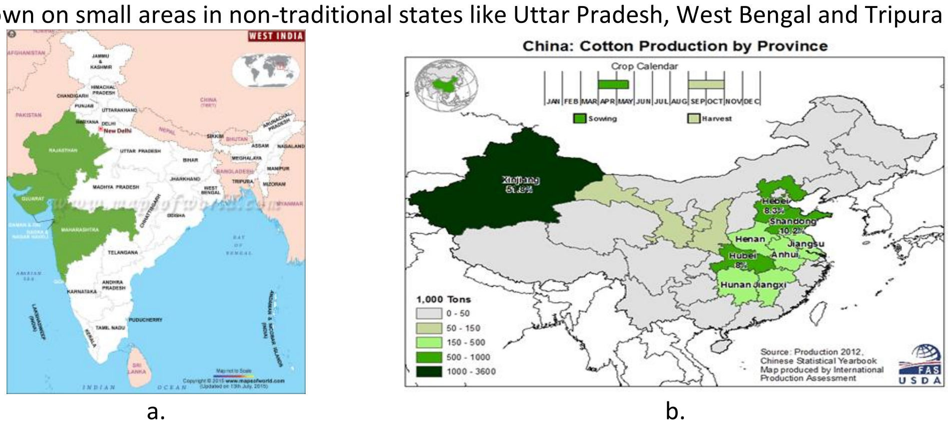
The largest cotton-producing countries in 2018/19 were China and India, which accounted for about a half of the total world. Brazil and the United States together accounted for about one-quarter of production, while Pakistan and Turkey as a whole accounted for about one-tenth of total production. The remaining 60 countries together produced about one-fifth of total world production. World cotton yields have shown a growth trend since the 1950s. However, the pace of technology development and adoption slowed after 2007/08, and world yields were still close to 800 kg/ha in 2018/19. Global cotton production has become increasingly fragmented, with a proliferation of programs to collect data, promote improvements, or convince consumers of responsible production practices. Some of these programs are organized by growers in a given country, others are sponsored by suppliers, and still others are multinational initiatives supported by the private sector and governments. Within this paper, a comparative research method is used to analyse the production between the leading countries i.e. China (24.76% of total production), and India (19.43% of total production). Secondary data has been collected through primary sources. Most of the secondary data used in this paper is from the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) - a website that disseminates statistical data collected and maintained by the Food and Agriculture Organization (FAO).

2. Predispositions of China and India

2.1 Geographical location

China follows a single standard time offset of UTC + 08:00, despite spanning five geographical time zones and bordering 14 different countries. With an area of about 9.6 million km^2, it is the third largest country in the world. The Chinese climate consists mainly of dry seasons and humid monsoons, resulting in significant temperature differences between winter and summer. In winter, north winds come from high latitude areas that are cold and dry, and in summer, south winds come from coastal areas at lower latitudes that are warm and humid [2]. The major regions where cotton is grown are Xinjiang-Uyghur Autonomous Region, Yangtze Basin (including Jiangxi and Hubei provinces), and Huang-Huai Region (mainly in Hebei, Henan, and Shandong provinces). However, according to the agro-climatic regions, they belong to the three zones of the Northwest Cotton Growing Region, the Yellow River Valley Region and the Yangtze River Valley Region, which together account for 99.5% of the cotton cultivation area with a total yield of 99.7%. The area under cultivation was 5.3 million hectares in 2012 [3].

India's border, which is about one-third of its coastline, touches six countries. It is bordered by Pakistan to the northwest, Nepal, China and Bhutan to the north and Myanmar (Burma) to the east. Bangladesh to the east is surrounded by India to the north, east and west. The island nation of Sri Lanka lies about 65 kilometres off the southeast coast of India across the Palk Strait and Mannar Bay. The country of India, together with Bangladesh and much of Pakistan, forms a clearly defined subcontinent, separated from the rest of Asia by the imposing Himalayan mountain ranges to the north and the neighbouring mountain ranges to the west and east. In terms of area, India is the seventh largest country in the world. The climate of India can be classified as a hot, tropical country, with the exception of the northern states of Himachal Pradesh and Jammu & Kashmir in the north and Sikkim in the northeastern hills, which have a colder climate with a more continental influence. In most parts of India, summer is very hot. It begins in April and lasts until early October when the monsoon rains begin. They can be very heavy and cause flooding and damage, especially along India's major rivers, the Bramaputhra and the Ganges. There are ten major cotton growing states in India, which are divided into three zones, namely the northern zone, the central zone and the southern zone. The northern zone consists of Punjab, Haryana and Rajasthan. The central zone comprises Madhya Pradesh, Maharashtra and Gujarat. The southern zone comprises Andhra Pradesh, Telangana, Karnataka and Tamil Nadu. Besides these ten states, cotton cultivation has also gained importance in the eastern state of Orissa. Cotton is also grown on small areas in non-traditional states like Uttar Pradesh, West Bengal and Tripura [4].



a. b.

Figure 1: Main regions for the cotton production: a. in India, b. in China [5, 6]

2.2 Population

China's demographics show a large population with a relatively small percentage of young people, due in part to China's one-child policy. In 1982, China's population reached one billion. As of November 2020, China's population stood at 1.412 billion. According to the 2020 census, 91.11% of the population was Han Chinese and 8.89% belonged to minorities. China's population growth rate is only 0.59%, ranking 159th in the world. China conducted its sixth census in 2010, the seventh census was completed in late 2020, and the data released in May 2021 only included statistics on mainland China. According to the seventh census conducted in 2020, about 63.9% of China's total population lived in cities. The urbanization rate in China has been steadily increasing in recent decades. The urbanization rate of China, the world's second-largest economy, rose from 36% in 2000 to about 51% in 2011, and that year the urban population exceeded the rural population for the first time. According to the urbanization plan announced by the Communist Party and the State Council in March 2013, China aims to achieve 70% urbanization by 2030. The rate of urbanization varies widely in different parts of China. In western or central China, urbanization is less pronounced, but in eastern China, more than two-thirds of the population already lives in cities [7].

The current population of India is 1,397,605,690 on October 20, 2021, based on the latest United Nations data prepared by Worldometer. India's population represents 17.7% of the total world population. India ranks second on the list of countries (and dependencies) in terms of population. The population density in India is 464 per km^2. The percentage of urban population is 35.0% (483,098,640 people in 2020). The median age in India is 28.4 years [8].

2.3 Economy

China accounts for a quarter of the world's population and its middle class grew by 400 million people by 2018 [9], while in 2015 it had the status with the most middle class people in the world [10]. In 2027, China is expected to reach 1.2 billion [11]. In terms of the number of billionaires in the world, China has ranked first since 2018, and second in terms of the number of millionaires, where there are 658 billionaires [12] and 3.5 million millionaires [13]. China is considered to be the country with the richest people and has overtaken the United States in 2019 [14], that is, as of 2019, one hundred million Chinese are among the top ten percent of the richest people in the world, that is, those who have a personal net worth of at least 110,000 US dollars [15]. China has the most billionaires in the world in 2020, more than the US and India combined, and in March 2021, the number of billionaires in China reaches 1,058 with a total wealth of $4.5 trillion. According to the Hurun Global Rich List 2021, cities in China such as Beijing, Shanghai, Shenzhen, Hong Kong, Hangzhou and Guangzhou are the cities with the most billionaires, more than any other country [16].

In its global economic outlook, the International Monetary Fund (IMF) has kept its growth forecast for India at 9.5% and 8.5% for fiscal years 2022 and 2023, respectively. Importantly, it predicts that India will retain the tag of the fastest growing economy in the world. At the monetary policy meeting, the Reserve Bank of India also kept its growth forecasts for fiscal 2022 at 9.5% and revised its second quarter forecasts sharply to 7.4% from 6.8% earlier [17].

India has emerged as the fastest growing major economy in the world and is expected to be one of the top three economies in the world in the next 10-15 years, underpinned by a strong democracy and strong partnerships. India's gross domestic product (GDP) at current prices was $694.93 billion in the first quarter of fiscal 2012. This is according to preliminary estimates of GDP for the first quarter of 2021-22. In the ranking of countries by the size of their economies and total net worth, the US is ahead of China, mostly followed by the UK, Japan, India or Germany. However, when countries are ranked by average per capita wealth - or even by average per capita wealth - other countries come out on top. Using two measures, Switzerland was the richest country in the world with the highest average per capita wealth of about $674,000 per adult. The richest country by average per capita wealth was Australia, with about $238,000 in 2020. Per capita wealth probably shows a more balanced picture of a country's wealth, since it takes into account that smaller countries with fewer citizens naturally accumulate less wealth overall. However, the calculation of the average still does not take into account how wealth is distributed. Median wealth - the wealth of a person who shares their country with an equal number of richer and poorer people - is different. It increases when the country's wealth is more evenly distributed [18].

3. Comparative analysis of production in China and India

3.1 Production rate

The sown areas of cotton make up about 30 percent of the total sown area of all the various money crops. The main regions, according to which cotton is the main crop, are the Xinjiang Uyghur Autonomous Region, the Yangtze River Basin (including Jiangxi and Hubei Provinces) and the Huang-Huai Region (mainly in Hebei, Henan, and Shandong Provinces). However, according to agro-climatic regions, they are under the three zones of the northwest cotton land region, the Yellow River Valley region, and the Yangtze River Valley region, which together make up 99.5% of the cotton area with a total yield of 99.7%. The areas planted in 2012 were 5.3 million hectares, and the average yield was 1,438 kilograms. According to FAO statistics for 2012, cotton production was 6.84 million tonnes and cottonseed production 13.68 million tonnes [19].

For the Indian government, the revival of Suvin (a cross of Sea Island cotton from St. Vincent in the Caribbean and Suyatha, an Indian variety) has been a priority for some time. ELS denotes a category of cotton fibre whose hair length is more than 32.5 mm. India today imports 5 to 6 hundred thousand bales ELS to meet its demand for higher quality yarn for fabrics and finished products. In India, the standard bale size is 170 kg. The central government and the Ministry of Textiles have focused on expanding Suvin farming, which has lagged behind for years due to various reasons. The main concern is also the growing import of long staple cotton by clothing and luxury segments in India, which are not found in sufficient quantities here [20].

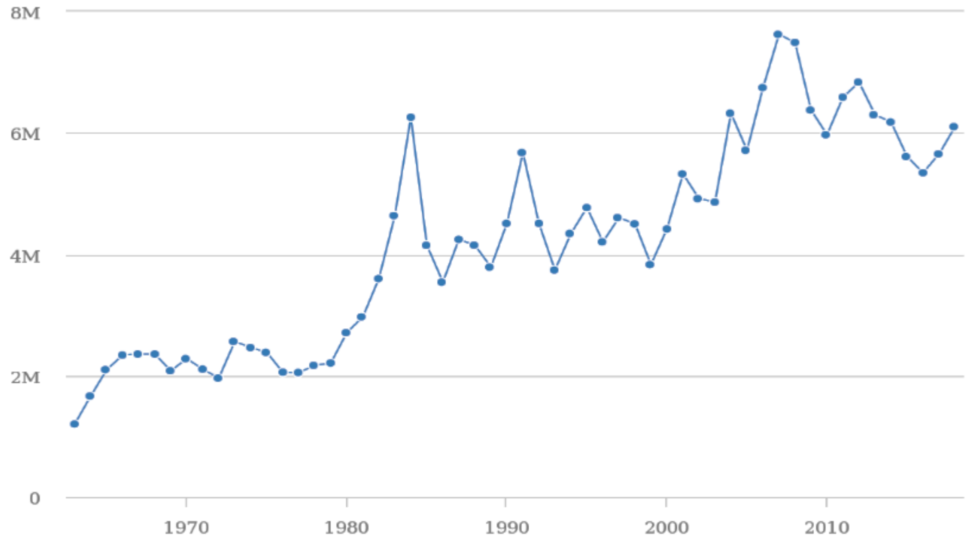


Figure 2: Production of cotton from 1963 to 2018 in China [21]

According to the presented data, the lowest amount of production in China was visible in 1963 with 1,200,000,000 kg, while the largest production was in 2007 with 7,623,597,000 kg.

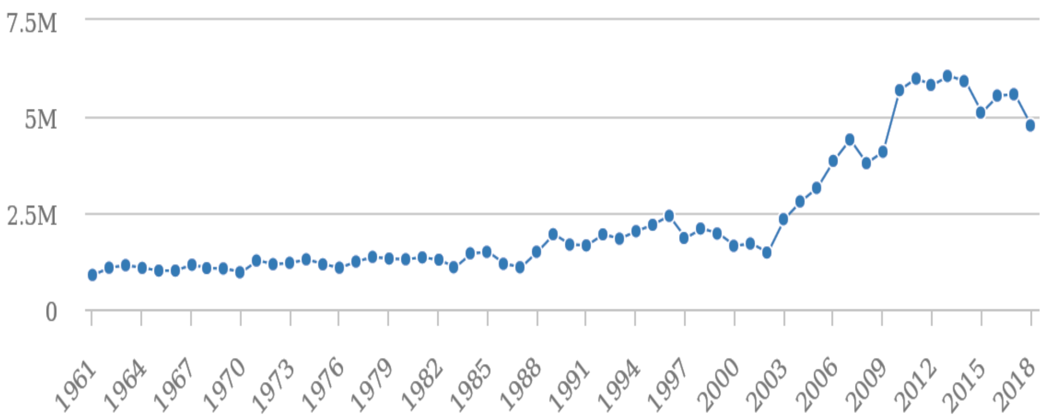


Figure 3: India cotton production for a period 1961 to 2018 (in tonnes) [22]

3.2 Prices

The initial price was 1,216 USD/tonne (1.06 €/ kg) in 1991, while the lowest price was 914.8 USD/tonne (0.80 €/ kg) in 2001 and the highest price was 4,166.2 USD/tonne (3.69 €/ kg) in 2011 and the latest was 3,118.8 USD/tonne (2.72 €/ kg) in 2019.

The fall in prices in 2014 was due to the oversaturation of cotton, so much that China stopped buying cotton from farmers, and farmers received subsidies [23].

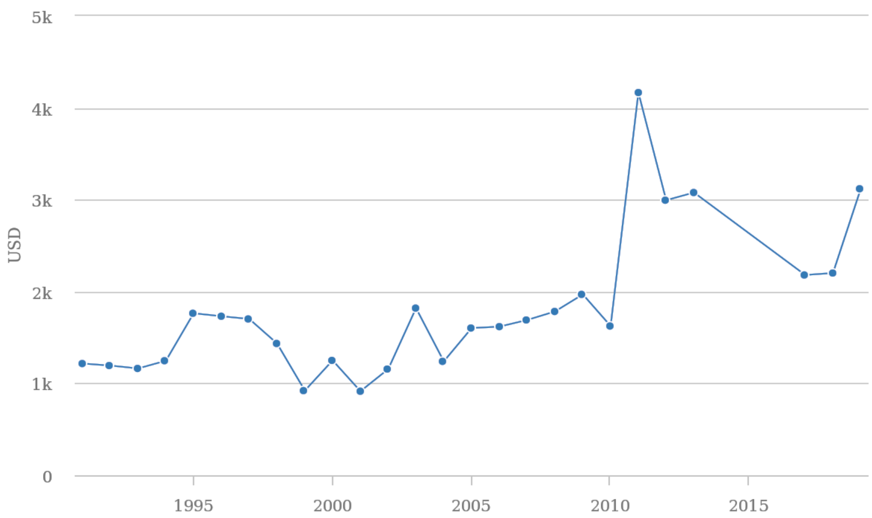


Figure 4: Prices of cotton in China for the period 1991 to 2019 [24].

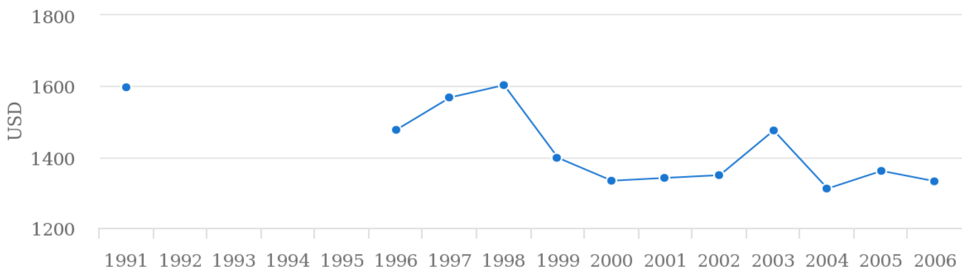


Figure 5: Cotton prices in India for the period 1991 to 2006

Starting price for Indian cotton lint was 1,476.5 USD/tonne, while the final one was 1,331 USD/tonne. Highest price was 1,602.9 USD/tonne in 1998, lowest stood at 1,310.6 USD/tonne in 2004.

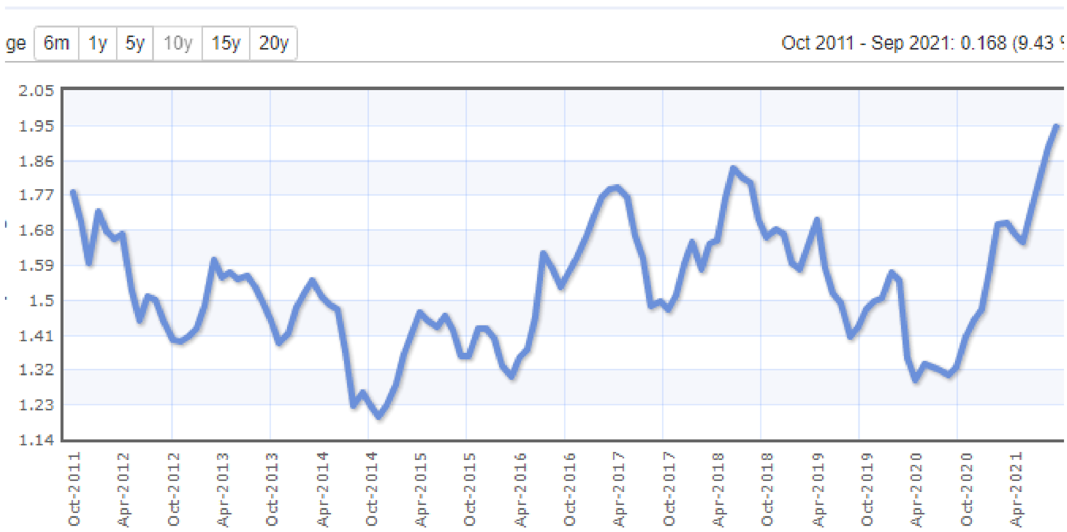


Figure 6: Cotton prices in the world from 2011 to 2021 [25].

According to the graph (Fig. 6), the starting price in 2011 was 1.78 €/kg, while the highest price in 2021 was 1.95 € /kg. The lowest price of cotton was in 2014 and amounted to 1.19 €/kg, while the final price is 1.95 €/kg.
Declining production, along with falling demand and paralysis of cotton exports to the United States are some of the factors that motivated falling prices. The coronavirus also affects the cotton market. From the beginning of 2020 to March 24, 2020, cotton prices have fallen by 23%, which is one of the biggest decreases since the beginning of the century. The last deflationary trend reversal occurred between mid-2018 and August 2019. At that time, the decline

was mainly influenced by the trade war between China and the United States. Tensions between the two countries caused cotton prices to fall by €0.32 to €1.1/kg in August 2019. The US Department of Agriculture has included a large impact of the trade war in its forecast for 2020. The institution estimates that cotton production in the US will fall by 9% this year to 12.5 million hectares and 600,000 bales. However, as de-escalation between the two countries continued, cotton prices began to recover last August, reaching a high of €1.37/kg as of February 2019. Since then, the coronavirus has forced mills to shut down, freezing production and closing stores, damaging demand from Asia, Europe and the Americas. The first sign of a turning point appeared in late February 2020, with cotton trading at €1.18 on the 28th day of 2020, cotton was traded at €1.18, far from €1.30/kg the previous day. Raw material prices temporarily stopped their fall on 2 March 2020, trading at €1.20/kg. However, the decline soon continued and on 12 March 2020 cotton prices fell to €1.02/kg. According to the latest estimates by the International Cotton Advisory Board (ICAC), cotton trade will grow by 2% this season, reaching 9.4 million tons. The body estimates that cotton prices will reach €1.53/kg at the end of the season. The recent decline has brought cotton prices to their lowest level in a decade. Since then, cotton prices have recovered and peaked in 2010 and 2011 due to huge accumulation of stocks in China, reaching €4.06/kg in 2011. Cotton prices were very popular, ranging from €1.77 in 2013 to €1.09/kg in December 2014. Cotton prices also fluctuated in the last campaign, ranging from €1.90 at the beginning of the season to €1.6/kg at the end [26].

3.3 Import and export

International trade makes up a significant part of the overall Chinese economy. Since it was a Second World country at the time, a considerable part of China's trade with the Third World was financed by grants, loans, and other forms of assistance. Major efforts were made in Asia, particularly in Indonesia, Myanmar, Pakistan, and Sri Lanka, but substantial loans were also made in Africa (Ghana, Algeria, Tanzania) and the Middle East (Egypt). However, after the death of Mao Zedong in 1976, these efforts were scaled back. Thereafter, trade with developing countries became negligible, although Hong Kong and Taiwan emerged as important trading partners during this period.

Since the beginning of economic reforms in the late 1970s, China has attempted to decentralise its foreign trade system to integrate with the international trading system. In November 1991, China joined the Asia-Pacific Economic Cooperation group, which promotes free trade and cooperation in economics, trade, investment, and technology. China had total exports of 2,498,569,865.64 in thousands of US dollars and total imports of 2,068,950,254.60 in thousands of US dollars, resulting in a positive trade balance of 429,619,611.04 in thousands of US dollars. In 2020, China's major exports were automatic data processing machines and components, followed by textiles, garments and clothing accessories, mobile phones and integrated circuits [27].

China's textile industry is the largest in the world in terms of both production and export. In 2013, China exported $274 billion worth of textiles, almost seven times more than Bangladesh, the second largest exporter with exports worth $40 billion [28]. This accounted for 43.1% of world clothing exports [29].

Indian textile industry contributed 7% to industrial production (value) in 2018-19. Indian textile and clothing industry contributed 2% to GDP and 12% to export earnings in 2018-19 and accounted for 5% of global textile and clothing trade. India's textile and clothing exports accounted for 11% of trade shipments was 11%in 2019-20. The textile industry has about 4.5 million employees, including 35.22 hundred thousand handloom workers across the country. Cotton production is expected to reach 37.10 million bales (6307 million kg) and consumption 114 million bales (19380 million kg) in the 21st fiscal year, an increase of 13% over the previous year. It is estimated that the domestic textile and clothing market was worth $100 billion in fiscal year 19.

India's raw cotton production is estimated to have reached 35.4 million bales (6018 million kg) in fiscal 2020. In fiscal 2019, fibre production in India stood at 1.44 million tonnes and will reach 2.40 million tonnes in fiscal 2021. (till January 2021), while yarn production was 4.762 million kg during the same period.

Exports of textiles (all textiles, cotton yarn/fabric/manufactured fabrics, artificial yarn/fabric/manufactured fabrics, handicrafts other than handmade carpets and jute, including floor coverings) stood at $2.99 billion in June 2021. In July 2021, exports of cotton yarns/fabrics/made-up fabrics, handicrafts, etc. from India increased by 50.86% in June 2021 as compared to June 2019 [30].

India's exports of textiles and allied products were worth $30.4 billion in fiscal 2020-21, down 10% year-on-year due to the pandemic. The Ministry of Textiles recently reported that exports increased 87% year-on-year to $16.6 billion in the first five months of this fiscal year, supported by a strong economic recovery in key markets [31].

Indian textile products are exported to more than a hundred countries. However, the US and EU countries account for the largest share of Indian textile and clothing exports. The countries of the largest global export destinations for Indian textiles are the USA, the United Arab Emirates (UAE), Bangladesh, Great Britain and Germany. India exported textiles worth about $ 8.22 billion to the United States, making it our largest textile export destination, followed by the UAE ($ 2.28 billion) and Bangladesh ($ 2.17 billion) during 2019-2020 [32].

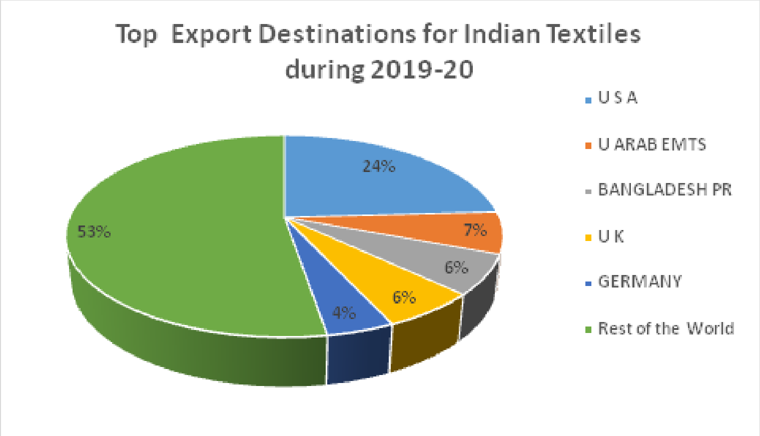


Figure 7: Export destinations for Indian textiles during 2019-20 [32]

Indian textile imports make up about 50% of yarn and fibre, which was used as an added value of textile. The top textile and apparel import sources of India during 2019-20 and their share in total textile import is given below.

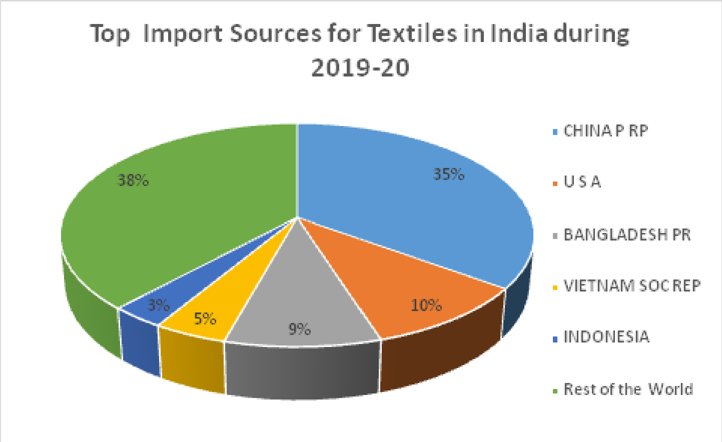


Figure 8: Import sources for textiles in India during 2019-20 [32]

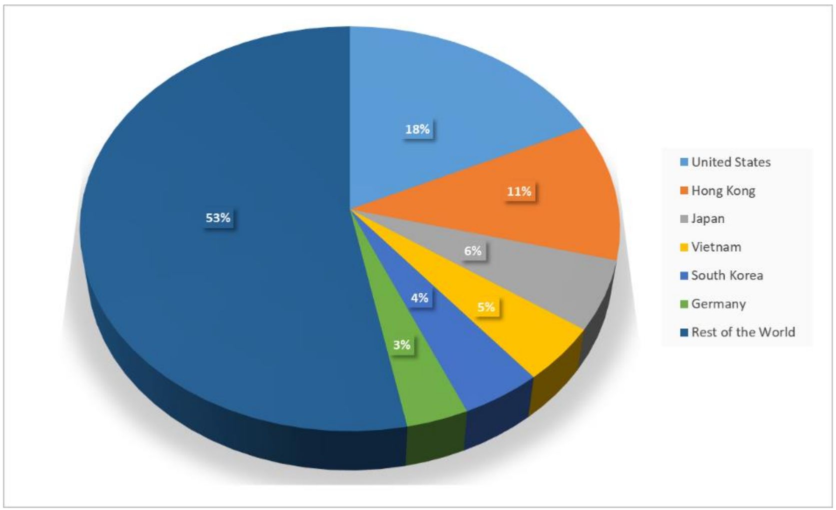


Figure 9: Export of textile China [33]

China's textile exports are highest to the United States with 18%, followed by Hong Kong with 11%, while textile imports are held equally by Japan and South Korea with 10%.

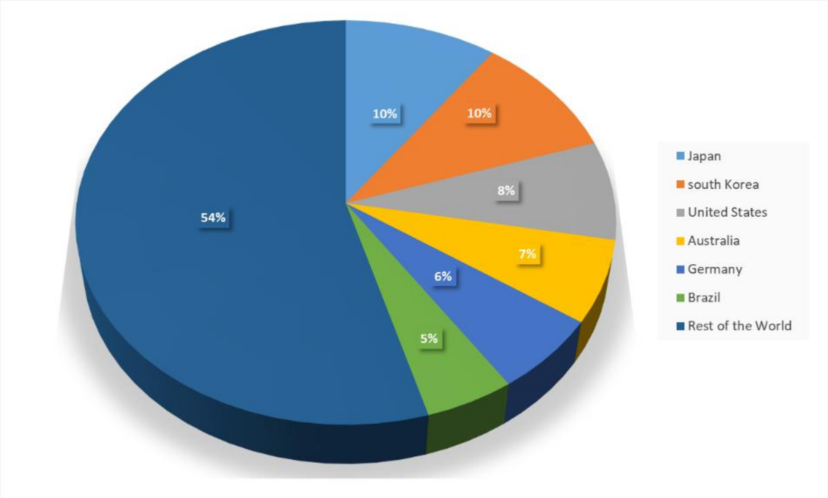


Figure 10: Imports of textile in China [34]

4. Conclusion

From the data obtained, it can be concluded that China, with all its difficulties over the years, is one of the largest producers of cotton and clothing. Cotton prices fluctuate over the years depending on the world situation, and production also depends on climate change and many other parameters, so there will always be ups and downs in this industry.

Cotton plays a very important role in the Indian economy. It is termed as the most important cash crop of India. It sustains the Indian cotton textile industry, which is the single largest segment of organized industry in the country. It also provides profitable employment to millions of people engaged in harvesting, picking and marketing, cleaning and pressing of cotton. The Indian cotton crop, which occupies about nine million hectares annually, is the largest in the world and accounts for more than one-fourth of the world's cotton area.

Aknowledgement

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Original Article

MODELLING OF POLYESTER FABRIC DYEING AFTER ITS TREATMENT WITH EUTECTIC SOLVENT

Dragan DJORDJEVIC[1]; Marija KODRIC[2]; Radica KRSTIC[3]; Nenad CIRKOVIC[4]

[1] University of Nis, Faculty of Technology in Leskovac, Leskovac, Serbia; drdrag64@yahoo.com
[2] Innovation center University of Nis, Nis, Serbia; izida50@gmail.com
[3] University of Nis, Faculty of Technology in Leskovac, Leskovac, Serbia; radicanicic@rocketmail.com
[4] University of Nis, Faculty of Technology in Leskovac, Leskovac, Serbia; nenadcira@gmail.com
* Corresponding author: Dragan Djordjevic, drdrag64@yahoo.com

Abstract: *Modelling of dyed fabrics made of 100% polyester fibers with disperse dye, after pre-treatment with the eutectic solvent was studied in this paper. The aim of pre-treatment with eutectic agents is to modify the surface of the polyester fibers in order to improve the adsorption properties as well as the possibility of dyeing in atmospheric conditions. According to the results of the examination of the polyester fabric, it was found that the absorption of the disperse dye is greatly improved after the treatment with a eutectic solvent. The data obtained from the Freundlich equation confirm that this model provides a sufficiently accurate description of the experimental data and the dyeing process. There is a heterogeneous surface of the substrate with uneven distribution of adsorption heat on the surface and with the possibility of formation of multilayer adsorption.*
Keywords: *polyester; eutectic solvent; dyeing; disperse dye; modelling*

1. Introduction

Polyester (PES) fibers (usually polyethylene terephthalate - PET) belong to a group of synthetic fibers with active sites to which dye molecules can attach. These are a large number of ester groups, as well as a number of carboxyl groups located at the ends of the chains, with which the dye molecules establish hydrogen bonds. On the other hand, what is a problem, PES fibers have a pronounced hydrophobic character and compact structure, which complicates the dyeing process, leading it to extreme conditions. An alternative is to modify these fibers or to modify the usual dyeing process, that is, to increase the rate of dye diffusion into the fibers [1]. The rate of colour diffusion in the fiber can be intensified by increasing the permeability of the fibers, or by increasing the ability to swell the fibers. This can be achieved, for example, by adding simple organic compounds in the dye solution - carriers. Carriers cannot be completely removed from the fibers by washing after dyeing, so, given their relatively toxic and dermatological effects, as well as problems with the colour fastness of textiles to light and shrinkage of textiles, they deserve careful use [2, 3]. For easier and simpler dyeing of PES fibers, various methods of pre-preparation are used today. Thus, hydrolytic modification of the surface of polyester materials (treatment with different alkalis) is mentioned to obtain a better appearance, feel and simpler dyeing. In addition to this, ionic liquids and eutectic mixtures are increasingly used in this field, as ecological products and friends of nature [4]. Ionic liquids are chemicals composed entirely of ions with a melting point below 100 °C. Due to their unique properties, they are increasingly replacing traditional volatile organic solvents. On the other hand, eutectic solvents are a class of ionic liquids based on eutectic mixtures of two compounds. These are mostly mixtures of choline chloride with metal chlorides ($ZnCl_2$, $SnCl_2$, etc.) or hydrogen bond donor compounds such as amides, acids or alcohols [5, 6].

The paper clarifies the ability of adsorption of disperse dye for previously treated PES fibers with the usual ecological additives according to the standard dyeing recipe, without the use of carriers. Pre-treatment of PES fibers aimed at surface modification with the help of eutectic solvents, which would lead to a relaxation of the hydrophobic-crystalline structure of the fibers with an increase in surface permeability. Modelling of polyester dyeing with selected isothermal models will clarify the expediency of pre-preparation of polyester with the eutectic agents.

2. Experimental

Polyester fabric (100% polyethylene terephthalate) was used, with the following characteristics: warp and weft fineness per 16×2 tex, warp and weft density of 36 and 30 threads/cm and the surface mass of 230 g/m^2. Prior to dyeing, a sample was prepared with the eutectic solvent (mixture), with the aim of surface modification for greater hydrophilicity. The eutectic solvent was prepared as follows: 1 mol of ethylene glycol (Oleohemija, Serbia) and 0.5 mol of choline chloride (Merck KGaA, Germany) was mixed at 70 °C during stirring until completely dissolved and obtaining a homogeneous medium.

Samples of polyester fabric were treated in a bath with the ecological agents, the ratio of liquid and textile was 50:1, the bath temperature was 60 °C, and the processing time was 90 min. All polyester treatments with eutectic solvent were carried out in a Linitest laboratory device. Upon completion of the process, PES fabric samples were rinsed copiously with distilled water and washed in detergent (40:1, 60 °C, 30 min, Felosan NKB 2 g/dm^3). After drying, the samples are ready to be dyed. Disperse dye C.I. Disperse Red 73 ($C_{25}H_{24}N_6O_2$, M=440.50 g/mol) was used for dyeing, the structure of which is shown in Figure 1. The applied dye belongs to the class of mono azo dyes, it has a relatively small molecule and it is suitable for polyester.

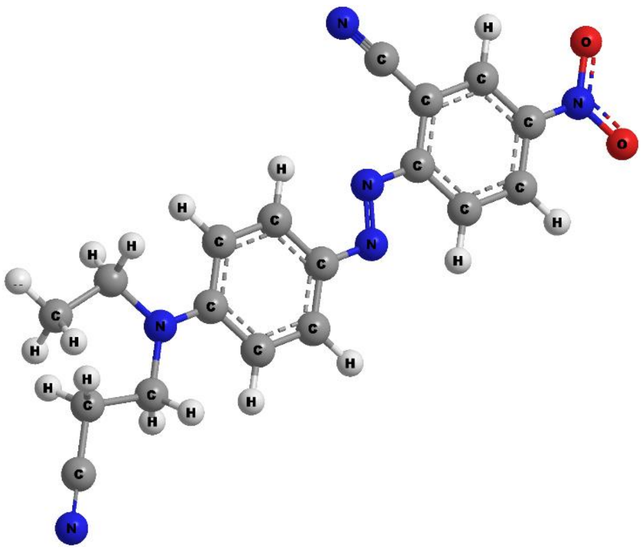


Figure 1: The structure of the disperse dye C.I. Disperse Red 73 used (by ChemBioDraw Ultra 14.0 software)

The dye-adsorption test was performed in following settings: the mass of PES fabric was constant (1 g), the dyeing bath had a constant volume (0.1 dm^3), the concentration of disperse dyes ranged from 10 to 100 mg/dm^3, while the processing time, with continuous stirring (120 rpm), ranged from 5 to 60 minutes at 98 °C. UV-VIS spectrophotometry and Cary 100 Conc UV-VIS apparatus, Varian (maximum absorption at 500 nm) were used to determine the dye concentration in the solution. The amount of adsorbed disperse dye per unit mass of treated polyester fabric [7] (adsorption capacity at time *t* or at equilibrium time *e*) was calculated:

$$q_{t,e} = \frac{\left(C_o - C_{t,e}\right) \cdot V}{w} \qquad (1)$$

Where: C_o (g/dm^3) was the initial dye concentration; $C_{t,e}$ (g/dm^3) was the dye concentration at time *t* or at equilibrium time *e*; *w* (kg) fabric mass and *V* (dm^3) was the solution volume from which adsorption was performed.

The Freundlich adsorption isotherm is empirical in nature and describes adsorption on an energetically heterogeneous surface on which molecules are adsorbed in interaction. This model describes well the multilayer adsorption [7]. The Freundlich model is represented by the following equation:

$$\ln q_e = \ln K_F + \frac{1}{n_F} \cdot \ln C_e \qquad (2)$$

Where: K_F, (mg/g)·(dm^3/mg)(1/n) and n_F - constants characteristic of the predicted system: adsorbent, adsorbate and solvent.

Henry is the simplest adsorption isotherm that describes the adsorption of adsorbates at relatively low concentrations when all adsorbate molecules are separated from the nearest neighbours [8]. The equilibrium concentrations of adsorbates in the liquid and adsorbed phases are related by the linear expression:

$$q_e = K_{He} \cdot C_e \qquad (3)$$

Where: q_e - adsorbed amount of adsorbates in equilibrium or adsorption capacity (mg/g); C_e - equilibrium concentration of adsorbates in the liquid phase (g/dm^3); K_H - Henry equilibrium constant of adsorption.

Fowler–Guggenheim linear equation [9] looks like this:

$$\ln \frac{C_e \cdot (1-\theta)}{\theta} = -\ln K_{FG} + \frac{2 \cdot W \cdot \theta}{R \cdot T} \tag{4}$$

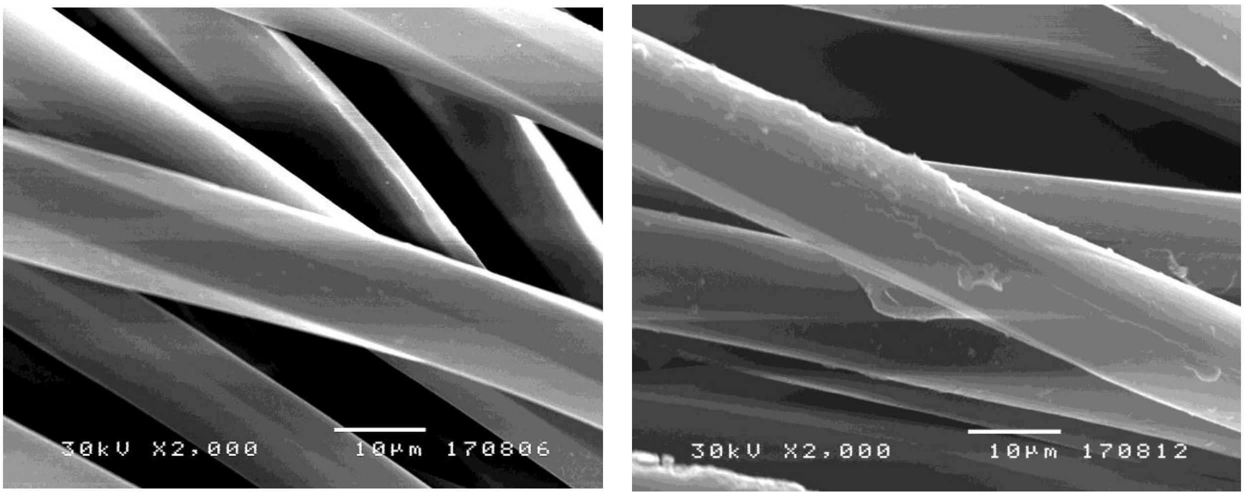
Where K_{FG} is the Fowler-Guggenheim equilibrium constant (dm^3/mg); $\vartheta=(1-C_e/C_0)$ is the degree of surface coverage; W is the interaction energy between adsorbed molecules (kJ/mol); R is the universal gas constant and is equal to 8.314 J/mol·K, and T is the absolute temperature (K).

The values of K_{FG} and W were evaluated from the intercept and the slope, respectively, of the linear plot of $\ln(C_e(1-\vartheta)/\vartheta)$ versus ϑ based on the experimental data.

3. Results and discussion

Figure 2 shows surface micrographs of untreated and eutectic mixture-treated PES fibers (magnification 2000×). The surface of the raw PET fabric was clean and smooth, while the treated sample had an altered surface morphology with an eroded surface, stratification resulting in greater surface roughness.

In a similar study [10], the surface of the raw PET fabric was clean and smooth, while the sample, after chemical modification using the eutectic solvent choline chloride and oxalic acid, had an incised surface morphology with a small number of eroded peeled PET fibers.

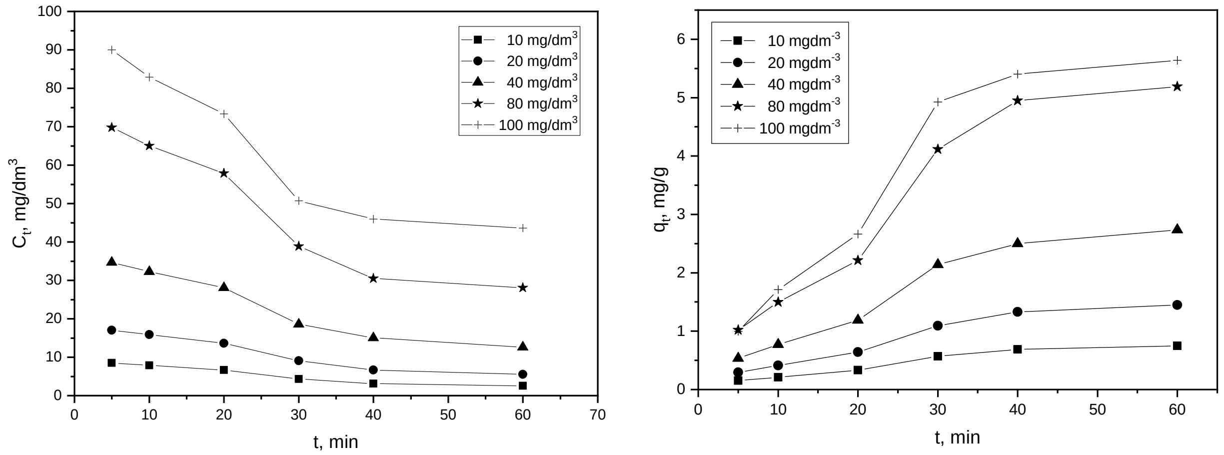


a. b.

Figure 3: Micrographs of PES fiber samples a) untreated sample; b) sample treated with eutectic solvent

PES is mainly dyed with non-ionic dyes (disperse dyes) specially synthesized to match this hydrophobic fiber. Selected colour C.I. Disperse Red 73 has a low molecular weight, which facilitates its entry and diffusion in highly crystalline PES fibers. This fiber does not absorb a significant amount of water, the dye is absorbed only in amorphous regions, i.e., it does not enter the crystal regions of the fiber. During dyeing, the rate of diffusion of dye molecules to the surface of the fiber is always higher than the rate of diffusion in the fiber [11].

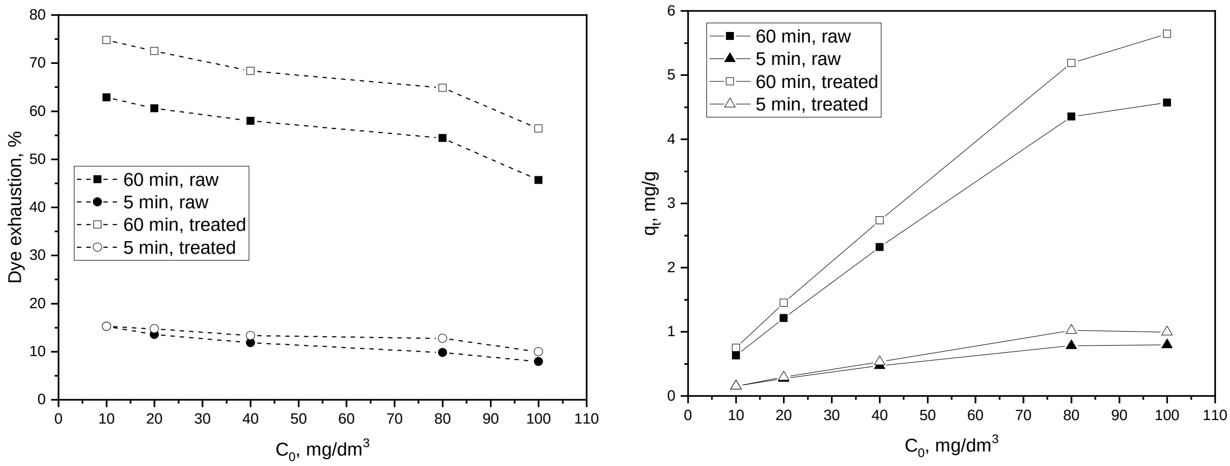
The influence of time on the change of dye concentration (Fig. 3a) during the dyeing of the treated polyester solvent as well as on the adsorption capacity (3b) is shown in the graphs in Figure 3. As the dyeing time increases, the adsorption capacity (q_t) increases, while the concentration of dye in the solution decreases over time. As the dyeing process proceeds, the initial concentration of disperse dye (C_0) decreases proportionally, initially faster and then slower, reaching a minimum at equilibrium time.



a. b.

Figure 4: Change in dye concentration and adsorption capacity during dyeing of eutectic mixture-treated polyester

When comparing the parameters of the dyeing process of raw polyester and eutectic solvent-treated polyester, the dependences shown in the graphs of Figure 4 are obtained. The graphs in this figure show the comparative curves of the variables for the shortest and longest dyeing times. It can be seen from the graph that less dyes remain in the solution and that the adsorption capacity is higher when dyeing solvent processed-polyester compared to raw polyester. It has been confirmed that dyeing polyester after treatment with eco-friendly eutectic solvent leads to greater exhaustion of dye to the fibers compared to dyeing raw polyester. This behaviour is practically reflected in all dye concentrations and all dyeing times.



a. b.

Figure 5: Comparison of dye adsorption parameters between raw polyester and eutectic mixture-treated polyester

Pre-treatment of polyester seems to go in the direction of developing the action of eutectic solvent, presumably due to enhanced glycolysis reaction caused by ethylene glycol and choline chloride, fiber structures are opened, surface morphology is rearranged and greater adsorption of dispersed dye is allowed. Also, this greater exhaustion of dye can be explained, in addition to the above, by the possibility that the crystallinity of PES fibers is partially transformed during solvent treatment due to removal of oligomers from surface layers and due to the real possibility, that such treatment could dislocate parts of macromolecules among microcrystallites area. In other words, for the dye molecules to diffuse within the fibers, a free volume must be formed in them. Treatments by the eutectic solvent appears to help reorganize free volume within the fiber through thermal shifts in the chains of molecules and dye molecules that enter this free space. At the same temperature, the thermal displacement of the molecular chains creates a more permeable and flexible substrate allowing faster dye diffusion, which is partly provided by treatment of eco-friendly solvent.

Modelling of equilibrium dyeing was done by analyzing three isothermal models, Freundlich, Haslay and Henry. The graph in Figure 5 represents a linear interpretation of the Henry adsorption isotherm. Linear distribution of Henry type is frequently used as referent for isotherm adsorption of textile dye on polyester [8]. Among the isothermal models considered in this study, Henry's law is the simplest, has only one unknown parameter, and can be successfully applied in many cases. For the specific case of adsorption of disperse dye per 1 g of polyester (98 °C), according to the graph in Figure 5, this model does not adequately cover the experimental point with its fitted curve, so it cannot be used to characterize a specific case of adsorption.

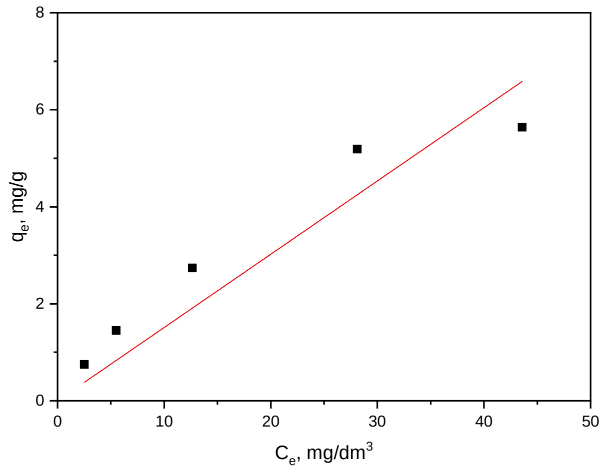


Figure 6: Henry adsorption isotherm for the system of disperse dye– eutectic mixture-treated polyester

The graph of Figure 6 represents Freundlich isotherm for adsorption of disperse dye onto the adsorbent (eutectic solvent-treated polyester fabric), for a constant amount of adsorbent and a temperature of 98 °C. The Freundlich model has the highest value for R^2 (0.988) and is therefore the most acceptable for the description of eutectic solvent-treated polyester staining with disperse dye.

Freundlich isotherm implies the existence of a heterogeneous surface with the uneven distribution of the adsorption heat on the surface and with the possibility of formation of multilayer adsorption [7]. Based on this graph, the values of Freundlich constants are determined, and via them, the competence of this model for describing the process of applied dye adsorption for polyester is evaluated.

If it is assumed that dyeing occurs by a mechanism that provides for Freundlich model, in an early stage of adsorption, the monolayer of adsorbed dye molecules is formed. The formation of multilayers of adsorbed dye molecules at non-specific sites on the fiber immediately follows through the self-association of adsorbed dye molecules. Newly adsorbed dye molecules can associate with previously adsorbed molecules within the substrate. There are also aggregated dye molecules from the bath that can also be adsorbed. Aggregation of the dye within the fiber and, thus, the formation of multi layers of adsorbed dye molecules is likely to happen, regarding the fact that long and flat molecules of disperse dye tend to self-associate in solution via π-π interactions between adjacent dye molecules.

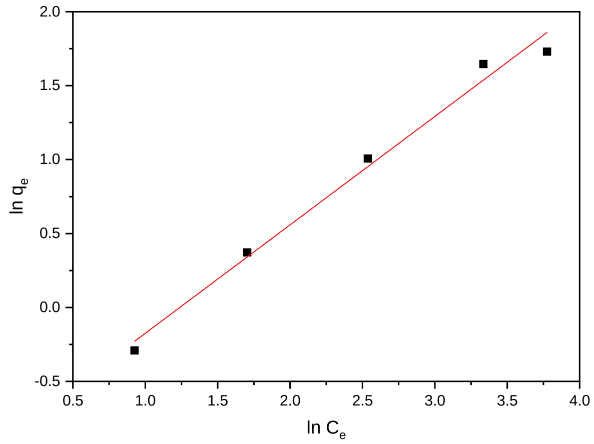


Figure 6: Freundlich adsorption isotherm for the system of disperse dye– eutectic mixture-treated polyester

The Fowler-Guggenheim isotherm is the simplest equation developed by considering lateral interaction of the adsorbed molecules. The heat of adsorption varies linearly with loading. If the interaction between the adsorbed molecules is attractive (i.e., *W* is positive), the heat of adsorption will increase with loading. That is why there is increased interaction between adsorbed molecules as the loading rises. This means that if the measured heat of adsorption shows an upward trend with respect to loading, it indicates the positive lateral interaction between adsorbed molecules [9]. Contrarily, if the interaction among adsorbed molecules is repulsive (i.e., W is negative, a specific case in this research, W=-30.42 kJ/mol), the heat of adsorption shows a decline with loading. Thus, in the specific case of dyeing polyester with a disperse dye, the lateral interaction between the adsorbed dye molecules is repulsive.

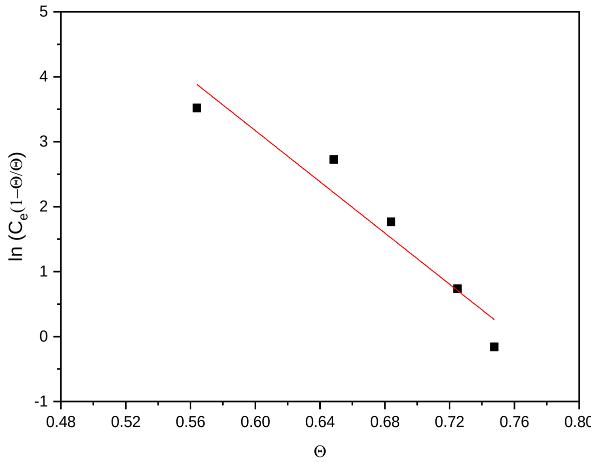


Figure 7: Fowler-Guggenheim adsorption isotherm for the system of disperse dye–eutectic mixture-treated polyester

The adsorption data for the disperse dye adsorption onto the eutectic solvent-treated polyester were calculated and summarized in Table 1. According to the data in this table, the statistical parameter for defining the validity of the model, the coefficient of determination, is the weakest in the isothermal Fowler – Guggenheim model (R^2=0.928). The Freundlich and Henry models have better values for the coefficient of determination, (R^2=0.988 and 0.957, respectively).

Henry's model proved to be acceptable in this case, although it does not have the best R^2. The full power of this model is seen at low adsorbate concentrations, without considering surface coverage.

K_F, one of the Freundlich constants, is used as a relative measure of adsorption capacity. A lower value (K_F =0.4 in this case) indicates a weaker adsorption capacity. Other Freundlich constant, n_F, is an empirical parameter that is changed with a degree of heterogeneity, indicating the degree of non-linearity between the capacity of receiving the dye and concentration of non-adsorbed dye, and relates to the distribution of bound ions to the surface of the adsorbent-fabric. In general, 1/n_F<1 shows that adsorbate is adsorbed enough on the adsorbent, adsorption capacity increases, and there are new positions for adsorption; the higher the value of n, the greater the intensity of adsorption. The results confirm that n_F>1, i.e., 1.36>1, or 1/n_F<1, i.e., 1/1.36<1, that is 0.73<1.

Table 1: Analytical expressions and parameters of the used models for the description of adsorption of the disperse dye to the eutectic mixture-treated polyester

Analytical expression of the model	Model parameters		R^2
Henry: $q_e = 0.15 \cdot C_e$	K_{He} (dm3/g)	0.15	0.957
Freundlich: $\ln q_e = -0.91 + 0.73 \cdot \ln C_e$	K_F (mg/g)·(dm3/mg)(1/n)	0.40	0.988
	n_F	1.36	
Fowler-Guggenheim: $\ln \frac{C_e \cdot (1-\theta)}{\theta} = 15 - 19.72 \cdot \theta$	K_{FG} (dm3/mg)	0.0000003	0.928
	W (kJ/mol)	-30.42	

4. Conclusions

Pre-treatment of polyester fabric with a eutectic mixture (ethylene glycol and choline chloride) improves the hydrophilicity of the fibers and allows dyeing in atmospheric conditions. The eutectic mixture consists of alcohol and salt that are biodegradable and biocompatible which is also being widely used as a feed additive for livestock (choline chloride).

Treated polyester fibers with a combination of ethylene glycol and choline chloride absorb more dispersed dye compared to untreated-raw PES fibers, the adsorption capacity increases over time, the exhaustion of dye from the solution on the fiber increases and the dye concentration in the solution decreases.

Modelling of disperse dye adsorption, i.e., dyeing of pre-treated PES fabric was tested under different conditions without carriers in the dyeing bath. It was found that dyeing-adsorption depends on the time of contact, the initial concentration of the dye, as well as the fact that it is a multilayer adsorption on a heterogeneous surface without major side interactions between the dye molecules.

The data obtained from the Freundlich equation confirm that this model provides a sufficiently accurate description of the experimental data and the dyeing process. The Henry isotherm gives acceptable results and contributes to the clarification of the dyeing. The Fowler-Guggenheim model, with a slightly weaker statistical parameter, assumes the absence or weaker interaction between adsorbate molecules on the surface of the polyester fiber.

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Original Article

FUNCTIONALIZED MICROCAPSULES WITH SILVER FOR MEDICAL TEXTILES

Iva REZIĆ[1]*; Mislav MAJDAK[1]; Petra KIRIN[1], Marko VINCEKOVIĆ[2], Slaven JURIĆ[2], Katarina SOPKO STRACENSKI[2], Kristina VLAHOVIČEK-KAHLINA[2], Maja SOMOGYI ŠKOC[1]

[1] University of Zagreb, Faculty of Textile Technology; iva.rezic@ttf.hr
[2] University of Zagreb, Agronomy Faculty; marko.vincekovic@agr.hr
* Corresponding author: iva.rezic@ttf.hr

Abstract: *World Health Organization has recognized the problem of antimicrobial resistance as one of the most important issues in world health protection. Due to the increasing resistance of harmful bacteria and other microorganisms to conventional drugs, it is necessary to develop new solutions for medical textile materials. The antimicrobial properties of silver ions are intensively investigated in a form of silver ions and silver nanoparticles, so their application on medical textile materials is very important. Therefore, this study aimed to functionalize textile surfaces with antimicrobial microcapsules filled with antimicrobial substances. The characterization tests were performed by ultraviolet and visible spectrometry on samples containing silver in microcapsules in both nanoparticle and ionic forms. Testing of the samples was performed on ready-made microcapsules obtained from sodium alginate, which contained silver in their core. In contrast, the outer shell was made of zinc sulfate 7-hydrate. The encapsulation method using the Buchi Encapsulator B-390 encapsulator was used to obtain these microcapsules. For characterization purposes, the test was performed on a two-beam Lambda 20 instrument, manufactured by Perkin Elmer from the United States. The test was performed in the ultraviolet and visible range, in the range of 190 to 900 nm. The test was performed in an aqueous medium in which the microcapsules released silver. The obtained test results will enable the determination of the concentration of silver released over time from microcapsules in an aqueous medium, and based on the obtained results, the antimicrobial properties of silver ions will be estimated based on the released quantities that are efficient for removal of certain strains of microorganisms on textile medical materials.*
Keywords: *antimicrobial resistance; microcapsule; silver; medicine textile; coatings*

1. Introduction

The textile industry has recognized the importance of materials functionalization. Medicine materials need antimicrobial coatings in order to obtain efficient antimicrobial properties. Therefore the usage of metal ions and metal nanoparticles as antimicrobial reagents is present in a wide variety of textile manufacturing products. Some of those items are sports clothing, uniforms, medical materials and other protective items. The antimicrobial activity of silver ions and silver metal nanoparticles is the result of its chemical properties, but moreover of their size (ranging in between a few nanometers to much larger particles). This size range is small enough to make nanoparticles available for interaction with the microorganisms on their surfaces and/or with their cores [1]. Metal nanoparticles show strongantimicrobial activity not only on bacteria but as well as on spores resistant to high temperature and high-pressure [2]. Therefore nanoparticles are used on textile materials to obtain reinforced antibacterial materials resistant to tear. In addition to antibacterial properties, anti-odor, self-cleaning and medicine textiles are achieved.

Silver, in a form of ion, is recognized as a powerful antimicrobial reagent throughout history [3]. Since threads had fragile textile cores made of silk, or other natural fibers the characterization of multilayer samples is a complicated analytical task [4, 5]. The chemical characterization of antibacterial protective layers is important for scientific, technological and industrial aspects. The methodology proposed is the combination of microscopy and spectroscopy [7-13]. The most frequently used spectroscopic methods are UV-VIS, FTIR, inductively coupled plasma – optical emission spectroscopy (ICP-OES) and inductively coupled plasma – mass spectroscopy (ICP-MS) [14-17]. In addition, chromatographically enhanced sample preparation can provide better resolution and faster analysis of complex samples [19-23]. In most prominent cases the combination of different approaches enables fast and efficient characterization of textile materials that contain metal parts, metal ions or metal nanoparticles [24 – 28]. Therefore this work was focused on the characterization of antimicrobial coatings on textile materials containing microcapsules with silver ions and silver nanoparticles.

The origins of the microencapsulation process lie in the pharmaceutical and paper industries of the 1940s. However, the textile industry began introducing encapsulated products between 1980 and 1990 [3]. Namely, the pharmaceutical industry has long used microencapsulation to prepare capsules containing active ingredients. Over the past 10 years, this approach has been extensively researched by the agricultural, food, cosmetic and textile industries. The number of commercial microcapsule applications in the textile industry continues to grow, particularly in the textile industry of Western Europe, Japan, and North America. Textiles with new properties and added value are appearing more and more. In medical textiles or technical textiles, the industry is increasingly encouraging the use of microencapsulation agents for finishing materials and finishing properties, which was not possible or cheap using other technology. Textile manufacturers are showing increasing interest in applying permanent fragrances to textiles and leather [3]. Other potential applications include insect repellents, dyes, vitamins, antimicrobial drugs and special medical applications, antibiotics, hormones, and other drugs [3].
Microencapsulation can have two different purposes:
a) block the substance inside the microcapsule when diffusion of the product is not desirable
b) gradual release of the active ingredient within the microcapsule which in that case should have a more brittle wall

Various methods are used to encapsulate microparticles, which are divided into physical and chemical. The choice of microencapsulation technique depends on the substances used, size, biocompatibility and biodegradability, physicochemical properties (substances in the core and shell), the proposed mechanism of release of the active substance from the core and the cost of the process. Microencapsulation procedures are listed in Table 1.

Table 1: Physical and chemical methods of encapsulation

Physical methods	**Chemical methods**
Air suspension coating	Matrix polymerization
Coextrusion with submerged nozzles	Liposome technology
Coextrusion with a stationary nozzle	Simple and complex coacervation
Rotating disk atomization	Solvent extraction
Spray-drying	Evaporation of solvent
Spray-cooling	Phase separation by coacervation
Fluid coating	Polymerization at the phase boundary
Centrifugal process with multiple openings	In-situ polymerization
Centrifugal extrusion	Nanoencapsulation
Physical methods	Chemical methods

The choice of the technique depends on the following parameters:
a) for what purpose the microcapsules will be used
b) inertness to the encapsulating agent and the enveloping agent
c) the required release time of the encapsulated agent
d) the optimal concentration of the active encapsulating agent
e) a mechanism for releasing the active agent from the microcapsule (eg pH, pressure, solubility, time and agitation (shaking))
f) the method of release of the active agent (continuous, immediate or controlled release)
g) particle size, density and stability requirements of the encapsulated agent
h) the price of microcapsules, preparations or applications with respect to the final product.

Currently, microencapsulation technology is used in the field of chemical finishing due to its versatility and flexibility. A major advantage of this technology is the ability to protect the active ingredients from factors such as oxidation, heat, acidity, alkalinity, moisture or evaporation [3]. It also simultaneously protects the ingredients from interaction with other compounds in the system, which may result in degradation or polymerization. Another important advantage of this technology is its controlled release properties which is the best choice to increase antimicrobial efficiency and minimize environmental damage.

The advantages of microencapsulation are following:
- Protect sensitive materials from the environment before use
- Prevention of degrading reactions (oxidation, dehydration)
- Controlled, permanent or time controlled release
- Safe and practical handling of toxic materials
- Controlled and targeted drug delivery
- Handling liquids as solids [3]

The concept of microencapsulation dates back to the 1930s when the spray-drying technique was used. Microencapsulation technology was also used by NASA in the early 1980s to control the thermal properties of clothing, especially for use in space suits [3]. Phase-changing materials (PCM) have been encapsulated to reduce the extreme temperature differences to which astronauts are exposed in space. After that, the application of this technology spreads to almost all areas of human activity and needs. In the last 25 years, the application of microcapsules in the agricultural, food, cosmetic and textile industries has been intensively researched. Microencapsulation is a process in which tiny particles or droplets are surrounded by a coating where the final products are small capsules with useful properties. Microencapsulation can also be defined as the process of surrounding or coating one substance within another on a very small scale, yielding capsules in the range of less than one to several hundred µm. The potential size range of the microcapsules produced is huge, with a typical diameter between 2 and 2000 µm. The walls of the capsule are usually 0.5-150 µm thick, while the proportion of core material in the capsule is usually between 20 and 95% by weight. A substance that is encapsulated can be called a core, active ingredient or agent, filler or internal phase. The material comprising the core is referred to as the coating, membrane, shell, or wall. [3].

Microencapsulation is a technique that isolates particles (in liquid, solid or gaseous state) inside the envelope and produces spherical products, micro or nanometer in size. The coating protects the active substance, *i.e.* the core, from the external environment. Microcapsules are particles in the range of 1–1000 µm that contain the active substance (liquid or solid) surrounded by a natural, semi-synthetic or synthetic polymer shell. The structure of microparticles can generally be classified in several ways: as a single-core microcapsule surrounded by a shell, as a microsphere with a scattered core in a continuous matrix network, and as more complex structures (multilayer microcapsules or multishell microspheres). Solutions, dispersions or emulsions are most commonly used to make the core. The compatibility of the core material with the shell is an important criterion for increasing the efficiency of microencapsulation and pre-treatment of the core material is often performed to improve compatibility. Pigments, dyes, monomers, catalysts, hardeners, flame retardants, softeners, etc. can be encapsulated [3]. The purpose of this work was to test if the microencapsulation can be a carrier of silver for further application on medical textiles. For this purpose, the preparation steps of microcapsulation, the functionalization steps of dip coating with sol-gel procedure, and the characterization of released silver by UV-VIS was performed.

2. Materials and Methods

2.1 Samples

The solid silver nitrate) and silver nanoparticles (colloidal stabled suspension) were purchased from MERCK, Darmstand, Germany. Samples for functionalization were pure cotton and viscose materials intended for medical purposes.

2.2 Microencapsulation

Microcapsules can have a single wall or multiple shells arranged in different thicknesses. The structure of the microcapsule is shown in Figure 1.

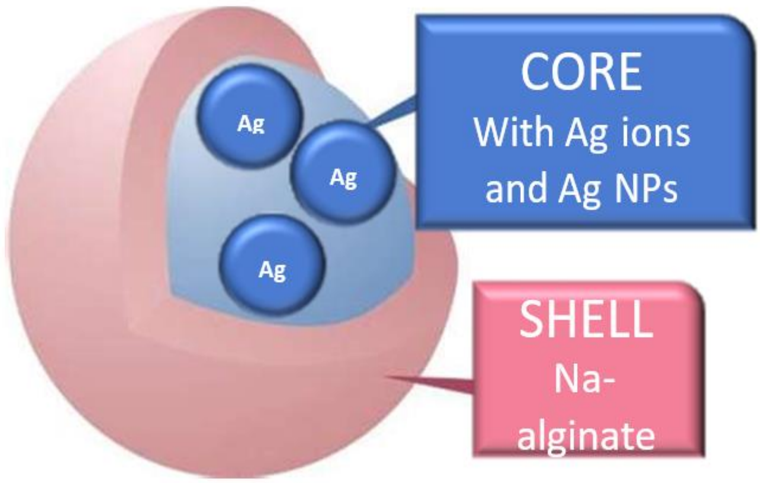

Figure 1: Structure of microcapsules with antibacterial silver

2.3 Sol-gel procedure

The sol gel is one of the oldest application of thin films and coatings on textiles. In this work the sol gel procedure with GLYMO precursor and HCl catalyzator was applied on woven 100% viscose materials, and used in order to form a thin film very quickly by the process of immersion using a very small amount of raw materials. After the immersion, the samples were dried on room temperature for 24 hours and heated for one hour at 100 degrees. The result was a uniform coating which is very suitable for antimicrobial protection (self-sterilizing or hygienic coatings). This procedure was chosen since it provided great opportunities in creating new surface properties of textiles, such is shown in Table 2. [3]

Table 2: Examples of improving the properties of textiles by sol-gel process

Surface properties	Water/oil repellency, wear resistance, (photo-) catalytic activity, barrier function
Optical properties	Color, photochromic effect, UV absorption
Textile properties	Fabric drop, comfort, feel, absorbency, permeability
Improved properties	Heat resistance, magnetic properties, electrically conductive properties
(Bio-) active systems	Biocidal treatments

Coatings obtained by the sol-gel process are used to improve the properties of substrates and to protect against mechanical, chemical or microbiological influences. There are several such coating techniques (Table 3).

Table 3: Sol-gel coating techniques

Sol-gel coating techniques
Dip coating
Spray coating
Flow coating
Capillary coating
Roll coating
Printing
Spin coating
Chemical coating

It is very important to choose the appropriate coating procedure as well as a good knowledge of the coating and the substrate. The main methods of application are immersion and rotation.

Dip-coating immersion is a process in which the substrate is immersed in a liquid and then extracted at a certain speedat a controlled temperature and atmospheric conditions. Immersion is very slow, which allows the coating to be oriented into a more favorable, denser structure.

The immersion process consists of 3 phases:

1. Immerse the substrate in the solution
2. Forming a wet layer by pulling out the substrate
3. Gel coating by solvent evaporation.

Evaporation of the solvent is a cause of the destabilization of the salts. This process further leads to gelling andforming of a thin coating. The salt particles are stabilized by surface tension. Particle attraction leads to very strong gelling. The sol-gel coating gels by evaporating the solvent during drying, and by the action of capillary forces the flexible gel shrinks while the solvent evaporates. As cross linking occurs, the coating becomes stiffer so that the coating can no longer shrink and the solvent withdraws into the pores of the gel. The resulting gel must be thickened by heat, while the coagulation temperature itself depends on the composition.

Several factors affect the thickness of the film during immersion: Viscosity of salts during immersion and sample emergence, the gravity, soil surface tension, inertia of the edge layers of the solo during the ascent from the solo, surface tension gradient and coupling/separation pressure (only affects when the coating thickness is less than 1 μm).

2.4 UV-VIS detection

For characterization, the Lambda 20 spectrophotometer was used (Perkin Elmer, two-beam with monochromator optical mesh). Its operating range was in a range of 190 nm - 1100 nm, and it was equipped with two sources of electromagnetic radiation (halogen and deuterium lamp) and a photodiode as a detector. The samples in solvent forms were transformed into the violet complex with dithizone and recorded under the maximal working wavelength of 550 nm.

3. Results and Discussion

When preparing the microcapsules, it was initially necessary to rinse the Buchi B-390 encapsulation device for a few minutes. A thin stream of ethanol (water), nitrogen gas and impurities go out into a special beaker where the liquid is thrown away after the cleaning process is completed. During the cleaning process, samples were prepared. During the cleaning period, it was of great importance to clean the encapsulator's nozzle, to avoid clogging. This was performed by using an ultrasound bath *Elma S 10 H Elmasonic*. In this case, a sample of solid silver nitrate, $AgNO_3$) and a sample of sodium chloride AgCl are used to obtain microcapsules. The epic with sample 2 was washed with the prepared solution of dilute sodium alginate, thus transferring the sample to a separate vial together with the remaining amount of dilute sodium alginate. Stir again to homogenize the sample and sodium alginate well. It was then necessary to prepare 500 mL of a 1% solution of calcium chloride, $CaCl_2$. Since all solutions were prepared and the device was purified, it was then necessary to set the operating parameters: ø (diameter of the extension) = 300 µm, f (frequency) = 400 Hz and p (pressure) ˜ 70 mbar). Encapsulation was performed by placing a bottle of sample solution and sodium alginate on the left side, releasing gas and the mixture flowing slowly forward into a beaker with calcium chloride (with constant stirring with a magnet) forming small capsules or spheres (because they do not have envelope). The process lasts until all the solution is encapsulated. After completion of the process, the mixture was allowed to stir for another half hour. During the mixing process, visible changes from a cloudy solution to the gradual formation of a white precipitate could be observed. Thus, the reaction of sodium alginate and calcium chloride produces calcium alginate (and sodium chloride), *i.e.* a gel was formed according to the reaction:

$$2NaC_6H_7O_6 + CaCl_2 \rightarrow 2NaCl + C_{12}H_{14}CaO_{12} \qquad (1)$$

After 30 minutes the spheres took on a much clearer shape and the deposition process was complete. This completed the process and the spheres were ready for the filtering process. Filtration of the microcapsules was performed through a tissue. During filtration, the spheres had to be rinsed with sterile water. The process itself was very slow. The spheres prepared in this way were very soft and it was noticed that with the outflow of excess liquid, they remain on the fabric of almost transparent color. Since the spheres obtained were very delicate, grainy and soft, it was necessary to transfer them very carefully with a spoon into the cuvette. In order to remain undamaged and in as many numbers as possible, they had to be precisely and carefully scraped off the fabric. The NaCl effects on the release of silver was not investigated.

Figure 2: *a* Filtration of prepared samples and *b* stored microcapsules

Cuvettes with spheres must be stored in a cool and dark place because otherwise they disintegrate and disintegrate attoo high a temperature. Furthermore, depending on the composition and purpose, the microcapsules may be of different colors as well as sizes and shapes, and not just transparent as they are prepared for the purposes of this work.

Table 4: Release of silver ions in destilled water from three different samples of microcapsules determined by UV-VIS spectroscopy, Lambda 20, Perkin Elmer dual beam spectrometer expressed as the intensities of the signals (A) of three different microcapsulae samples of 150 micrometers in diameter observed with dithizone reagent.

Time	A(Sample 1)	A(Sample 2)	A(Sample 3)
0	0,009239	0,009138	0,009239
1	0,010145	0,009742	0,009642
2	0,011556	0,011254	0,011153
3	0,012463	0,011757	0,011757
4	0,013369	0,012362	0,012261
5	0,013269	0,013369	0,013067
24	0,01619	0,015082	0,015082

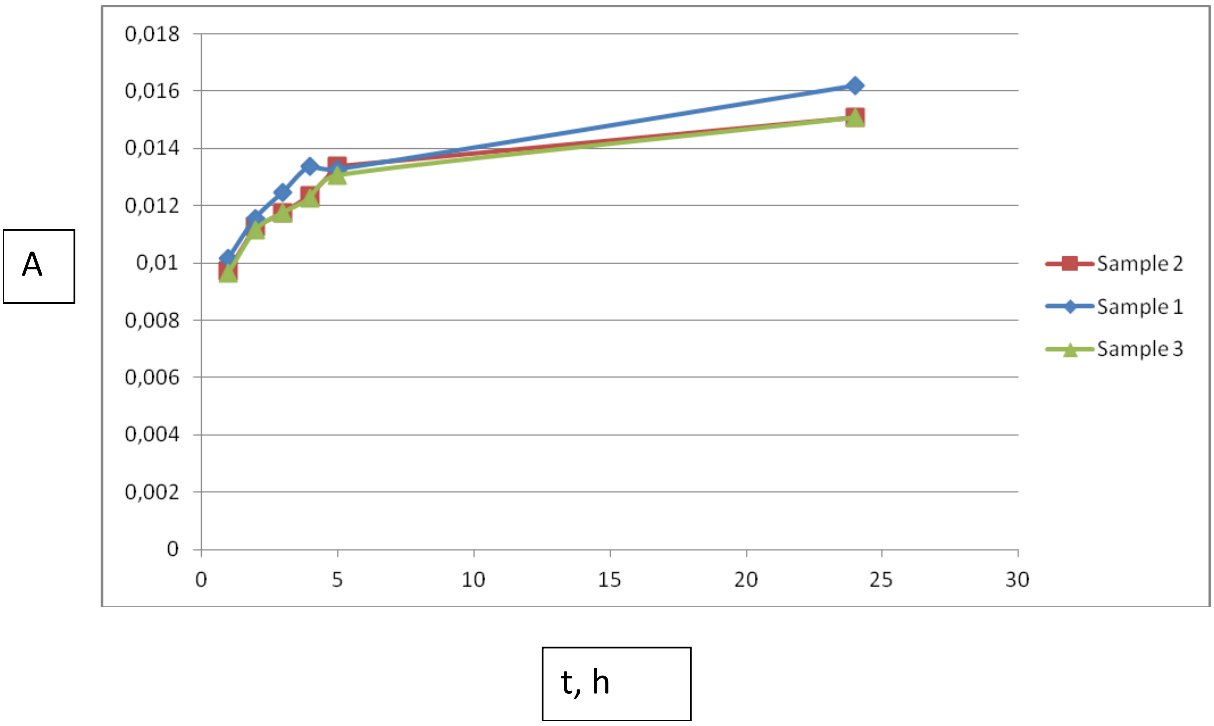

Figure 3: Graphical representation of silver ion release.

As can be seen from the Figure 3 that presents the release of silver during 24 hours, the release of silver ions slows down and a plateau is is achieved which is applicative for coatings on medical textiles in which this release effect is desired. Moreover, the obtained results correspond to the literature data that were used to calculate and optimize the released quantities of the silver (Figure 3).

Microencapsulation tha enables such release of antimicrobial silver can play a role in continuous development, e.g., by allowing sensor chemicals to be attached to sportswear and medical products so that they will be able to warn of harm or danger to the user. Systems can also be developed to deliver measured doses of fighting chemicals, muscle aches, or other more serious injuries. The range of potential applications of microencapsulation in textiles is as large as the imagination of textile designers or manufacturers.

4. Conclusion

These results of this investigation (shown in Table 4 and in Figure 3) should enable further steps in creating more powerful antimicrobial tools efficient against microorganisms. Furthermore, microencapsulation in the future will be an indispensable part of the functionalization of various textile materials, from geotextiles, agrotextiles to medical textiles and medical aids. The best way for most textile microcapsule applications would be a system that is easy to apply, does not affect existing textile properties, and has a shelf life on clothing that allows for a normal maintenance process. Currently, although capsules can survive 25-30 wash cycles, ironing and other processes such as drying can cause a dramatic reduction in the desired effect [3]. In the future, consumer desire for new and unique effects will always prevail. In the growing desire for comfort, the consumer always demands a fresh scent and softness. He also expects these properties to last the life of the garment. Microencapsulation can provide long-term results for certain goals. Due to the desire for a healthier and more productive lifestyle, it is necessary to produce such textiles that interact with the consumer, which reduces stress, promotes comfort and relaxation through active delivery from the microcapsule.

Silver ions and nanoparticles have anti-bacterial effects on a wide range of Gram-positive and Gram-negative bacteria, including antibiotic-resistant strains. They are widely used because of their chemical stability, catalytic activity, and high conductivity, as well as their exceptional antimicrobial activity due to their high surface-to-volume ratio, which provides them with better contact with microorganisms. Encapsulation methods are used in the textile, pharmaceutical and cosmetic industries to deliver biologically active substances to desired places. The availability of new active nanoparticles has opened up opportunities for the development of new matrices and applications that can be used in the development of various products, and encapsulation is a relatively new technology that enables the storage, stability and slow release of active substances. Materials for forming microcapsules are mainly carbohydrates (starch, cellulose, gums), proteins (milk proteins - caseins and whey proteins, gluten, gelatin) and lipids (fatty acid-line,alcohols, glycerides, waxes, phospholipids) or a combination thereof. Microcapsules are becoming increasingly present in the functionalization of textile polymers. Techniques for encapsulating bioactive constituents include co- conservation, micro-encapsulation by hot-air flow, micro-encapsulation of fluidized particles, micro-encapsulation by extrusion and supercritical fluids, emulsification and cocrystallization. In this work, microcapsules were investigated byspectroscopy to determine the silver content of the samples that is leached during 24 hours, and from the obtained results it can be concluded that the range of the released antimicrobial agents was in correlation with the current literature data and is the basis of our future steps in preparation of powerful antimicrobial coatings for medical materials.

Acknowledgements

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Original Article

DETERMINATION OF THE INFLUENCE OF STERILIZATION ON THE PROPERTIES OF COMPRESSES

Jana JURAN[1]; Maja SOMOGYI ŠKOC[2]; Jelena MACAN[3]; Iva Rezić[2]

[1] PhD student at University of Zagreb Faculty of Textile Technology, Zagreb, Croatia; juran.jana94@gmail.com
[2] University of Zagreb Faculty of Textile Technology, Zagreb, Croatia, maja.somogyi@ttf.unizg.hr, iva.rezic@ttf.unizg.hr
[3] University of Zagreb Faculty of Chemical Engineering and Technology, Zagreb, Croatia, jmacan@fkit.hr
***** Corresponding author: maja.somogyi@ttf.unizg.hr

Abstract: *In this paper, the influence of moist heat sterilization and ethylene oxide sterilization on the physical-mechanical properties of compresses was investigated. The investigation was performed on commercially available samples of compresses. The resistance of cellulose to various chemical agents primarily determines the behaviour of cotton fibres under the action of various chemicals, where for use in the field of medicine (medical textiles) during sterilization there must be no change in physical-mechanical and chemical properties. In order to determine the effect of two types of sterilization on cotton fibre compresses, according to EN 14079:2008, standardized methods of textile strength in the experimental part of the paper was used. Determination of degree of polymerization with morphological characteristics determined by scanning electron microscope (SEM) were carried out as well. The results showed that ethylene oxide sterilization slightly increases the degree of polymerization (DP). This fact does not affect the safety of using the compresses, because a higher value of DP compress indicates better mechanical properties, what is necessary for their usage.*
Keywords: *compresses; moist heat sterilization; ethylene oxide sterilization; medical textiles; testing*

1. Introduction

Wound compresses are widely used in medicine, during operations, for the treatment of postoperative work and for hygienic purposes. The main purpose is the care of infected wounds with higher excretion, as well as the treatment of a wide range of external wounds due to the high power of absorption and for the disinfection of puncture sites [1]. Infections are a common cause of surgical failures, and nowadays transplantation and implantation of apoplastic prostheses are often the cause of death [2]. For this reason, the use of sterilized compresses is very important. Compress sterilization, i.e. sterilization is any process that completely removes or destroys all forms of microorganisms and their transmissible agents, such as bacteria, viruses, fungi, spores and the like. An item can be considered as sterile if the probability of living microorganisms present is less than 1: 1,000,000 (1 million). In other words, per 1 million sterilized items, a surviving microorganism may be present on only one item. All instruments and objects that enter the area of the body or that encounter wounds must be sterile [3]. Sterilization can be dry, wet, chemical, UV radiation or some other modern method. Physical-chemical processes (ethylene oxide, formaldehyde, peroxide plasma) are used for *thermostable materials*, while physical processes (hot steam under pressure, moist heat, dry heat, ionizing radiation, annealing, and filtration) are used for *heat-resistant materials* [4].

Textiles (coats, sheets, compresses, diapers, and bandages), metal objects (instruments), rubber and glass objects are sterilizing with moist heat sterilization. The mechanism of destruction of microorganisms is based on the destruction of cellular proteins [5]. **Moist heat sterilization** under pressure is a reliable procedure for the destruction of all types of microorganisms and their spores. Compressed hot water vapour has a good ability to penetrate sterilisable materials. Moist heat sterilization is performed in special devices, autoclaves (Figure 1a). Factors of a certain temperature and pressure are important for the destruction of microorganisms, during the prescribed time [6].

Depending on the type of material to be sterilized, the temperature in the autoclave ranges between 126 and 138 °C, the pressure between 1.5 and 2.5 bar, and the sterilization time is from three to 30 minutes. In this paper, the conditions of moist heat sterilization are the trade secret of the manufacturer.

Ethylene oxide sterilization is the method of choice for high temperature sensitive materials (plastic or rubber objects, sharp objects, sensitive instruments, objects that are implanted in the patient's body). Ethylene oxide gas is a sterilizing substance with bactericidal, fungicidal and virucidal action. It is flammable and toxic, and in direct contact with the skin and mucous membranes causes burns, so it requires special care [5]. Ethylene oxide sterilization is a complex process involving several parameters that contribute to the efficiency of sterilization. In the presence of ethylene oxide, the temperatures in the chamber are from 54 to 55 ° C and the pressure from 1.5 to 5.5 bar, for 1-2 hours, automatically regulated by the interrelationships of these factors, the sterilization process takes place. Ethylene oxide is flammable and toxic, and in direct contact with the skin and mucous membranes causes burns, so it requires special care. Ethylene oxide sterilization is performed in special sterilizers (Figure 1b).

The ethylene oxide sterilization process must be validated in accordance with the requirements of the standard EN ISO 11135: 2015 [6].

a) b)

Figure 1: Sterilization devices a) autoclave; b) sterilization with ethylene oxide

Sterilization of compresses in any of the above ways must not affect the basic building material of cotton - cellulose. During sterilization, there must be no change in the degree of oxidation, reduction in the degree of polymerization, degradation of the molecular structure, no change in appearance (discoloration, coloured stains), loss of strength and partial or complete decomposition of the compress.
The cotton compress is quite hygroscopic where the hydrophilicity of cotton increases after boiling and bleaching, and for this reason the cotton compress is suitable for sterilization with moist heating. Regarding the behaviour of cotton (cotton compresses) in the action of various chemicals, the behaviour is primarily determined by the resistance of cellulose to chemicals. Relatively good resistance to alkalis and organic solvents can be noted, and less to inorganic acids [7]. The highest quality cotton fibres are used to make compresses, regardless of the method of cotton classification. Cotton is one of the most important raw materials for making compresses, and the main difference between compresses on the market is whether it is made of gauze or non-woven material. Compresses made of gauze are most often made of cotton and in the form of fabric, the density of which varies depending on the yarn. In the case of cotton compresses, it is very important that they contain at least one interwoven strip on the edge parts in order to avoid pulling out the thread. The compress contains a minimum of eight and a maximum of 16 flat layers that are folded at defined angles [8].
At the time of writing, and within the available literature no similar work as this has been found. Compresses belong to the group of medical products that directly affect human health and therefore control of sterilized batches of cotton compresses would be necessary. Cotton is a natural fibre whose properties are determined by genetic nature, where, regardless of the optimal sterilization conditions, desired or unwanted cellulose reactions can occur.
The standard EN 14079: 2008 prescribes the basic performance requirements and methods of testing compresses, but does not address the verification of the impact of sterilization [9]. This paper is a scientific contribution to the consideration of the influence of sterilization on cotton compresses through the standardized method of determining the strength of compresses, determining the degree of polymerization and determining morphological characteristics using a scanning electron microscope (SEM).
The aim of this paper is to determine whether there is a change in the physical and mechanical properties of cotton compresses after sterilization – moist heat sterilization and sterilization with ethylene oxide.

2. Experimental

2.1 Textile Materials

The research was conducted on two series of commercially available samples from a renowned manufacturer. Six samples of cotton compresses, two of which were untreated, two samples were sterilized with moist heat and two samples were sterilized with ethylene oxide were tested.

2.2 Sterilization

In this paper, the conditions for sterilization of ethylene oxide are a trade secret of the manufacturer. Sterilization was carried out in the plant of the manufacturer.

2.3 Methods

Basic characteristics of the textile materials, i.e. composition was determined according to the ISO 1833-1:2020, mass per unit area according to ISO 3801:1977 and thickness according to ISO 5084:1996.
The tensile strength test was performed in accordance with the EN 14079:2008*, Non-active medical devices -- Performance requirements and test methods for absorbent cotton gauze and absorbent cotton and viscose gauze* and EN ISO 13934-1:2008, *Textiles -- Tensile properties of fabrics -- Part 1: Determination of maximum force and elongation at maximum force using the strip method*.

The tensile properties of compresses – strip method on a tensile strength tester, code 2510, Tensolab 3000, Mesdan, Italy was carried out (Figure 2). Five samples in the weft and five samples in the direction of warp were prepared. Each piece of sample were 50 mm wide and sufficiently long (350 mm) to allow the clamps of the machine to be 200 mm apart when the piece was inserted. Each piece were clamped between the jaws of a constant rate of traverse machine and speed of movement of 100 mm ± 10 mm per min was applied. The preload depended on the mass per unit area of samples.

Figure 2: Appearance of the test sample in the clamps prepared for testing

Determination of degree of polymerization was carried out by viscosity method (Ubbelohde viscometer) with bis(ethylenediamine)copper(II) hydroxide solution. DIN 54270-3:1977-08, Testing of textiles, determination of the limit-viscosity of celluloses (Figure 3).

a) b)

Figure 3: a) Apparatus for determination of degree of polymerization, b) Mixing samples

Surface structure and morphological characteristics of the cotton compresses were investigated by scanning electron microscope (SEM) TESCAN VEGA III EASYPROBE, with the operating voltage of 20 kV. Magnifications were 500 and 10000x, samples were coated with Au/Cr.

3. Results and discussion

Basic characteristics of the untreated textiles before and after sterilization were performed according to the standards. The results of composition, mass per unit area and thickness are listed in Table 1. In the way of the easiest following determined results, all treatments with belonging codes are shown in Table 1 as well.

Table 1: Characterization of samples

Test characteristics	Standard	Samples					
		1			2		
		untreated	moist heat sterilization	ethylene oxide sterilization	untreated	moist heat sterilization	ethylene oxide sterilization
		1A	**1B**	**1C**	**2A**	**2B**	**2C**
Composition [%]	ISO 1833:2003	cotton	cotton	cotton	cotton	cotton	cotton
Mass per unit area [g/m^2]	ISO 3801:2003	26	25	25	25	25	24
Thickness [mm]	EN ISO 5084:2003	0,20	0,20	0,20	0,20	0,20	0,20

3.1 Results of strip test

Results of maximum force using the strip method are shown in Table 2.

Table 2: Results of strip test

CODE		1			2		
		1A	**1B**	**1C**	**2A**	**2B**	**2C**
		F[N]	F[N]	F[N]	F[N]	F[N]	F[N]
WARP	**X**	**86,28**	**75,46**	**79,08**	**94,42**	**82,50**	**91,46**
	δ	5,750	8,333	6,900	0,051	12,620	4,210
	V[%]	6,66	11,04	8,72	0,05	15,29	4,61
WEFT	**X**	**52,51**	**47,47**	**40,97**	**49,19**	**45,36**	**47,17**
	δ	5,766	5,901	1,702	2,940	3,151	4,892
	V[%]	11,04	12,44	4,16	5,97	6,96	10,37

The breaking strength values of samples 1A, 1B and 1C in the warp direction are between 76 and 87 N, and in the weft direction between 41 and 53 N. The breaking strength values of samples 2A, 2B and 2C in the warp direction are between 83 and 94 N, and in the weft direction between 45 and 49 N. From the results shown in Table 2, a trend can be observed that the initial samples have higher values of breaking force, compared to sterilized samples. The results obtained for moist heat sterilized samples are lower, than results obtained for ethylene oxide sterilization in the warp and weft direction (from samples 2A, 2B and 2C). This may be due to the manipulation of samples, i.e. preparation of samples for both sterilization where there is a shift in the density of the warp and weft threads, which in turn affects the results of breaking force and breaking stretching of cotton compresses.

3.2 Results of degree of polymerization

Table 3 gives the results of the degree of polymerization.

Table 3: Results of degree of polymerization

Characteristics / code	1			2		
	1A	**1B**	**1C**	**2A**	**2C**	**2B**
Degree of polymerization	2131	2519	2561	2519	2519	2603

The average degree of polymerization for cotton varies from 800 to 8000, depending on the type of cotton. Samples sterilized with the ethylene oxide show the differences, which is assuming that is connect with the residue of the precipitating agent. Higher value of degree of polymerization of compress indicates better mechanical properties, what is necessary for their usage. From the above it can be concluded that the sterilization with the moist heat was carried out carefully and cautiously, and that no damage was observed to the cellulose, i.e. cotton – compresses (sample 2).

3.3 Results of surface and morphological characteristics

Results of surface and morphological characteristics are shown in Table 4.

Table 4: Surface and morphological characteristics of samples taken with SEM

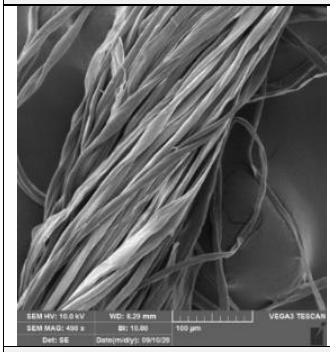
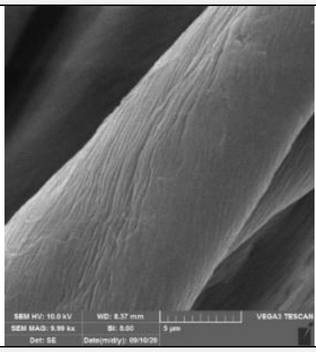
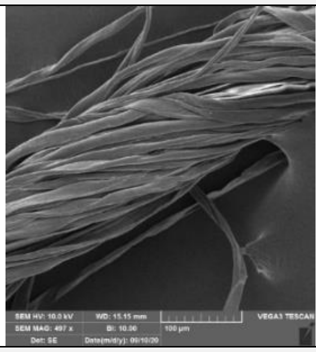
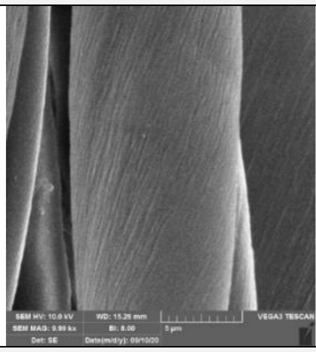
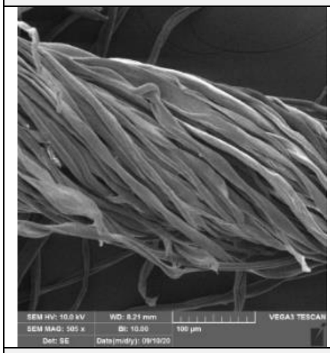
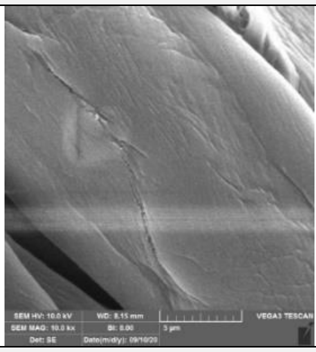
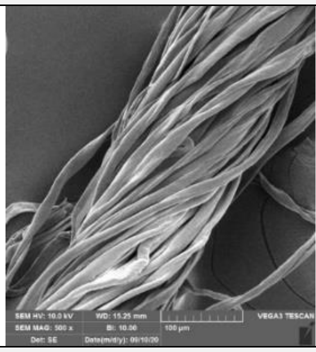
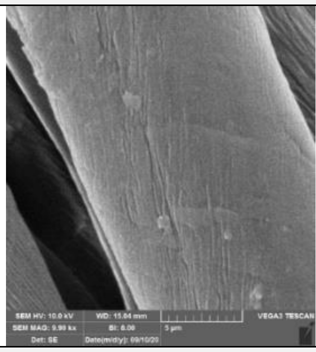
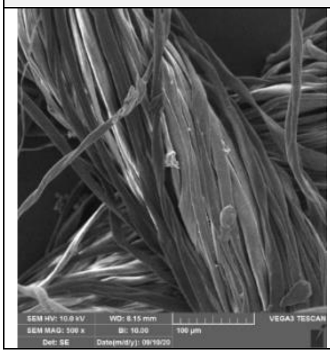
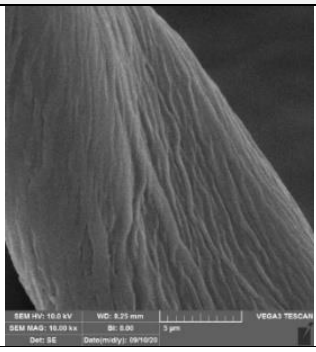
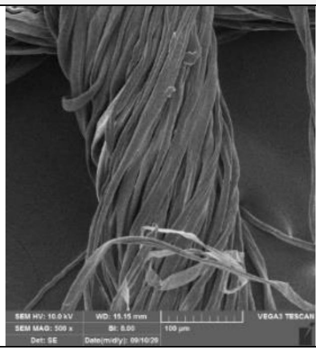
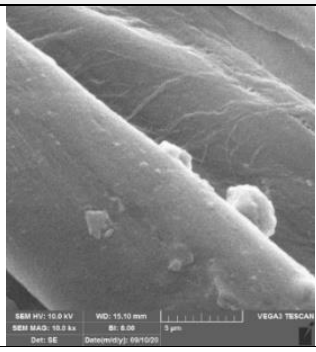
500x	10000x	500x	10000x
1A		2A	
			
1B		2B	
			
1C		2C	
			

Table 4 shown surface and morphological characteristics of untreated and sterilized samples. Images shown that there was no change in the surface by the action of sterilization, since no visually noticeable significant changes between the samples are visible. At a magnification of 10000x, samples 1B and 2B show a slight change in the form of a crack, which is assumed to be not necessarily due to sterilization but may have been damaged during sample preparation. Dots are visible on samples 1C and 2C, which is considered to be the residue of the precipitating agent, since these samples were treated with ethylene oxide sterilization.

4. Conclusion

The aim of this study was to determine whether there is a change in the physical and mechanical properties of cotton compresses after steam sterilization and ethylene oxide sterilization. Determining the degree of polymerization for the sterilization with moist heat, show that the length is negligibly increased for sample 1, but not for sample 2. Increasing is not so significance high but is present. That can be considered as a mistake of the meter or method, it can be concluded that this type of sterilization was carried out carefully and cautiously, and that no damage was observed cellulose, i.e. cotton - compresses. Samples sterilized with ethylene oxide show the little differences in obtained values, which assumed that is, connected with the precipitating agent. SEM images confirms that, little dots on the surface of the fibre are the residue of the precipitating agent. The results of the tensile strength test - strip test did not detect significant differences between the sterilized specimens and the untreated specimens. In addition to the physical and mechanical properties of the compress, it is necessary carried out test of the chemical properties, since changes of the fibres can be observed with certainty only in this way.

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Original Article

THE WEAR RESISTANCE OF SOCKS MADE OF DIFFERENTLY SPUN MODAL YARNS

Antoneta TOMLJENOVIĆ[1]; Juro ŽIVIČNJAK[2]; Ivan MIHALJEVIĆ[3]

[1] University of Zagreb Faculty of Textile Technology, Zagreb, Croatia; antoneta.tomljenovic@ttf.unizg.hr
[2] University of Zagreb Faculty of Textile Technology, Zagreb, Croatia; juro.zivicnjak@ttf.unizg.hr
[3] University of Zagreb Faculty of Textile Technology, Zagreb, Croatia; ivan.mihaljevic@ttf.unizg.hr
* Corresponding author: juro.zivicnjak@ttf.unizg.hr

Abstract: *The applicability of modal fibers, which provide exceptional contact comfort and have better hydrophilicity than cotton, in knitting of socks is insufficiently researched. Therefore, in this paper wear resistance of three groups of men's socks, made in the highest percentage of single ring, rotor and air-jet spun modal yarns of the same linear density in full plating by textured polyamide 6.6 yarns of different linear density were evaluated. Evaluation of socks wear resistance was carried out by investigation of propensity to surface pilling and abrasion resistance of plain knits sampled from the leg and the foot parts, both before and after five repeated washing and drying cycles, using Martindale abrasion and pilling tester according to the standardized test methods.*
Keywords: *socks; modal fibers; yarn type; abrasion resistance; propensity to surface piling; textile testing*

1. Introduction

The socks are knitted next-to-skin-type garments worn on the feet and often covering the ankle and some part of the calf. They have to fulfil high demands of wear resistance, particularly lower propensity to surface pilling and higher abrasion resistance. Abrasion, which is an unavoidable problem, usually occurs on the heel, sole and toe of the socks. The sock rub within the shoes, slippers or even the ground. The first stage of abrasion is small pills balls entanglement because of the loose fibers unravels from the knit surface during usage and laundering, resulting in an unsightly appearance and unpleasant handle. Eventually the fibers which bind the pills to the surface breakdown and hole or thinning occur [1, 2]. As the wear resistance of socks depends on their construction and fibers used, it is very important to select yarns for their production. The casual men's socks are usually made of cotton yarns for softness and comfort, and blended with polyamide and/or Lycra for improved fit, durability and shrink resistance [3]. Modal fibers (man-made artificial fibers from cellulose), which provide exceptional contact comfort and have better hydrophilicity than cotton, were usually used for high quality underwear [4]. The applicability of modal fibers in knitting of socks is insufficiently researched [5].

Socks were usually knitted with spun yarns produced by conventional ring spinning system, but more recently unconventional rotor and air-jet spun yarns have been appeared, resulting in different structure and properties. The ring spun yarns are characterized by an assembly of ideal cylindrical helix of well oriented fibers with a hairy surface. The rotor spun yarns consist of two-zone structure containing a core of fibers that are aligned with the helix of the inserted twist and form the bulk of the yarn and an outer zone of wrapper fibers, which occurs irregularly along the core length. The air-jet spun yarn consists of a majority of fibers in an almost untwisted state in the core and a surface layer of fibers wrapped around the core with irregularly along the core length, similar to rotor yarn. The yarn with the lowest hairiness is the yarn produced using an air-jet spinning technique, followed by the yarn spun using a rotor spinning technique, while the yarn spun using traditional ring spinning shows the highest hairiness. Ring spun yarn has the highest tenacity (and elongation at break), followed by air-jet spun yarn, while rotor spun yarn has the lowest tenacity [6, 7].

Therefore, with the fact that the applicability of modal fibers and yarns made of them by unconventional rotor ad air-jet process is insufficiently researched in knitting of socks, in this paper wear resistance of three groups of men's socks, made in the highest percentage of single ring, rotor and air-jet spun modal yarns of the same linear density in full plating by textured polyamide 6.6 yarns of different linear density were evaluated. Evaluation of socks wear resistance was carried out by investigation of propensity to surface pilling and abrasion resistance of plain knits sampled from leg and the foot parts, both before and after five repeated washing and drying cycles, using Martindale abrasion and pilling tester according to the to the standardized test methods.

2. Materials and methods

Three differently spun modal yarns of the nominal linear density 20 tex chosen for the knitting purpose were used: standard single ring spun yarn, single rotor and air-jet spun yarns, all made of bright staple modal fibers of linear density of 1.3 dtex and length of 38/40 mm:

- Ring spun modal yarn was produced using the carding manufacturing process, comprising fiber preparation phases (opening, blending and carding), spinning preparation (drawing, pre-spinning and ring spinning), winding and cleaning. A Zinser 351 ring spinning machine connected to an Autoconer X5 winding machine was used for the ring spinning process.
- Rotor spun modal yarn was produced using the carding manufacturing process, comprising fiber preparation phases (opening, blending and carding), spinning preparation (drawing) and rotor spinning. A Schlafhorst A8 rotor spinning machine was used for the spinning.
- Air-jet modal yarn was produced using the carding manufacturing process, comprising fiber preparation phases (opening, blending and carding), spinning preparation (three drawing passages) and air-jet spinning. A Rieter J 20 machine was used for spinning [7].

Three groups of calf length man's socks of the same size (EU 42) made in the highest percentage of modal fibers in full plating by textured polyamide 6.6 yarns of different linear density were knitted using Lonati automatic sock-knitting machine with E9 gauge of cylinder diameter 95 mm (3 ¾ '') with 108 needles and 2 knitting systems. After knitting and sewing of socks toes, the socks were ironed at a temperature of 120 °C using a Cortese machine. Plain knit stich was used in the foot and leg area, and rib stitch was used at the top of the socks. Textured polyamide multifilament yarn was knitted into toe, hell, foot and leg areas of socks for reinforcement and support along with the three single spun yarns. Single Lycra yarn of linear density 54 tex was knitted into the ribbing at the top of the all socks to prevent their falling down. Properties of male socks produced, including values of fiber content, are shown in Table 1 and yarn properties used for knitting in Table 2.

Table 1: Properties of calf length man's socks

Sock group	Yarn type	Fiber content [%]	
		plain	rib
A	Modal: Ri, Ro or Ai	79 ± 1	55 ± 1
	Polyamide 6.6 (1)	21 ± 1	14 ± 1
	Lycra	/	31 ± 1
B	Modal: Ri, Ro or Ai	71 ± 1	52 ± 1
	Polyamide 6.6 (2)	29 ± 1	19 ± 1
	Lycra	/	29 ± 1
C	Modal: Ri, Ro or Ai	44 ± 1	42 ± 1
	Polyamide 6.6 (2)	28 ± 1	16 ± 1
	Cotton: Ri	28 ± 1	18 ± 1
	Lycra	/	24 ± 1

Table 2: Properties of yarns used in knitting

Yarn type	Linear density [tex]	Breaking strength [cN]	Breaking elongation [%]
PA 6.6 (1)	15.6	652 ± 8	26.7 ± 0.6
PA 6.6 (2)	22.0	991 ± 4	28.5 ± 0.2
Lycra	54.0	551 ± 14	321.0 ± 18
MD-Ri	20.0	487 ± 10	10.2 ± 0.2
MD-Ro	20.0	325 ± 9	7.2 ± 0.2
MD-Ai	20.0	406 ± 10	9.0 ± 0.2
Cotton-Ri	25.0	326 ± 8	3.8 ± 0.1

Legend: MD - modal fibers; Ri – ring spun yarns, Ro – rotor spun yarns, Ai – air-jet spun yarns; A, B and C – sock groups

The A and B groups of socks were knitted with three soft single spun modal yarns of the same linear density of 20 tex (spun by ring, rotor or air-jet spinning system), while in the group C one of the single spun modal yarns were replaced with coarser cotton yarn of linear density of 25 tex. The socks also differ in the linear density of yarn used for plating, where textured polyamide 6.6 (designation: PA 6.6 156 dtex f 42) in group A and textured polyamide 6.6 (designation: PA 6.6 220 dtex f 68) in groups B and C were used.

After the conditioning (at temperature of 20 ± 2 °C and air relative humidity of 65 ± 4 %) and sampling of socks (Figure 1) the influence of knit structure and different yarn types used for knitting on the wear resistance of socks were analyzed. Therefore, the following basic properties of socks were determined:

- mass of sock expressed in grams,
- plain knits mass per unit area according to the EN 12127 [8] expressed in g/m^2,
- plain knits thickness according to the EN ISO 5084 [9] expressed in millimeters,
- number of wales and courses per unit length of plain knits according to the EN 14971 [10].

The wear resistance of socks was tested by standardized test methods for determination of:

- the abrasion resistance of knitted footwear garments according to EN 13770, method 1 [11] and
- fabric propensity to surface pilling according to EN ISO 12945-2 [12].

All socks tested properties were determined before and after five repeated washing and drying cycles performed according to the procedure 3M of the EN ISO 6330 [13] at the temperature of 30 °C with mild agitation during heating, washing and rinsing using non-phosphate ECE reference detergent without optical brightener. After every washing cycle the socks were line dried in open-air (procedure A).

Figure 1: Sampling of socks: a) for testing of propensity to surface pilling; b, c) for testing of abrasion resistance

The abrasion resistance of socks was tested by Martindale test method (using modified specimen holders), where plain knit specimens are abraded against the reference wool abradant fabric with a cyclic planar motion in the form of a Lissajous figure. Circular specimens with diameter of 38 ± 5 mm are taken from the heel (Figure 1b) and sole (Figure 1c) of the socks and stretched over a flattened rubber surface. During the testing, specimens are loaded with the corresponding weight of 12 kPa, and the test is performed until the end point. End point is defined as occurrence of specimen breakdown (break of the yarn in the knitted structure) or significant thinning (wear of the basic spun yarns), what is periodically checked at predefined inspection intervals: for non-washed plain knits every 2000 abrasion cycles, and for five time washed and dried every 5000 abrasion cycles. During the inspection, pills were removed with sharp scissors with curved blades. The number of rubs to reach endpoint were recorded.

The propensity to surface pilling of sock was tested by modified Martindale method, where plain knit specimens are rubbed according to the Lissajous figure against the reference wool abradant loaded with the corresponding weight of 415 g. Specimens are cut in circular shape with diameter of 140 ± 5 mm and taken from the leg area (Figure 1a) of the socks. During the testing, specimens are visually assessed by comparing with photographs (degrees of pilling: 1- 5) after 125, 500, 1000, 2000, 5000 and 7000 rubbing cycles according to the EN ISO 12945-4 [14].

3. Results and discussion

The results of plain knits mass per unit area, thickness, number of wales and courses per unit length, and mass of socks obtained before and after five washing and drying cycles are presented in Table 3.

Table 3: Properties of socks and sock plain knits before and after five repeated washing and drying cycles

Sample	Mass of sock [g]		Mass per unit area [g/m²]		Thickness [mm]		No. of wales/cm		No. of courses/cm	
	Non-washed	5x washed	Non-washed	5x washed	Non-washed	5x washed	Non-washed	5x washed	Non-washed	5x washed
MD-Ri-A	19.87	19.93	267.97	295.05	0.88	1.02	6	7	7	8
MD-Ro-A	20.10	20.15	262.45	290.28	0.90	1.00	6	6	8	8
MD-Ai-A	20.21	20.33	261.48	316.56	0.93	1.08	6	6	7	9
MD-Ri-B	22.27	22.36	284.67	310.14	0.95	1.11	6	7	7	9
MD-Ro-B	22.31	22.36	279.88	327.18	0.99	1.09	6	6	8	9
MD-Ai-B	22.63	22.73	289.33	296.76	1.00	1.08	6	6	7	8
MD-Ri-C	23.74	23.79	292.87	326.66	1.01	1.15	6	6	7	8
MD-Ro-C	23.73	23.80	304.47	308.43	1.06	1.13	6	6	7	9
MD-Ai-C	23.81	23.91	310.77	329.62	1.04	1.12	6	6	7	8

Legend: MD - modal fibers; Ri – ring spun yarns, Ro – rotor spun yarns, Ai – air-jet spun yarns; A, B and C – sock groups

Coarser polyamide plating threads used in knitting of B and C groups of socks and cotton spun yarn used in socks of group C change the mass and structure of socks, in a way that these socks become thicker and heavier. All tested socks samples showed shrinkage after the laundering, resulting in knits tighter construction seen in the increase of sock knits mass per unit area, thickness, and mostly number of courses per unit length (Table 3).

The resistance to abrasion, estimated by the number of cycles to thinning of one component (spun yarns) on plain knit specimens taken from heel and sole of non-washed and five times washed and dried socks, are shown in figures 2 and 3.

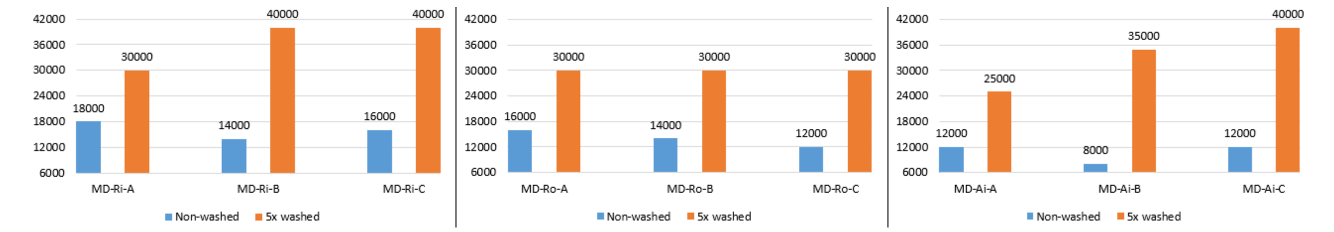


Figure 2: Abrasion resistance of non-washed and five times washed and dried plain knits taken from the heel of three groups of socks (A, B and C)

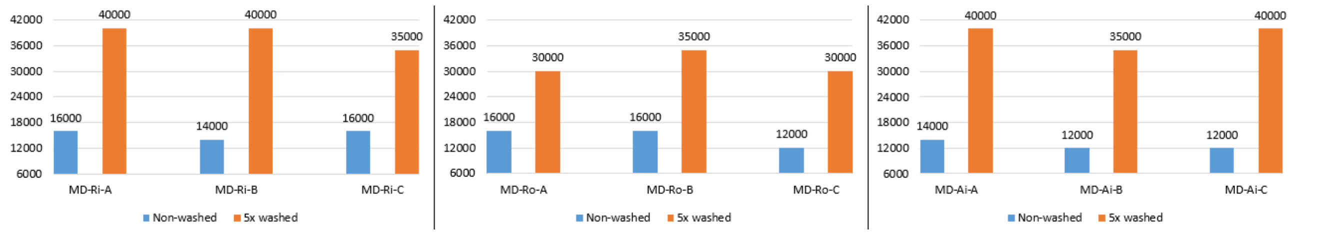
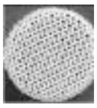
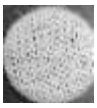
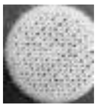
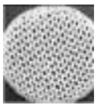
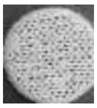
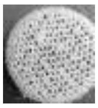
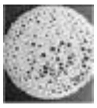
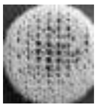
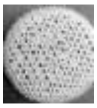
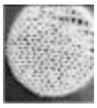
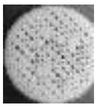
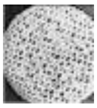
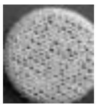
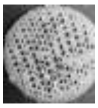
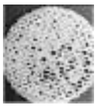
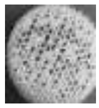
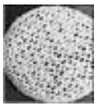
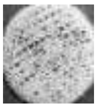
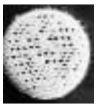
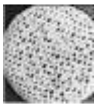
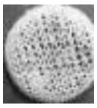
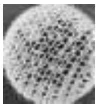
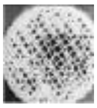
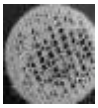
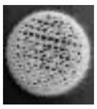
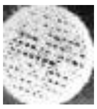
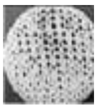
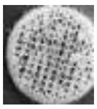
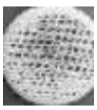
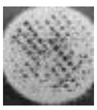
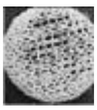
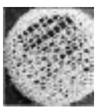


Figure 3: Abrasion resistance of non-washed and five times washed and dried plain knits taken from the sole of three groups of socks (A, B and C)

Yarn structure, linear density, twist and hairiness are the main properties which affect abrasion resistance of textile materials. The yarn spinning method has also an influence on the abrasion resistance [15]. When dealing with the knits, yarn breaking strength and breaking elongation, as well as tightness and elasticity of knitted structure, have significant influence on the results obtained. There can also be difference in knitting parameters used for heel and sole of the socks, and thus the difference in resistance to abrasion.

Table 4: Surface appearance of non-washed sock plain knits taken from the heel during the testing of abrasion resistance – visual determination of specimen significant thinning

Abrasion cycles	Non-washed sock knits sampled from the heel								
	MD-Ri-A	MD-Ri-B	MD-Ri-C	MD-Ro-A	MD-Ro-B	MD-Ro-C	MD-Ai-A	MD-Ai-B	MD-Ai-C
8000									
10000									
12000									
14000									
16000									
18000									

Legend: MD - modal fibers; Ri – ring spun yarns, Ro – rotor spun yarns, Ai – air-jet spun yarns; A, B and C – sock groups

Non-washed sock knits made of modal ring spun yarns have better abrasion resistance than those made of rotor and air-jet modal spun yarns, which is especially noticeable by heel specimens (Figure 2, Table 4). Ring spun yarns are hairier but more compactly structured and this well aligned compact structure doesn't promote easy fiber wear of. This can be connected also with the fact that ring spun yarns have higher breaking strength and elongation (Table 2) and that modal fibers are highly twisted on their surface than in rotor yarns. Generally, by non-washed plain knits of sock group A made of modal yarns in full plating by textured polyamide 6.6 yarn (1) of lower linear density, specimen breakdown occurs by highest values of abrasion rubs recorded. It was found that the use of coarser polyamide plating threads in knitting of B and C group of socks, as well as one cotton spun yarn in socks of group C does not affect the improvement of abrasion resistance of non-washed socks samples (Figures 2 and 3).

From the results presented in Figures 2 and 3, a great increase in abrasion resistance can be seen after the five washing and drying cycles in all tested socks samples. That could be connected with the higher compactness of sock knits structure (Table 3) and therefore higher elasticity of the tested specimens equally stretched over a flattened rubber surface of Martindale specimen holders. In most of laundered sock samples (of B and C groups) plated with coarser PA 6.6 (2) multifilament yarn of higher breaking strength is noticeable increase in abrasion rubs recorded when compared with socks group A.

With increasing the number of abrasion cycles, in all sock knits increases the propensity to surface pilling (Table 5). Best rated non-washed knits were found in sock group A, especially those made in the highest percentage of air-jet spun modal yarns because of their lower hairiness, specific regular and tightly structure when compared with ring and rotor spun yarns. The results presented in table 5 indicate that coarser polyamide plating threads in B and C group of socks, as well as cotton spun yarn in socks of group C have a negative impact on the sock knits propensity to surface pilling, which results in decrease of pilling grades.

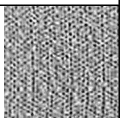
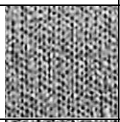
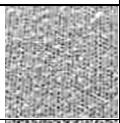
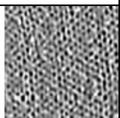
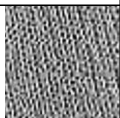
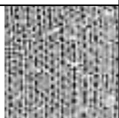
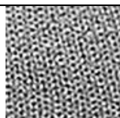
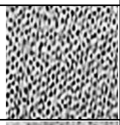
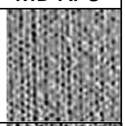
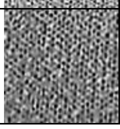
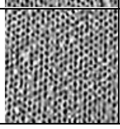
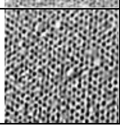
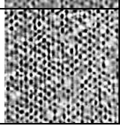
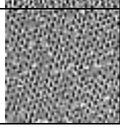
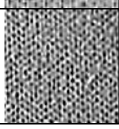
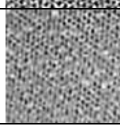
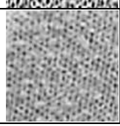
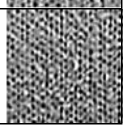
After 7000 pilling rubs, lower final grades were found in all tested laundered sock knit samples (Tables 5 and 6). The best grades and lower propensity to surface piling, after five consecutive cycles of domestic washing and drying are shown by sock knits made in the highest percentage of rotor spun modal yarns. The results obtained indicates the justification of testing performed on sock samples after the simulation of domestic care, although this is not provided within the standardized test methods for determination of propensity to surface pilling and abrasion resistance.

Table 5: Visually assessed propensity to surface pilling of non-washed and five-time washed and dried samples of sock knits by grades of pilling

Plain knit	Non-washed						5x washed					
sample	125	500	1000	2000	5000	7000	125	500	1000	2000	5000	7000
MD-Ri-A	4/5	4/5	4/5	4	4	3/4	4/5	4	3	2/3	2	2
MD-Ri-B	4	4	3/4	3/4	3	2/3	4/5	4/5	4	3/4	3	1
MD-Ri-C	3/4	3	2/3	2	1	/	4/5	4	3	2/3	2	1
MD-Ro-A	4/5	4/5	4/5	4	4	3	4/5	4/5	4	3/4	3	2/3
MD-Ro-B	4/5	4	4	3/4	2/3	2/3	4/5	4/5	4	4	3/4	3
MD-Ro-C	4	3/4	3	2/3	2	1	4/5	4/5	4	3/4	3/4	3
MD-Ai-A	5	5	5	5	4/5	4/5	4/5	3/4	3	2/3	2	1
MD-Ai-B	4/5	4/5	4/5	3/4	3	2/3	4/5	3	2/3	2	1	/
MD-Ai-C	4	3/4	3	3	1/2	1	4/5	4/5	3/4	3	2/3	2

Legend: MD - modal fibers; Ri – ring spun yarns, Ro – rotor spun yarns, Ai – air-jet spun yarns; A, B and C – sock groups

Table 6: Surface appearance of non-washed and five-time washed and dried sock plain knits at the end of reached final rubbing stage during the assessment of propensity to surface pilling

Sample	MD-Ri-A	MD-Ri-B	MD-Ri-C	MD-Ro-A	MD-Ro-B	MD-Ro-C	MD-Ai-A	MD-Ai-B	MD-Ai-C
Non-washed									
5x washed									

Legend: MD - modal fibers; Ri – ring spun yarns, Ro – rotor spun yarns, Ai – air-jet spun yarns; A, B and C – sock groups

4. Conclusion

The application of differently spun modal yarns in the knitting of socks impacted its wear resistance. The distinction between the socks made, was revealed after the domestic laundering cycles. The laundering cycles also showed the influence of the coarser PA 6.6 and cotton yarn, that differed in the abrasion and the pilling test. On the basis of the results obtained, it was concluded that for selection of the modal spun and plating polyamide yarns for socks production is necessary to consider their structure and the characteristics, but also the fact that yarn spinning technique, as well as the process of domestic care significantly influence sock knits wear resistance.

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Original Article

ALTERNATIVE METHOD OF DETERMINATION OF EVAPORATIVE RESISTANCE OF SOCKS MEASURED ON DRY THERMAL FOOT MODEL

Frederick FUNG[1*]; Zenun SKENDERI[2]; Lubos HES[3]

[1,3]Technical University of Liberec, Liberec, Czechia; info@tul.cz
[2] University of Zagreb, Zagreb, Croatia; tzg2022@ttf.unizg.hr
***** Corresponding author: tassfashion@gmail.com

Abstract: *This paper introduces an alternative method to test the evaporative resistance (Ret) of clothing using a dry thermal foot model. In a regular regime, when testing Ret of clothing, a sweating thermal foot model would be used; however, the expensive cost, high maintenance and malfunction of sweating holes cause many problems. A different method of Ret measure is recommended. Experiments were according to the ISO 11092 standard[1-2] when the environmental climate is in a steady-state to measure the Ret of samples. In the experiment, a wet (but not dripping wet) 100% cotton sock was put onto the thermal foot model as the base of the "sweating layer." Tailor-made socks from testing materials were put on the thermal foot model until steady-state, then measurement started. The tailor-made sock[3] was introduced to create a closely fitted sock to wear on top of the sweating layer for the experiment. In the Result section, the dry measurements - thermal resistance (Rct) - were also taken for comparison and discussion to the wet measurements - evaporative resistance (Ret).*
Keywords: *thermal resistance; evaporative resistance; alternative method; thermal foot model; tailor-made*

1. Introduction

In the clothing industry, thermal manikins, thermal foot models, and thermal hand models[4-6] are commonly used electrical devices for testing clothing properties. These electrical devices can give the thermal resistance (Rct) values of the tested garment or clothing. However, when testing for the evaporative resistance (Ret) of clothing, a "sweating" thermal model is needed. The sweating version of the thermal model contains sweating holes embedded on the surface of the device from where water droplets are being secreted to stimulate the process of sweating. The sweating thermal models usually cost a lot more than the dry thermal models; maintenance difficulties and sweating holes are easily clogged that not many research institutes nor universities own them. In order to solve this problem, a different method of Ret measure on the dry thermal model is needed to develop.

In this paper, a different approach of measuring Ret of sock on a dry thermal foot model is applied by using a sock of 100% cotton that fits closely to the thermal foot model, and the sock was wetted before putting on the foot model to create the layer of sweat. Then, wait until the climatic chamber conditions were steady-state before the Ret measurement started. Details of the process are explained in the following sections.

2. Material and Experiment

$$Ret_{Tot} = Ret_O + Ret_A + Ret_M \quad (1)$$

When the climatic chamber conditions are in a steady-state, the total evaporative resistance (Ret_{Tot}) is equal to the summary of the boundary layer of the sweating thermal foot model (Ret_O), the air gap (Ret_A) and the evaporative resistance of the material (Ret_M) as shown in Eq. (1). Indirect contact of material to the sweating thermal foot model, the air gap layer will be minimized that the total evaporative resistance will be equal to the sweating thermal foot model (Ret_O) plus the evaporative resistance of the material (Ret_M) only as in Eq. (2).

$$Ret_{Tot} = Ret_O + Ret_M \quad (2)$$

When calculating the Ret_M of the material in direct contact on the foot model, the total evaporative resistance minus the boundary sweating layer of the thermal foot model; is equal to Eq. (3), and all units of Ret are in [m²/Pa/W].

$$Ret_M = Ret_{Tot} - Ret_O \quad (3)$$

For the thermal resistance (Rct), the total thermal resistance (Rct_{Tot}) is equal to the summary of the naked thermal foot model (Rct_O), the air gap (Rct_A) and the thermal resistance of the material (Rct_M) as shown in Eq. (4). The unit of Rct is [m^2/°C/W].

$$Rct_{Tot} = Rct_O + Rct_A + Rct_M \tag{4}$$

When in direct contact of material to the thermal foot model, the air gap layer will be minimized that the total thermal resistance will be equal to the thermal foot model (Rct_O) and the thermal resistance of the material (Rct_M) only as in Eq. (5),

$$Rct_{Tot} = Rct_O + Rct_M \tag{5}$$

Also, under the direct contact condition, calculating the Rct_M of the material is the total thermal resistance minus the boundary layer of the thermal foot model; that is equal to Eq. (6),

$$Rct_M = Rct_{Tot} - Rct_O \tag{6}$$

2.1 Thermal Foot Device and Software

From the above equation 1 to 3, the Ret_o sweating layer is needed to be established. The thermal foot model was used, and a sock of 100% cotton was wetted and put on it, as shown in Figures 1 and 2. When the thermal foot software showed that the climatic chamber conditions were in a steady-state, the measurement started.

Figure 1: Bare thermal foot model hanging inside a climatic chamber

Figure 2: A 100% wetted cotton sock is put on the thermal foot model as the sweating layer

The software (Figure 3) is directly connected to the thermal foot model. On the visual panel, the left side shows the device's power consumption [W] and surface temperature [°C] through the sensors built-in the thermal foot. The right side of the panel is divided into three parts: the top part shows the current ambient temperature [°C], relative humidity [%] and the wind speed [m/s]; the middle part is recording twenty tested values (each test lasts for one minute) and the current conditions (device surface temperature, power consumption and Rct/Ret) of the thermal foot in line graphs; the lower part is presenting the final mean values of the surface temperature and the power consumption of the thermal foot; Rct/Ret/Clo of the material or the Rct_o/Ret_o/Clo when the device is naked.

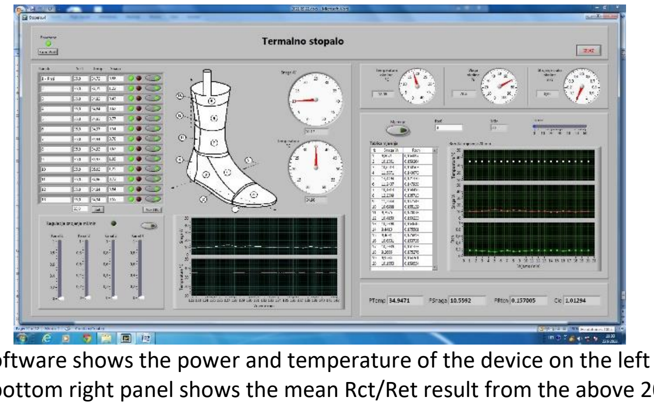


Figure 3: Thermal foot model software shows the power and temperature of the device on the left panel; 20 tested values on the right panel; the bottom right panel shows the mean Rct/Ret result from the above 20 testing values

The thermal foot model[7] is a silver-made, true human foot proportion composed of thirteen heat zones that the temperature of each heat zone can be adjusted individually. The dimension of the device is 26cm height, 26cm length, 10cm width. The thermal foot is suspended in the center of the climatic chamber, and the operating conditions are shown in Table 1.

Table 1: Standard ISO 11092 operating conditions

Test Standard	Type of Test	Thermal Foot Temperature (ºC)	Ambient Temperature (ºC)	Ambient Relative Humidity (%)	Air Velocity (m/s)
ISO 11092 Non-isothermal	Thermal Resistance (Rct)	35±2	20±5	65±5	1±0.5
ISO 11092 Isothermal	Evaporative Resistance (Ret)	35±2	35±5	40±5	1±0.5

2.2 Sample Preparation

Sample materials were plain-woven, including two 100% cotton and two 100% polyester; each was of different thickness and weight. The basic properties of these four materials are shown in Table 2.

Table 2: Basic properties of four materials

	Structure	Thickness (mm)	Square Mass (g/m²)	Fabric Density. warp/weft(threads/10cm)
Cot W	Plain woven	0.3	130	26/24
Cot P	Plain woven	0.39	140	26/24
Pes G	Plain woven	0.39	170	22/16
Pes B	Plain woven	0.26	170	14/12

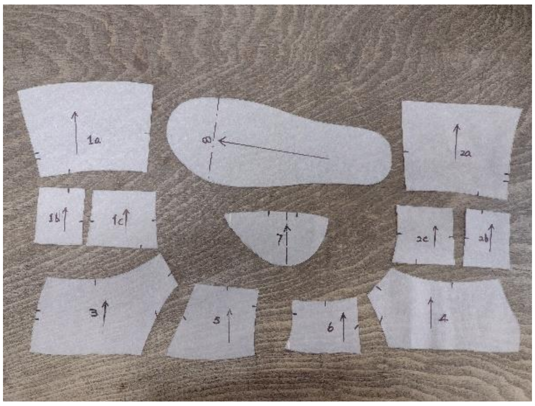
In order to fit materials to the thermal foot model, a sock pattern set is needed. By using molding method[3], the base sock patterns were created. Procedures of sock patternmaking are shown in Figure 4a-g.

Figure 4a: The base sock (sweating layer) is on the thermal foot, and elastic bands are used to divide the foot into sections for unmolding and patternmaking

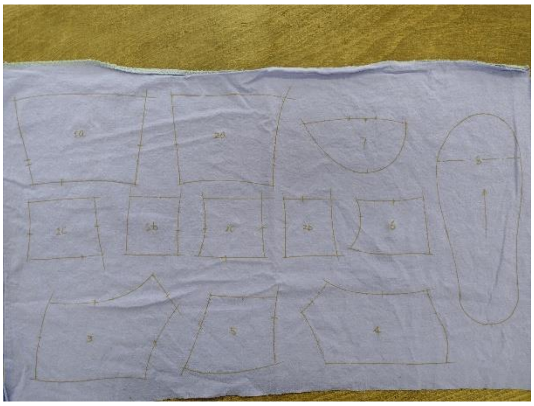
4b: A plastic shrinkwrap is applied to cover the entire foot model

4c: Fabric backing electrical tape is used to reinforce the plastic shrinkwrap, mold the shape of the foot; and transfer the elastic band markings onto it

4d: After unmolding, the form is cut open along the elastic band markings and the contour of the shape; then numbered



4e: From 3D pattern pieces turn into 2D pieces; noticed all the small wedge-like cuts and overlapping are smoothed out in each pattern piece



4f: 2D pattern pieces are traced onto the material, 1cm seam allowance is added onto the surrounding of each pattern piece for sewing

4g: After the cut and sew process, material pattern pieces are turned into a 3D sock that is ready to be tested

An air gap is minimized in the base sock pattern pieces; however, an air gap can be added. The method is to treat the foot model as a cylindrical column, then find out the radius by the circumference formula (4).

$$\text{Circumference} = (2\text{radius})\cdot\boldsymbol{\pi} \tag{4}$$

When desired air gap distance adds to the radius, it becomes the new circumference with a built-in air gap as in Eq. (5).

$$\text{Circumference with air gap} = 2(\text{radius} + \text{air gap})\cdot\boldsymbol{\pi} \tag{5}$$

When Eq. (5) minus Eq. (4) increases the length of the circumference, which can be equally distributed to the pattern pieces. In this experiment, 5mm and 10mm air gap distances were added to the basic sock patterns before the cut and sewed process.

2.3 Experiment

In the experiment, two socks were prepared from each material (a total of four materials); one with 5mm air gap distance, another with 10mm for a total of eight socks. Each sock was tested for Rct and Ret on the thermal foot model. Each Rct/Ret measurement was the mean value of twenty tests and each test lasted for one minute. The final result was the mean taken from three measurements.

3. Results

Each sock's evaporative resistance (Ret) and thermal resistance (Rct) were tested according to each ISO standard. After six measurements, the mean Ret_o and Rct_o are 0.1702 [m^2/Pa/W], 0.1316 [m^2/°C/W]; respectively. The Ret and Rct results of materials with 5mm and 10mm air gap distance are calculated by Eq. (1) and (4). They are shown in Table 3 as follows:

Table 3: Ret and Rct results from the combinations of 4 materials and 2 air gap sizes

Ret [m²/Pa/W]	Cot W	Cot P	Pes B	Pes G
5mm	0.1397	0.1372	0.1195	0.1421
10mm	0.1421	0.1439	0.1324	0.1447
Rct [m²/°C/W]	Cot W	Cot P	Pes B	Pes G
5mm	0.0546	0.0572	0.0488	0.0517
10mm	0.0577	0.0626	0.0593	0.06

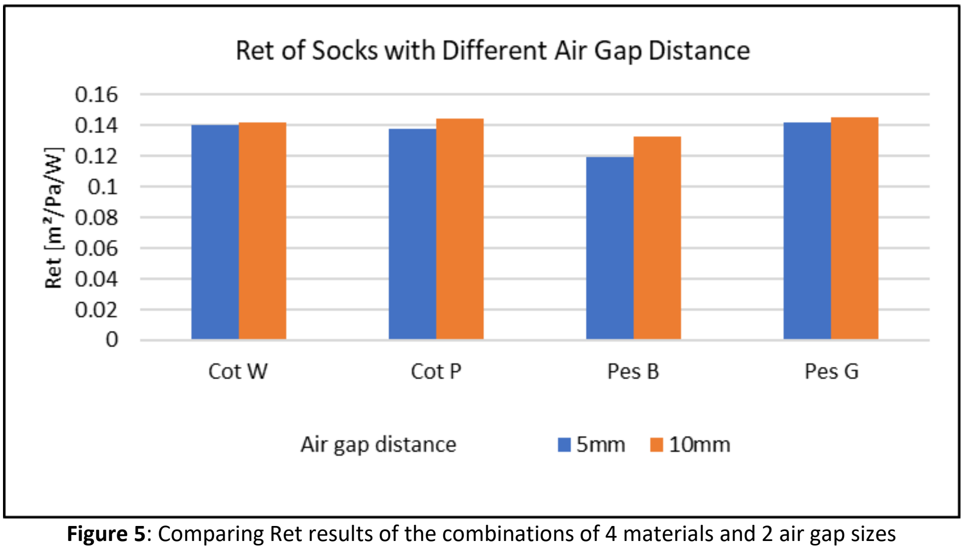


Figure 5: Comparing Ret results of the combinations of 4 materials and 2 air gap sizes

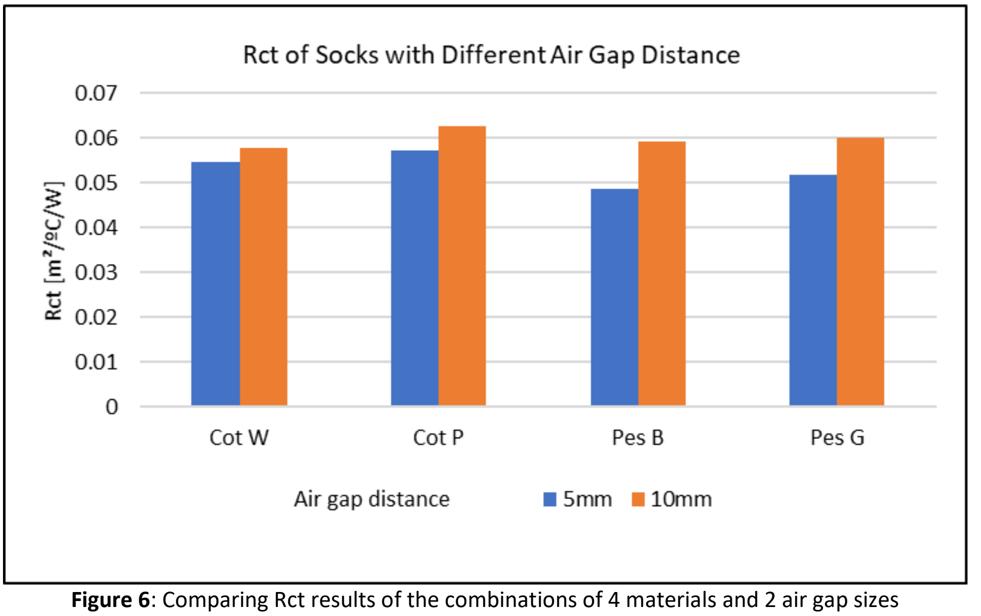


Figure 6: Comparing Rct results of the combinations of 4 materials and 2 air gap sizes

4. Conclusion

This paper used an alternative method to determine the evaporative resistance (Ret) from the dry thermal foot model. Combinations of four materials (made into socks) and two air gap distances (5mm and 10mm) were tested for their Ret values using the alternative method. Same combinations of materials and air gap distances were also tested for their Rct values for comparison. Results show that when air gap distance increases, resistance increases in both Ret and Rct test results (Figure 5-6), though the increase in Ret resultant values is less compared to Rct resultant values. This scenario may be caused by 1). Labour error - the first time experimenting with the alternative method; 2). The wetness of sock control; 3). Isothermal condition - conditions of the climatic chamber are not fully automatic; manual labour is needed. However, the overall results are expected: an increase in air gap distance and an increase in resistance until free convection comes in[8-10]. These logical and expected results have already been experienced and written by many researchers regarding air gaps, heat and mass transfer topics[11-14], which concluded that the alternative method of using a "sweating layer" on a thermal foot model could determine the Ret value of the material. Further development and verification are needed for the Ret alternative method improvement.

Acknowledgement
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Original Article

INFLUENCE OF WEFT DENSITY ON THE ELASTICITY LIMIT AND YIELD POINT OF FABRICS UNDER THE TENSILE LOAD

Željko PENAVA[1]; Petar PERUŠKO[1]

[1]Faculty of Textile Technology, University of Zagreb, Pr. b. Filipovića 28a, 10000 Zagreb, Croatia
*Corresponding author: zpenava@ttf.hr

Abstract: When tensile force acts on woven fabric samples, unwanted plastic deformations and tearing of the fabric may occur. In order to avoid the occurrence of plastic deformation in the fabric, the elasticity limit and the yield point of the material should be known. For this purpose, raw cotton woven fabrics have been deposited in the plain and in the twill weave with same warp density and different weft densities. From the obtained force-elongation curves, for all weft densities, when force acts in warp and in weft direction, the elasticity limit and the yield point were determined. This paper analyzes the impact of weft density change on values of maximum force, breaking force, force at the yield point and force at the limit of elasticity. When the force acts in the weft direction, as the weft density increases, so do the values of the elasticity limit and the yield point. Fabrics in a plain weave with a higher weft density have a greater possibility of elastic and elastoplastic deformation, than fabrics in a twill weave.
Keywords: woven fabric; plain weave; twill weave, tensile force, yield point; limit of elasticity

1. Introduction

The use of textile materials in various industries is increasing, and knowledge of their physical and mechanical properties, is very important. When measuring, on the mechanical properties of fabric affect nonlinear viscous elasticity, friction between fibers, yarns, fabric density, geometrical changes during connection to external forces, and changes in temperature and humidity [1]. Woven fabric is from the physical point of view an anisotropic structure with elastic properties. It is considered neither completely elastic nor completely plastic. Tensile forces cause tearing of the woven fabric or the appearance of viscoelastic or plastic deformations [2, 3]. Such deformations are undesirable because undesirable effects, poor quality of the finished product, eg. woven fabric, can only be observed in the final stages of processing. Therefore, the good quality of the finished product is achieved if during the use of woven fabric ensure such conditions in which the deformation will be within the elastic area. In order to avoid the appearance of plastic deformation in the woven fabric, one should know at which tensile force such deformations will occur.

The mechanical properties of textiles under the action of tensile load began to be studied in 1937. [4, 5]. Uniaxial stretching is the most common procedure for testing and analyzing the physical and mechanical properties of textile products [6, 7]. Many researchers start from the classical theory of elasticity with the assumption that woven fabric is an anisotropic material with two planes of symmetry [8, 9]. At the beginning of elongation, the relation between force and elongation is proportional. With further elongation, it begins to grow faster than the force. Consequently, the relation between force and elongation is no longer linear [10, 11].

The aim of this paper is to determine the limit of elasticity (elastic region) and the yield point after which the plastic region occurs on the experimentally obtained force-elongation curves, and to determine the influence of fabric density on the limit of elasticity and yield point.

2. Theoretical part

The functional relation between stress and strain cannot be determined theoretically, but only by experimentally testing samples made of a particular material [12, 13]. When tensile force acts, stress occurs in the woven fabric resulting in its elongation. The load-elongation curve of the woven fabric is shown on Figure 1.

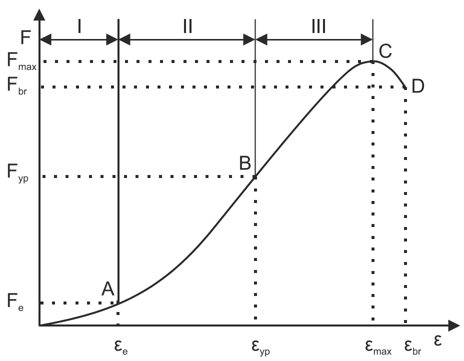


Figure 1: The characteristic diagram of force - elongation (F-ε) of the woven fabric

The characteristic points in Figure 1 are: F_{max}- maximum force, F_{br}- breaking force, F_{yp}- force at the yield point, F_e- force at the limit of elasticity, ε_{max}- maximum elongation of the fabric sample at maximum force, ε_{br} - elongation of the fabric sample to break, ε_{yp} - elongation at the yield point, ε_e- elastic elongation. The analysis of the load-elongation diagram, Figure 1, reveals that the curve consists of three main parts [14]. The first part is up to elasticity limit (ε_e, F_e) and is called the elastic region, which represents the elastic part of the woven fabric in which the yarns move within the structure. The sample had an elastic response concerning tensile force. The second part is from the elasticity limit (F_e, ε_e) to the yield point (ε_{yp}, F_{yp}) and is nonlinear curve. With increasing force, elastoplastic deformations occur. In this region along with the movement of yarns in the woven fabric, the relaxation of yarns in its elastic region occurs. The third part is linear and lies on the curve between yield point (ε_{yp}, F_{yp}) and maximum tensile force (ε_{max}, F_{max}). Behind yield point, with further increasing force, the yarn begins to deform, and the fabric absorbs permanent (plastic) deformations. Individual threads of the sample break, until the complete sample breaks.
The elasticity limit, yield point and point of maximum force of woven fabrics are determined on basis of the force-elongation diagram F (Ɛ) and on basis of F '(Ɛ) and F''(Ɛ). The force-elongation function as well as its first derivation and second derivation are shown on Figure 2.

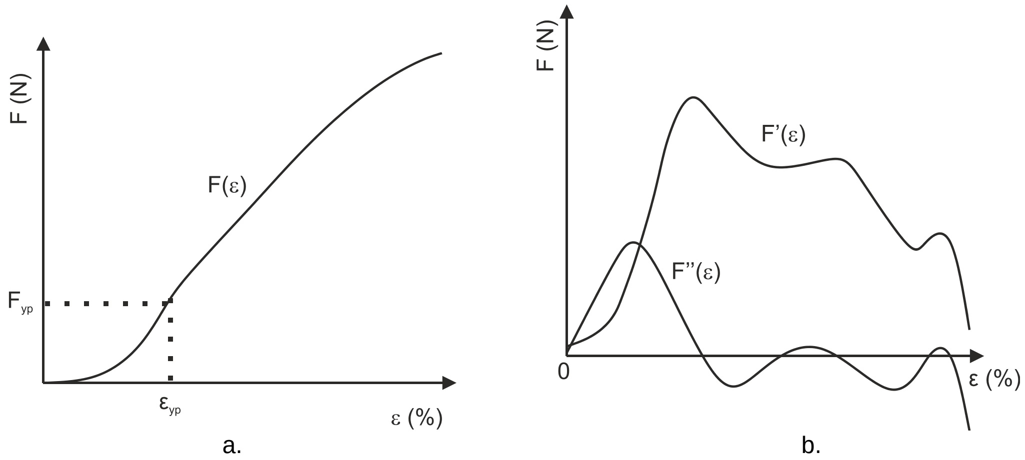


Figure 2: Dependency diagram force-elongation: a) the function F(ε), b) the first F'(ε) and the second F''(ε) derivation of the function

The maximum of the first derivation $(F'(Ɛ))_{max}$ indicates the permissible load F_{yp} up to the limit of which the fabric shows elastic and elastoplastic properties, Figure 2b. Up to this point, the woven fabric shows greater resistance to the tensile forces (F (ε) function increases). When the function of the first derivation reaches its maximum, at that point the second derivation equals 0, ie. F''(Ɛ)=0. Then a faster deformation of the woven fabric occurs until the destruction of the material (the function F '(Ɛ) decreases). The yield point is shown with the associated coordinates (F_{yp}, $Ɛ_{yp}$).
To determine the elasticity limit A(ε_e, F_e), the idea was applied to express the tensile force *F* as a linear elongation function *Ɛ*, where *d* is the coefficient of elasticity of material:

$$F = d \cdot \varepsilon \tag{1}$$

To model elastoplastic deformation, part II, the polynomial function will be applied as the simplest solution, where a_0, a_1, ..., a_m, are known coefficients:

$$F = Q(\varepsilon) = a_m \cdot \varepsilon^m + \cdots + a_1 \cdot \varepsilon + a_0 \tag{2}$$

The problem of fitting each part individually and determining the coefficients *d*, a_0, a_1, ..., a_m, is solved with the method of least squares [15, 16]. Equality conditions must be met in transitional point *A*:

$$d \cdot \varepsilon_A = Q(\varepsilon_A) \tag{3}$$

Also, the curve *F* – *Ɛ*, Figure 1, must be continuous (uninterrupted), i.e. transitions at point A must be smooth, so the differentials of functions must match in these points:

$$d = Q'(\varepsilon_A) \tag{4}$$

Polynomial *Q* of lowest degree, which would meet four mentioned equality conditions (3) and (4), must have 4 coefficients or the degree of polynomial Q must be m = 3, expression (5):

$$Q(\varepsilon) = a_3 \cdot \varepsilon^3 + a_2 \cdot \varepsilon^2 + a_1 \cdot \varepsilon + a_0 \quad (5)$$

In this case, the parameters of function *F(Ɛ)* shown in expressions (1) and (2) will be estimated by the least squares method, i.e. the sum of the squares of the differences between the analytical models and the experimental values will be minimized. Estimations of regression parameters should be determined, so it is:

$$\sum_{i=1}^{N} (F(\varepsilon_i) - F_i)^2 \rightarrow min \quad (6)$$

$Ɛ_i$, F_i are the experimentally obtained values of extension and corresponding force, *F* is the theoretical value of force.

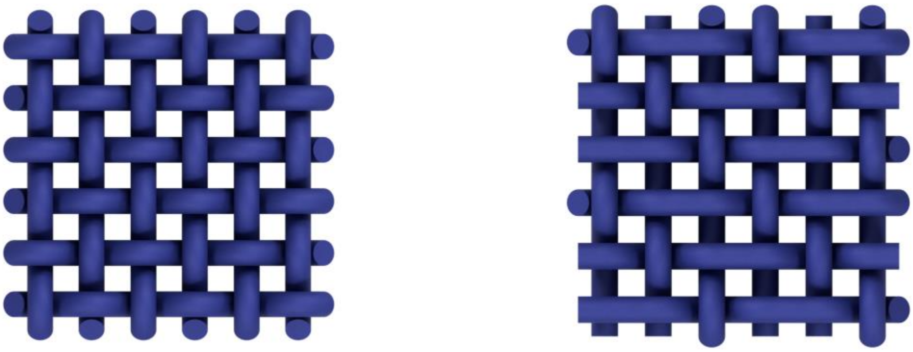
3. Experimental testing

In the experimental part of the paper, tests were carried out on elongation cotton woven fabric specimens in plain weave and twill weave with the same warp density and different weft densities. Tensile properties of all specimens were tested according with standard ISO 13934-1:2008 using the strip method for measuring fabric strength and its elongation on a tensile strength tester Textechno Statimat M. In this way, force- elongation (F-ε) curves were obtained. For the purposes of this testing standard specimens with dimensions 350 x 50 mm were cut, clamped in clamps of the tensile tester at a distance l_0=200 mm and pulling speed: 100 mm/min and subjected to uniaxial tensile load till rupture. It can be stated that the deformation rate is constant. Sample break time is 20 s. The specimens were cut in warp direction and weft direction. The direction of action of the tensile force during the test is always the same. Five tests were done for each mentioned direction of force action on the fabric specimen. Before testing all specimens were conditioned under the conditions of standard atmosphere (relative air humidity 65 ± 2%, at a temperature of 20 ± 2°C). In order to achieve balanced humidity, the yarn stood at standard conditions for 24 h before testing.

Table 1: Test results for basic fabric parameters

		Warp direction		Weft direction			
Fabric structure	**Fabric tag**	**Density (cm^{-1})**	**Yarn count (tex)**	**Density (cm^{-1})**	**Yarn count (tex)**	**Weight (g/m^2)**	**Thickness fabric (mm)**
Plain	P12	24.1	30.3	12.1	30.3	115.23	0.36
	P15	24.1	30.3	15.2	30.3	125.23	0.36
	P18	24.2	30.3	18.2	30.3	135.48	0.36
	P21	24.1	30.3	21.1	30.3	147.11	0.36
	P24	24.3	30.3	24.2	30.3	157.89	0.36
Twill	K12	24.0	30.3	12.0	30.3	114.89	0.36
	K15	24.2	30.3	15.1	30.3	126.23	0.36
	K18	24.1	30.3	18.1	30.3	134.84	0.36
	K21	24.1	30.3	21.2	30.3	145.98	0.36
	K24	24.1	30.3	24.2	30.3	156.91	0.36

Fabrics specimens of the stated structural characteristics were made on an OMNIplus 800 tt air-jet loom Picanol. In Table 1 are the actual (measured) values of structural parameters of the raw woven fabrics. Yarn linear density was determined by the gravimetric method according to standard ISO 2060:2008. Number of threads per unit length was determined according to standard ISO 7211-2:1984. Standard ISO 5084:2015 describes a method for the determination of the thickness of fabric. For all samples the thickness is same. The same yarn was used for the weft and the warp. Determination of the density of warp and weft threads was carried out using computer-controlled (stereo) microscope DinoLite. The design and modeling of fabrics was carried out using the Blender program in which it was possible to show its three-dimensionality, Figure 3, [17-19].

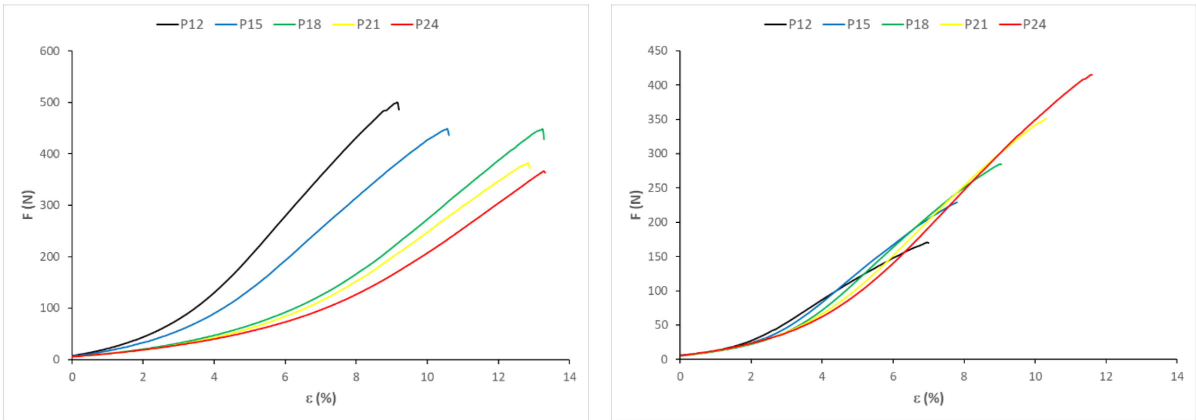


a. b.

Figure 3: 3D weave visualization in Blender: a) plain weave, b) twill weave

4. Test results and discussion

The first letter in the fabric label indicates the type of weave, the number indicates the weft density eg. P18 - plain weave, the weft density 18.1 cm^{-1}. A diagram of the mean values of the test results obtained for the action of tensile force F and the corresponding elongation ε when the fabric samples in plain weave are cut in the warp direction for all weft densities are shown in Figure 4a, and for weft direction, diagram is shown in Figure 4b.



a. b.

Figure 4: Diagrams (F-ε) for samples in plain weave with different weft densities: a) warp direction, b) weft direction

For plain weave, the mean values of the test results of force at the limit of elasticity F_e, elastic elongation ε_e, maximum force F_{max}, maximum elongation ε_{max}, breaking force F_{br}, elongation at break ε_{br}, force at the yield point F_{yp}, elongation at the yield point ε_{yp} are shown in Table 2, and for twill weave are shown in Table 3. The first derivation of the function F'(Ɛ) and the second derivation of the function F''(Ɛ) when the force acts in the warp and weft direction are used to determine yield point B (ε_{yp}, F_{yp}) after which plastic deformation occurs. The first derivative maxima $(F')_{max}$ represents yield point. Using the expressions (3) - (6), the elasticity limit (A) on F-ε curves was determined.

Table 2: Mean values of test results for plain weave

Fabric tag	Direction	ε_e (%)	F_e (N)	ε_{yp} (%)	F_{yp} (N)	ε_{max} (%)	F_{max} (N)	ε_{br} (%)	F_{br} (N)
P12	Warp	0.76	17.40	5.60	243.98	9.16	500.32	9.20	486.31
	Weft	0.80	10.56	3.40	65.35	6.96	170.72	7.00	169.96
P15	Warp	0.76	13.50	6.44	217.44	10.56	448.63	10.60	436.63
	Weft	0.88	10.72	4.52	104.15	7.80	228.87	7.80	228.87
P18	Warp	1.00	11.70	10.52	301.02	13.24	448.24	13.28	428.24
	Weft	1.12	11.47	5.32	129.92	9.00	284.91	9.04	284.67
P21	Warp	1.76	17.11	10.24	258.36	12.84	382.12	12.88	372.12
	Weft	1.20	13.80	6.96	199.22	10.28	350.93	10.32	350.85
P24	Warp	0.92	11.23	12.72	337.72	13.28	366.53	13.32	363.29
	Weft	1.28	15.05	7.60	223.31	11.56	415.28	11.60	415.17

When samples in plain weave are cut in the warp direction, the F_{br}, F_{max} values slightly decrease with increasing weft density, while belonging elongation ε_{br}, ε_{max} increase with the density of the weft. When samples are cut in the weft direction, the values of F_{br}, F_{max} and the belonging elongation ε_{br}, ε_{max} increase significantly with the density of the weft. The F_{yp} values decrease slightly and increase slightly with the increase in weft density when the samples are cut in the warp direction, while belonging elongation ε_{yp} increase significantly with the density of the weft. When samples are cut in the weft direction, with the increase in weft density, the F_{yp} values and the belonging elongation ε_{yp} increase significantly. The F_e and ε_e values decrease slightly and increase slightly with the increase in weft density when the samples are cut in the warp direction. When samples are cut in the weft direction, with the increase in weft density, the F_e and ε_e values ε_e increase.
A diagram of the mean values of the test results obtained for the action of tensile force F and the corresponding elongation ε when the fabric samples in twill weave are cut in the warp direction for all weft densities are shown in Figure 5a, and for weft direction, diagram is shown in Figure 5b.

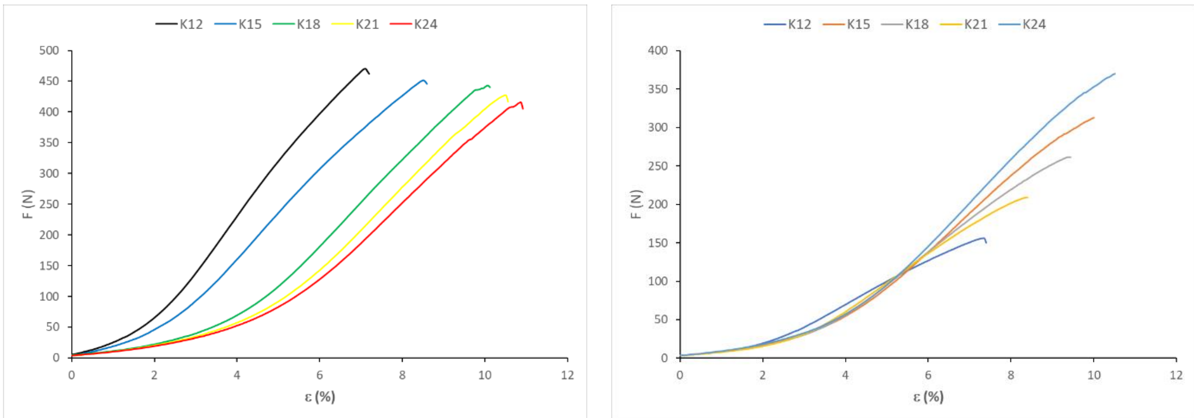


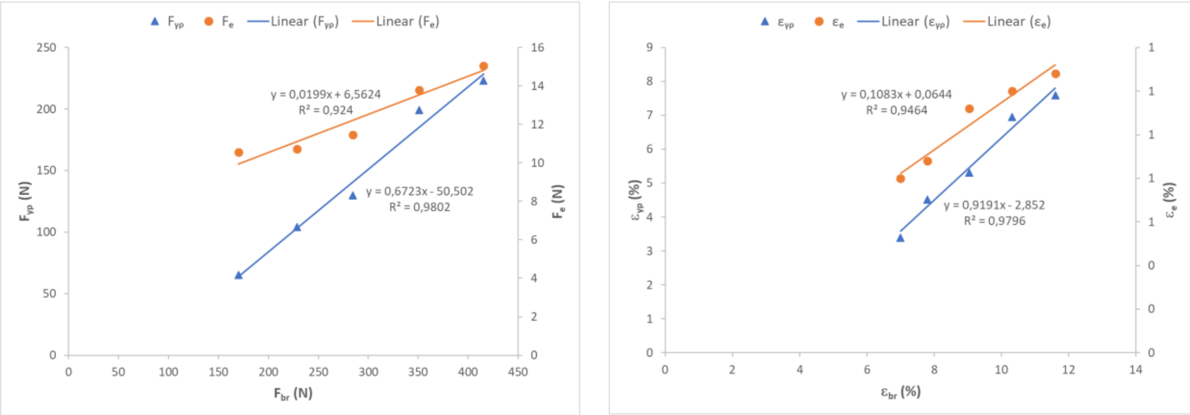
Figure 5: Diagrams (F-ε) for samples in twill weave with different weft densities: a) warp direction, b) weft direction

When samples in twill weave are cut in the warp direction, the F_{br}, F_{max} values slightly decrease with increasing weft density, while belonging elongation ε_{br}, ε_{max} increase with the density of the weft. When samples are cut in the weft direction, the values of F_{br}, F_{max} and the belonging elongation ε_{br}, ε_{max} increase significantly with the density of the weft. The F_{yp} values decrease slightly and increase slightly with the increase in weft density when the samples are cut in the warp direction, while belonging elongation ε_{yp} increase significantly with the density of the weft. When samples are cut in the weft direction, with the increase in weft density, the F_{yp} and ε_{yp} values decrease slightly and increase slightly. When samples are cut in the warp direction, with the increase in weft density, the F_e values decrease. The F_e and ε_e values decrease slightly and increase slightly with the increase in weft density when the samples are cut in the weft direction.

Table 3: Mean values of test results for twill weave

Fabric tag	Direction	ε_e (%)	F_e (N)	ε_{yp} (%)	F_{yp} (N)	ε_{max} (%)	F_{max} (N)	ε_{br} (%)	F_{br} (N)
P12	Warp	0.76	19.31	4.08	234.05	7.12	469.81	7.20	461.90
	Weft	0.96	8.26	4.04	69.78	7.32	155.90	7.40	150.01
P15	Warp	0.76	14.23	4.48	192.86	8.52	451.17	8.60	445.48
	Weft	1.20	10.16	6.76	174.83	10.00	312.95	10.00	312.95
P18	Warp	0.80	9.38	6.72	229.86	10.08	443.03	10.12	440.43
	Weft	1.08	8.69	6.00	136.70	9.40	261.88	9.94	261.72
P21	Warp	0.80	8.47	7.32	227.00	10.48	426.89	10.56	416.78
	Weft	1.00	9.32	5.04	98.35	8.36	209.43	8.40	209.13
P24	Warp	0.84	8.59	7.80	236.12	10.88	415.04	10.92	405.04
	Weft	1.24	9.59	7.12	206.42	10.52	369.87	10.52	369.87

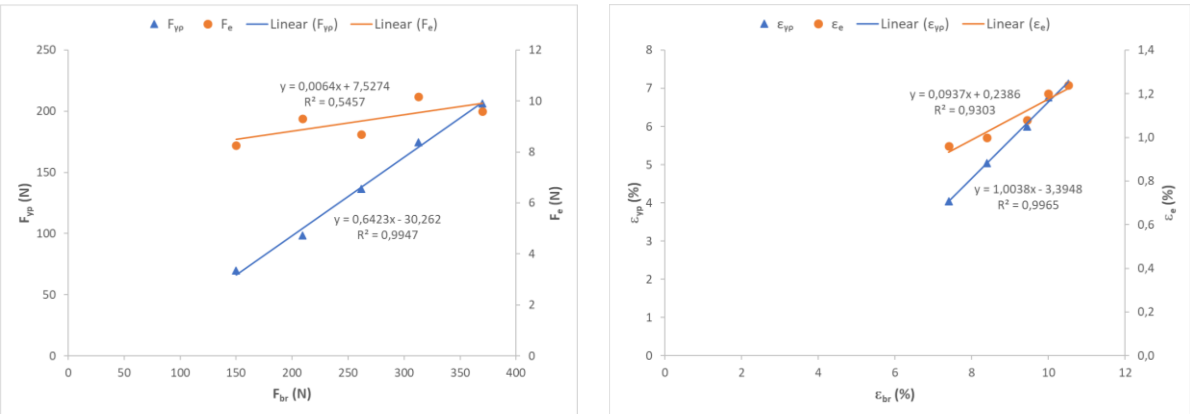
For plain weave, the relationship between the breaking forces, the elasticity limit forces, and the forces at yield point, for different weft densities, is shown in Figure 6a. The relationship between the elongation at break, the elongation at the yield point, and the elasticity limit elongation, for different weft densities, is shown in Figure 6b. The force acts in weft direction.



a. b.

Figure 6: Diagram for plain weave with different weft densities: a) the relationship between the breaking forces, the elasticity limit forces, and the forces at yield point, b) relationship between the elongation at break, the elongation at the yield point, and the elasticity limit elongation

For twill weave, the relationship between the breaking forces, the elasticity limit forces, and the forces at yield point, for different weft densities, is shown in Figure 7a. The relationship between the elongation at break, the elongation at the yield point, and the elasticity limit elongation, for different weft densities, is shown in Figure 7b. The force acts in weft direction.



a. b.

Figure 7: Diagram for twill weave with different weft densities: a) the relationship between the breaking forces, the elasticity limit forces, and the forces at yield point, b) relationship between the elongation at break, the elongation at the yield point, and the elasticity limit elongation

The woven fabrics do not behave ideally elastic even at low stresses. Based on the experimental results and the shape of the force-elongation curves, it can be concluded that elastoplastic behavior of the fabrics is observed in the analyzed area. The elastic limit is essentially the limit to which elastic deformations in the material dominate. After the elastic limit, a higher rate of material deformation occurs, and the fabric structure is disrupted. Therefore, the fabric elasticity limit represents the boundary load at which the deformations occurring in the fabric will not significantly affect the stability of the structure and the durability of the fabric.

5. Conclusion

The anisotropic woven fabric structure contributes to different, sometimes difficult to explain, fabric behaviors during elongation. The term "elastic limit" defines the limit to which elastic deformations in the fabric dominate. This is the limit when the material begins to deform faster under load and should therefore be considered as the limit of permissible loads. By defining the limit of elasticity and yield point of fabrics, one comes to the knowledge of the boundary intensities of the forces to which the fabrics can be subjected, without compromising their quality.

When the force acts in the weft direction, as the weft density increases, so do the values of the elasticity limit and the yield point. Fabrics in a plain weave with a higher weft density have a greater possibility of elastic and elastoplastic deformation, than fabrics in a twill weave. Fabrics in a plain weave can withstand higher values of maximum force and breaking force than fabrics in a twill weave.

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Professional Paper

THE "NOVI DVORI" COMPLEX AS INSPIRATION FOR THE DEVELOPMENT OF A NEW DESIGN

Ernestina Marković[1]; Katarina KRSTOVIĆ[2]; Vesna Marija POTOČIĆ MATKOVIĆ[3]

[1] University of Zagreb Faculty of Textile Technology, Zagreb, Croatia; ernestina.munisi@gmail.com
[2] University of Zagreb Faculty of Textile Technology, Zagreb, Croatia; katarina.krstovic@ttf.unizg.hr
[3] University of Zagreb Faculty of Textile Technology, Zagreb, Croatia; marija.potocic@ttf.unizg.hr
***** Corresponding author: marija.potocic@ttf.unizg.hr

Abstract: *This paper presents the complex process required to create a new product from an idea. It also shows how cultural heritage can live through new forms and preserve a traditional feature. The design is inspired by the geometric shapes that adorn the traditional building of Vršilnica in Novi dvori. The path to the development of the collection involves the evolution of ideas through personal research and design development, as well as the use of available technologies. The original idea for this project was a collection of socks inspired by historical buildings. Eight socks were developed with a jacquard pattern and knitted on the Lonati sock machine using the CAD-CAM Diagraph program.*
Keywords: design, knitting, socks, symmetry, Vršilnica, Novi dvori

1. Introduction

This paper presents the development of a knitwear design from the idea to the realization of the finished product. The design is inspired by the geometric shapes that adorn the traditional building of Vršilnica in Novi dvori. The openings of the building, with their composition, create a symmetry that is very common both in art and in knitwear design. The harmony and rhythm of the shape were transferred and elaborated for the sock collection.

2. Inspiration

The development path of a design collection includes idea development and personal research, exploring technical possibilities, and production. Inspiration can come from a variety of sources and is often a combination of a variety of inspirations and available sources. For example, in this work there is a combination of architecture and geometry. The idea alone is not enough to design an object, knowledge of the market is also important. This paper is about a combination of cultural heritage and tourism of the city of Zaprešić and its promotion. Sketches or a visual diary that offers a glimpse into the designer's personal creative journey are important for the proper development of the collection. Designers develop their identity through the way they gather and process research. Interesting results come from investigation and individual approach to the concept or theme [1].

The historical building of Vršilnica, which served as inspiration for this work, is located on the Novi dvori estate, where numerous agricultural buildings have been preserved. Although they are not representative buildings like castles and palaces, but fully functional buildings, they have a special landscape and cultural value. The threshing floor is a circular building 18 meters in diameter with a high, three-storey conical roof covered with shingles. Rooms were built on the north and south sides of the threshing floor to store hay, corn, etc. to protect them from moisture. Since a lot of dust is raised when threshing grain, the threshing floor was usually located outdoors. Therefore, this threshing floor in Novi dvori is one of the few preserved examples of the economic architecture of a noble estate from the 18th century.

Vršilnica was completely renovated in 2018 and is now a multimedia center for cultural events and business meetings [2,3,4,5]. Vršilnica Novi dvori is the only example of a completely preserved building of this type, not only in Croatia, but also in the wider cultural area of Central Europe (Fig. 1).

In architecture and the applied arts, ornament in the historical sense is decoration used to adorn parts of a building or an object. It used to be a symbol of wealth or social status. After its almost complete disappearance during modernism and its return in postmodernism, the lost language of ornament is now being rediscovered as a fundamental way to convey one's vision or image of the world beyond mere utilitarianism. Luxurious ornamentation is also found in traditional architecture, on 20th-century brick haylofts in continental areas (Figure 2). Since the hayloft had to be airy to dry the hay, the openings in the walls were "closed" with bricks with various ornaments [5].

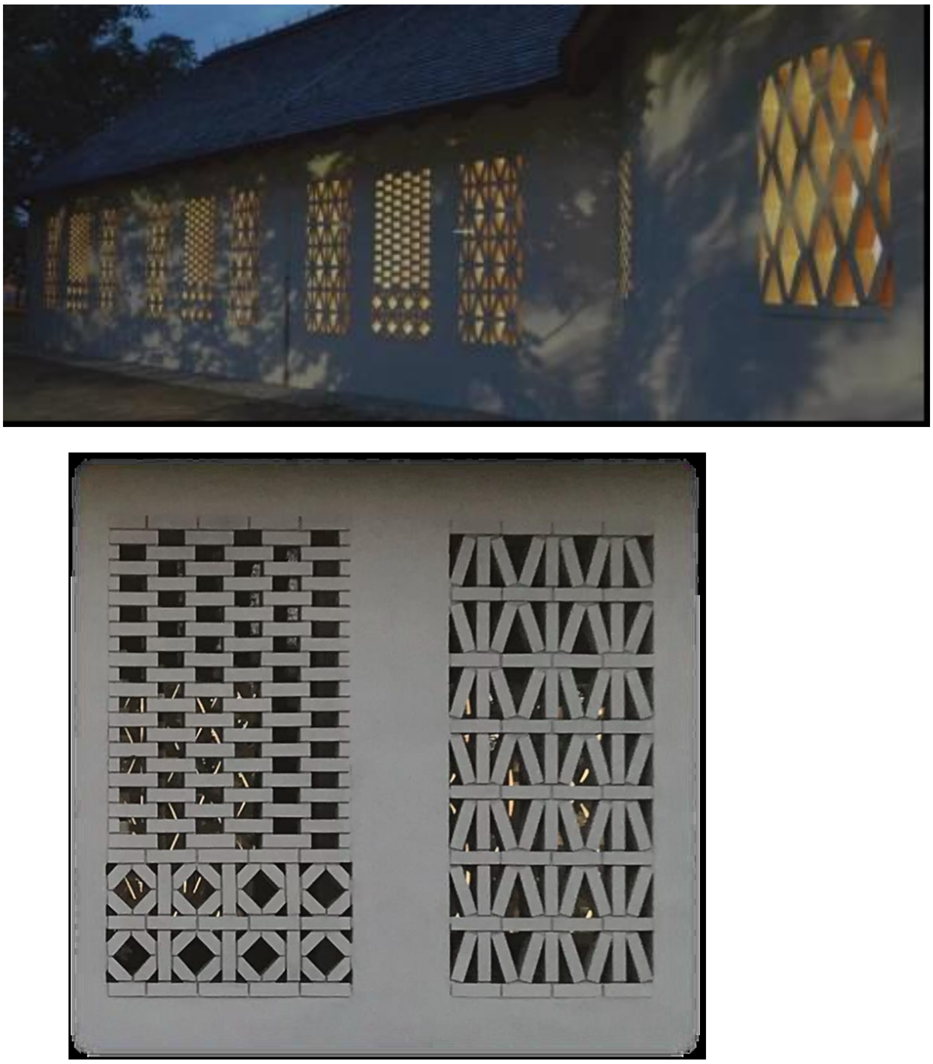

Figure 2. Brick openings, Vršilnica, Novi dvori [11]

The windows, i.e. the brick openings on Vršilnica, are decorated with geometric shapes, the composition of which creates symmetry and as such is the inspiration for the development of a new knit design. The word symmetry is of Greek origin and means "proportionality", a balanced arrangement of shapes in relation to axes or points. For symmetry, we need at least two shapes that maintain spacing between points. If we take two geometric figures, triangles, as an example, we see that three kinds of symmetrical balance are possible, depending on how we map the figure from one side to the other: a) mirror symmetry b) translation c) rotation. When something disturbs this harmony and balance, the composition is no longer perceived as symmetrical - an imbalance and visual tension is created. This happens because when we look at symmetry, our brain establishes a certain rhythm of objects and distances between them, it assumes the presence of a certain sequence and interval [12]. Mirror symmetry is based on the equality of two parts of the composition, which are located on opposite sides of the central axis of the image and are almost mirror images of each other. The orientation of the axis can be vertical or horizontal. Symmetry is said to be pure when the two halves of the composition mirror each other exactly. However, in nature it is quite rare, because it is no secret that the human body is not completely symmetrical. In most cases, we are dealing with incomplete symmetry - when the reflections are not completely identical and have minor differences [13].
From Figure 3, we can conclude that the openings that were the inspiration for the development of the new design have a composition with translational symmetry. We say that a shape has translational symmetry if it can be translated without changing the overall shape. Translational invariability means that the object is infinite in at least one direction. This is a type of symmetry where the elements of the composition are repeated at regular intervals. An example of this is the columns or windows of the building. In translational symmetry, the randomness of the direction of the elements plays an important role. This symmetry can be used to show rhythm, movement, speed or a very dynamic action [6,7].
The world is full of symmetrical forms and it can be said that the whole nature as well as its appearance in the artistic environment reflects the many possibilities of symmetry. Symmetry is one of the most important mathematical ideas that occur in many fields of science such as physics, chemistry or biology. It also appears in the visual and musical arts and in

architecture, from its beginnings to what we see today. There are numerous examples of symmetrical objects, reliefs, sculptures, statues, buildings, music, and works of art that are part of human cultural heritage, and in this work are the inspiration for the development of knitwear design [8,9,10].

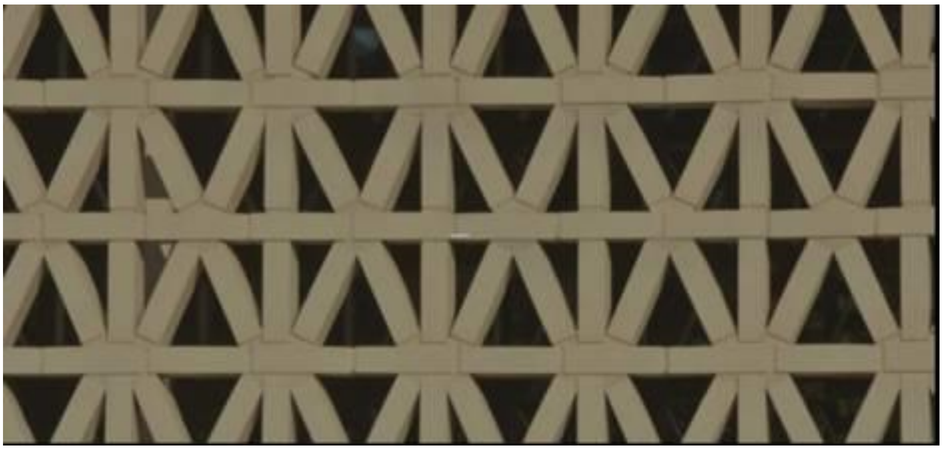

Figure 3. Vršilnica, brick openings

3. Development of the collection from the first sketches to drawings in the CAD-CAM system

For the realization of the sock collection we need a computer with special programs. The design of the socks is often created in the system CAD-CAM by Lonati, called Diagraph. It consists of several modules. The program Photon allows the creation and modification of different drawings that can be knitted on the single cylinder sock machine of Lonati. The first 10 sketches were made by hand, then 8 of them were selected for implementation and edited in Photoshop (Figure 4), where they were adapted to the shape of the sock. Then the pattern were drawn on graph paper and prepared for transfer to the program Photon, where the design of the sock is realized. The program works in such a way that the stitches are marked, that is, each stitch is assigned a yarn of the desired color and a pattern is created (Fig. 5).

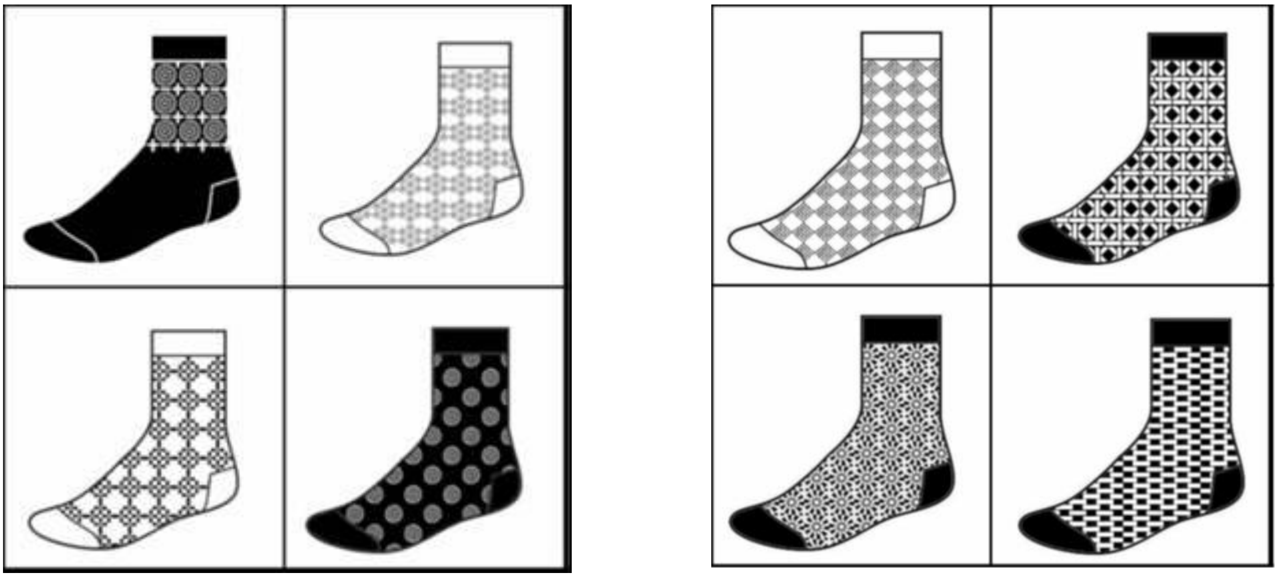

Figure 4. Sketches of socks in Photoshop

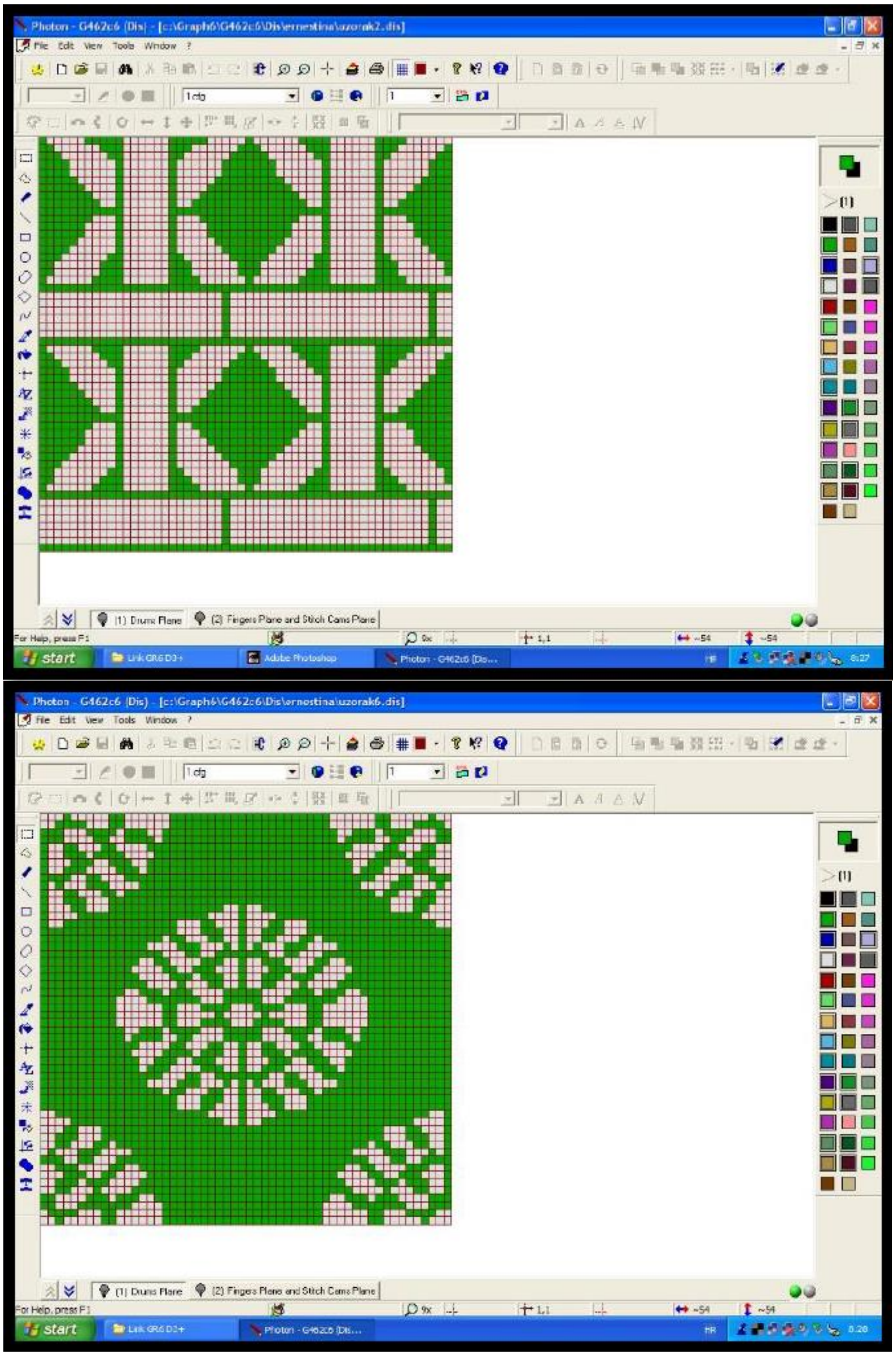

Figure 5. Example of design development in CAD / CAM system

4. Production of socks

Figure 6 shows the Quasar program for creating and modifying textile products on Lonati machines. On the left we see the basic structure of the active document (socks), on the right is the main window of the active document where all the changes are programmed and made [14]. In this program we make changes to the design of the sock or its length. It is also possible to change the length of the inner and outer elastic band, the pattern, the heel, the foot and the toe. The pattern in which the socks are made on the sock machine is single jersey jacquard. The raw material composition of the yarns used in the production of socks can be found in Table 1.

A collection of knitted socks inspired by hayloft openings is shown in Figure 7.

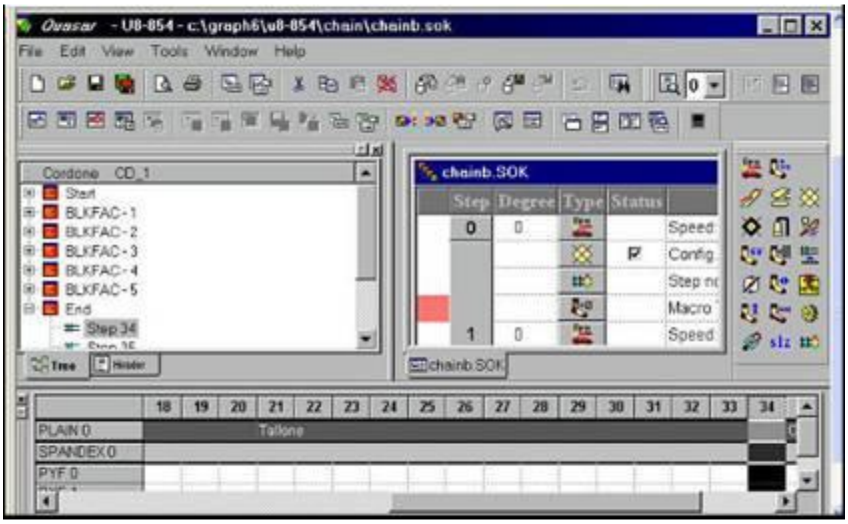

Figure 6. Introducing a new design into the sock program

Table 1: Yarns used in the production of socks

Type of yarn	Yarn fineness	Description
Cotton (100%)	50 tex	Yarn that knits throughout the sock
Polyamide (100%)	140 tex	Yarn that knits a pattern
Elastane (12%)/polyamide (88%)	150 tex	An elastic yarn that plates top of the sock

Figure 7. A collection of socks inspired by the symmetry of the openings on Vršilnica

5. Conclusion

There are numerous examples of art influenced by symmetry. These examples can be found in both ancient and modern times. Using some variations of symmetry can be a very useful tool for modelling in various areas of graphic design, which include illustration, applied and fine art photography, logo design, typography, and user interface design. Symmetry provides calmness, grandeur, elegance, balance and harmony in design. Symmetry does not require strict selection of elements for tone, texture, volume, weight. The beauty of the components is emphasized by their diversity and arrangement in relation to each other. Moreover, simplicity becomes ubiquitous (in performance and perception) in such cases. The elaboration of design from idea to product through this work proved the complex process required to develop new conceptual solutions. It also demonstrates how cultural heritage can be revived through new forms while maintaining a traditional feature.

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Original Article

APPLICATION AND FINISHING THE NONWOVEN LAYER FOR AUTOMOTIVE AIR FILTERS MEDIA

Maryam ADAVOUDI[1]; Zenun SKENDERI[2*]; Dragana KOPITAR[2]

[1] PhD student at University of Zagreb Faculty of Textile Technology, Republic of Iran, maryam.adavoodi@gmail.com
[2] University of Zagreb Faculty of Textile Technology, Zagreb, Croatia; zenun.skenderi@ttf.unizg.hr, dragana.kopitar@ttf.unizg.hr
* zenun.skenderi@ttf.unizg.hr

Abstract: *Most of the filter media used in fuel and oil filtration are manufactured by wet-laid processes using cellulosic fibres. Recent technological advances in extrusion-based nonwovens manufacturing have led to increased demand for spunbond or meltblown media in high-end fuel and oil applications. Filter media manufacturers have developed unique fibre and processing combinations to improve automotive oil and fuel filtration efficiency. In this research for producing the filter media, the nonwoven needle punching layer is produced and coated by resin for increasing moulding characteristics that adapts more easily to different shapes of final filter media. The release of collected particle in a fabric filter will be aided if the original fabrics are singed. The finishing process provides increasing the breaking force of the nonwoven and achieving the standard air permeability of the filter media.*
Keywords: *nonwoven fabric; air filter; polyester fibres; layer*

1. Introduction

Nonwoven fabrics have become an important segment of the textile industry in recent years. The technical developments in polymers, nonwoven processing and fabric finishing have led to significant improvements in fabric physical and mechanical properties including fabric handling, tensile properties, abrasion resistance, pilling and washing stability, that create prospects for nonwoven fabric applications in particular in apparel outerwear. This chapter briefly discusses the various nonwoven fabric production processes including web formation, web consolidation and finishing. An introduction to different joining techniques of producing the nonwoven fabric is also discussed and at the end the experimental part of paper that related to cabin car air filter media which produced by nonwoven needle punching fabric is outlined [1].
The definition of nonwoven by ISO 9092 has been adapted by CEN (EN 29092) and consequently by DIN, AFNOR, and all standardization offices in the EU. ASTM prefers to define nonwoven as "a textile structure produced by bonding or interlocking of fibres, or both, accomplished by mechanical, chemical, thermal, or solvent means, and combinations thereof. The term does not include paper, or fabrics which are woven, knitted, tufted, or those made by wool or other felting processes". This definition is available in many ASTM standards including D 123, D 1117, D 2646, D 3786, D 3787, D 5684, D 5732, D 5733, D 5734, D5735, and D 5736 [1].
Instead of yarns, nonwoven fabrics are made by directly entangling textile fibres together, to form a web. A manufactured web of directionally or randomly orientated fibres, bonded by friction, and/or cohesion and/or adhesion, excluding paper and products which are woven, knitted, tufted, stitch-bonded incorporating binding yarns or filaments, or felted by wet-milling, whether or not additionally needled. The fibres may be of natural or man-made origin [2]. Nonwovens come in handy in various aspects of our daily life across a wide range of fields from civil engineering and construction to agriculture, automobiles, clothing, cosmetics, and filtration [1].
Structure and properties of nonwovens are determined by kind of raw material used, manners of web forming, bonding and its finishing process. Depending on the manner of web forming, nonwoven can be divided as dry-laid, wet-laid and polymer-laid nonwoven [3]. Dry process of nonwoven production includes fibre preparation (opening, cleaning if necessary, and mixing), carding (more often using roller cards), cross-lapping, bonding (needling or thermal) as well as finishing.

2. Raw material used for nonwoven

All kinds of fibres can be used to produce nonwoven fabrics. The selection of fibres is based on the following features [4]:

- The cost-effectiveness,
- The ease of process ability, and
- The desired end-use properties of the nonwoven.

The commonly used fibres include natural fibres (cotton, jute, flax, wool etc.), man-made fibre like synthetic fibres (polyester, polypropylene, polyamide, rayon) and special fibres (glass, carbon, nanofibers, bio component, superabsorbent fibres). Two or more types of fibres are typically used for producing nonwoven. The fibres are usually blended in order to improve performance properties of nonwovens, such as strength and other properties. The fibre blends can be natural/natural, synthetic/synthetic, or natural/synthetic. Man-made fibres are the most widely used in the nonwoven

industry. Fibre characteristics influence not only nonwoven fabric properties but also processing performance. Web cohesion, fibre breakage, and web weight uniformity are the key quality parameters of nonwoven, this quality parameters are influenced by fibre parameters (diameter, length, tensile properties, finish, and crimp) [4].
Polypropylene fibres account for 60% of all the fibres used for nonwoven producing. Polyester is the second most widely used fibre next to polypropylene in nonwoven production. The advantages of polyester fibres include high strength, high modulus, high toughness, good abrasion resistance, good resilience, very low moisture absorbency, high melting temperature and heat distortion temperature, resistance to hazardous chemicals, oxygen barrier, inertness and biocompatibility. They can be processed using any of the main methods of nonwoven manufacture [1].

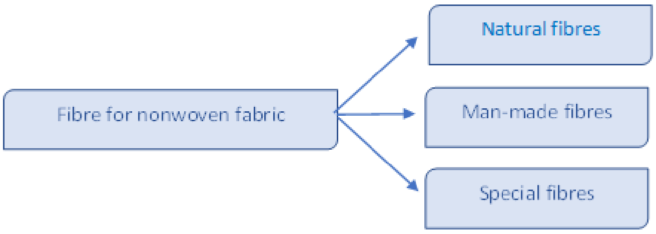


Figure 1: Types of raw fibres that used in nonwoven [4].

3. Manufacturing processes

The main methods of manufacturing processes in nonwoven production are as below in Figure 2. Dry-laid web formation is one of the old techniques and is very similar to the felting process. In dry laid web formation, fibres are carded (including carding and cross-lapping) or aerodynamically formed (air laid) and then bonded by mechanical, chemical or thermal methods [3].

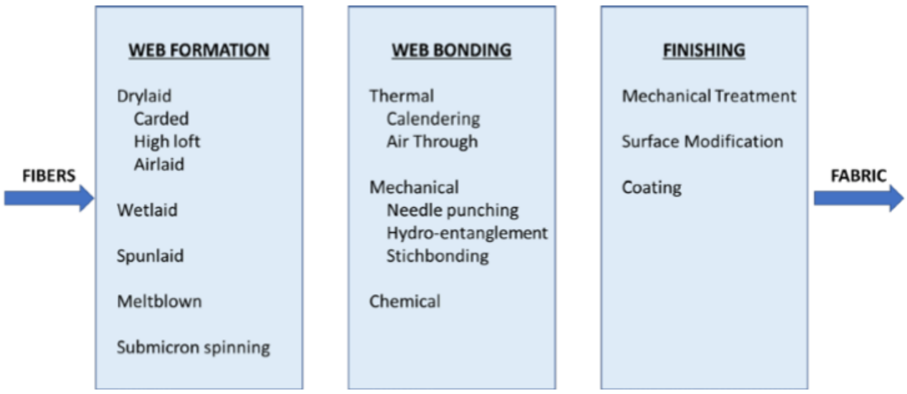


Figure 2: Process of nonwoven producing [5]

The arrangement of fibres in the web, specifically the fibre orientation, governs the isotropy of fabric properties and most nonwovens are anisotropic. Although it is possible to make direct measurements of the fibre orientation in a web, the normal approach is to measure the machine direction/cross direction (MD/CD) ratio of the web or more usually the fabric. This ratio of fabric properties, usually tensile strength, measured in the machine direction (MD) and cross direction (CD) reflects the fibre orientation in the fabric [3].
Needle-punched fabrics have characteristic periodicities in their structural architecture that result from the interaction of fibres with the needle barbs. In addition, needle marking caused by the punching effect of needles is frequently visible on the fabric surface [3].
Web Bonding is the second phase, where fibres are consolidated in order to increase strength. In thermal bonding the thermoplastic properties of fibres are used to form bonding between fibres. The web is passed between heated calendar rollers or hot air is blown through the web. Fibres must be thermoplastic like polypropylene. This is the most common method for producing nonwovens for medical textiles [3]. Mechanical bonding strengthens the web by increasing the inter-fibre friction, which is achieved by needle punching or hydro entanglement. Needles or a jet of water punches through the web and increases the physical entanglement of the fibres. In chemical bonding the web is bonded by liquid-based bonding agents like latex. The bonding agent may be applied by saturation bonding, spray bonding, print bonding or foam bonding [3].

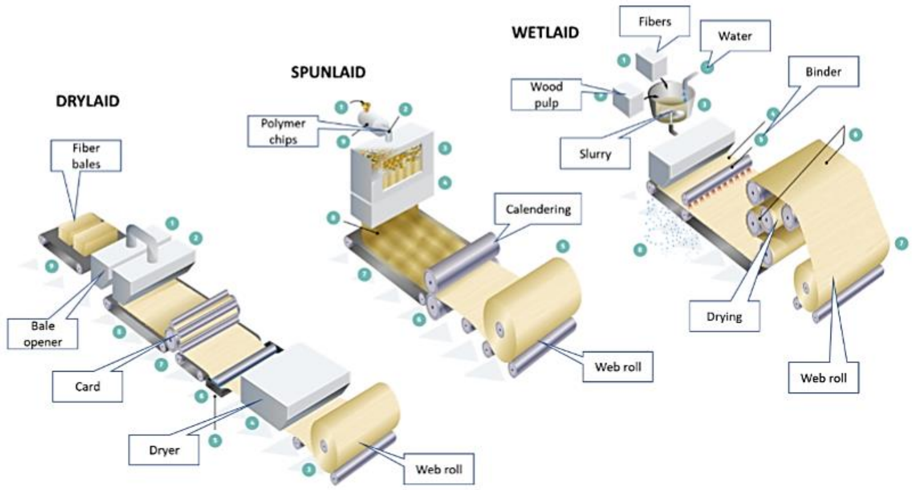


Figure 3: Web formation [5]

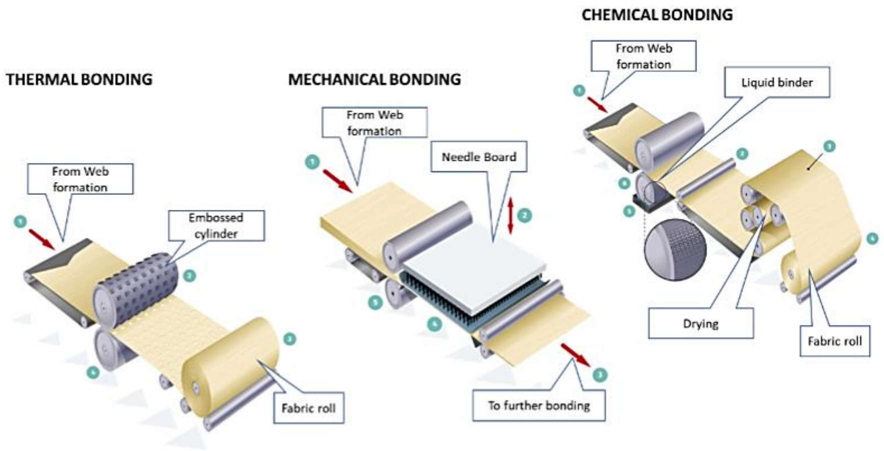


Figure 4: Web bonding [5]

4. Application of nonwoven

Nonwoven fabric formation is highly emerging technology for production of cheapest material of textile for different purposes. Nonwovens used in garments, home textiles, decorative purposes and technical textiles with their own performance requirements. Nonwoven product development will be delivered to customer or they can be utilized as semi-finished goods for non-textile production and assembly processes such as textile filters. These products are available in market in different sizes and shapes according to the purpose of usage and requirements [6].
Nonwovens are mainly used as filling material for thermal insulation and sound insulation in the home textile and decorative textile products [7].

4.1. Application of nonwoven fabric for air filters media

The nonwoven fabric filter is one of the four major filtration media (woven, nonwoven, paper and membrane filters) in the market. In comparison with woven fabric filters, nonwovens offer many unique technical characteristics, including greater permeability, greater specific surface area, and controllable pore size distribution, as well as smaller pore sizes; they have distinct different filtration mechanisms and advantages of greater filtration efficiency, lower energy consumption, and better cake discharge properties over woven filtration media. Filtration is another promising area of nonwoven applications in the engine compartment. Auto makers are seeking high performance filtration products with improved efficiency to capture particulates, provide enhanced filter rating, and extended filter lifespan [1].
Nonwoven materials are commonly used for engine intake air filter, gas tank filter, and transmission filter, where most filter media products are disposable. The major advantages of using these nonwovens are the ability to hold dirt, capability of design dimension and structure, and cost effectiveness. However, these nonwovens usually have a drawback in their wide pore size distribution. In some filtration areas, specific fibres are needed in order to achieve special end-use performance. Needle-punched nonwovens are felt-like and very flexible, having a fibrous network with distinctive pores,

which makes them suitable for applications in filtration and drainage. This has brought a new opportunity for nonwoven producers to help solve sophisticated filtration problems not only in diesel filtering but also in emitted gas and particulate filtering [8].

A filter medium is any material that, under the operating conditions of the filter, is permeable to one or more components of a mixture, solution, or suspension, and is impermeable to the remaining components. Broadly, the filtration process embodies solids–gases separations, solids–liquids separations, solids–solids separations, liquids–liquids separations, gas–liquid separations, and gas–gas separations and these are an essential part of countless industrial processes. Figure 5 shows the major uses of filters. Wide variations in filter material composition and structures are available in the market, depending on the field of application [8]. In this article the use of needle punching nonwoven for producing filter media that used in automotive air filter is shown on Figure 5.

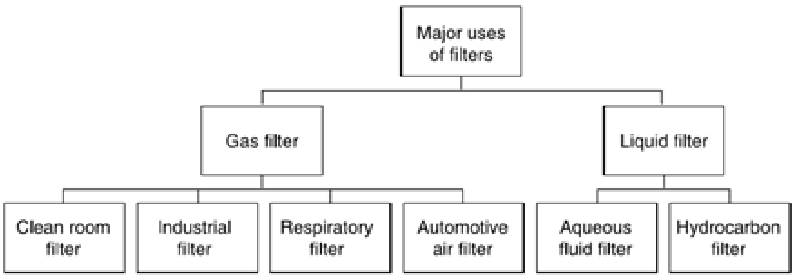


Figure 5: The major uses of filters

Traditionally, nonwoven materials are used for making disposable auto filters that used as air filter in engines of cars (Figure 6). In the case of gas filters, the most common applications are engine (automotive panel air filter, heavy duty air filter and cabin air filter. Future developments in auto filters will allow nonwovens to use thermal resistant fibres, composite structures, and activated carbon loading [3].

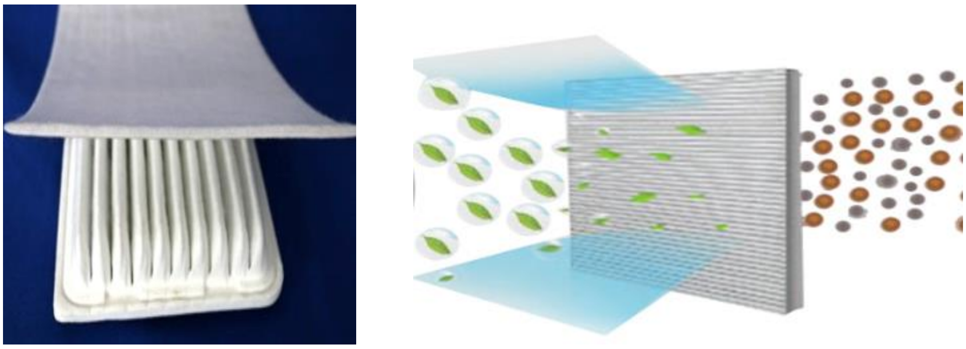


Figure 6: Non-woven air filter fabric for car cabin air filter

There are more than 50 filters in an average passenger car, contributing to functions ranging from the performance of the engine and oil and fuel consumption through to the quality of the air in the cabin. The application of nonwoven filter media in the fuel and oil filter segment of the transportation industry is affected significantly by governmental regulations related to the environment and the desire for longer intervals between engine filter replacements. Nonwoven filter media employed for filtering fuel and oil must demonstrate good chemical and temperature resistance. The filtration system is also constantly subjected to a great deal of vibration and shock, so the media must with stand extreme operating conditions and since the filter media represent the last line of defence for engines against contaminant-related wear and tear, the performance of the nonwoven must, in addition, be consistent and predictable during the service cycle. Most of the filter media used in fuel and oil filtration are manufactured by wet-laid processes using cellulosic fibres. Recent technological advances in extrusion-based nonwovens manufacturing have led to increased demand for spunbond or meltblown media in high-end fuel and oil applications. Filter media manufacturers have developed unique fibre and processing combinations to improve automotive oil and fuel filtration efficiency [9]. In this research for producing the filter media, the nonwoven needle punching layer is produced and coated by resin for increasing moulding characteristics that adapts more easily to different shapes of final filter media.

5. Experimental

5.1. Materials

All nonwoven fabrics are based on fibrous webs. Therefore, the characteristics of the web determine the physical properties of the final product. In this research white polyester and polypropylene fibres, as the main raw material of nonwoven, are used. The properties of the fibres that used in the main layer of air filter media are shown in Table 1.

Table 1: The physical properties of staple fibres used in this study

Type of fibre	Fineness, dtex	Length, mm	Percentage in total, %
Virginia polyester fibre	6.67	64	70
Virginia polypropylene fibre	3.33	64	30

In this paper, for the finishing the final nonwoven fabric, SBR (styrene butadiene rubber; PH-48 Paya Resin Company, Iran) is used to reach the suitable hardness of the filter media layer. The concentration of resin was 7% (a solution of mixing 7 kg of resin in 100 kg water).

5.2. Methods

In this research needle-punched nonwoven fabric is used as filter media, where fibres are bonded together mechanically through fibre entanglement and frictions after fine needle barbs repeatedly penetrated through the fibrous web. The double doffer roller card was used to produce the fibre web after blending the polyester and polypropylene fibres uniformity. The fibres are first opened and mixed by the opener, and then the opened feed mat is fed into the carding machine (TECNATEX – Truezschler FBK 536; Figure 7(a) to form a uniform single-layer fibre web. The principle of carding is a mechanical action in which the fibres are held by one surface while the other surface combs the fibres, causing individual fibre separation. Thus, the fibres would form and oriented when they passed through the carding process. In this research, needle-punched air filter layer have a range of nonwoven specifications between 210 g m^{-2} up to over 215 g m^{-2} containing 10 layers of web.

a) b)

Figure 7: a) The main cylinder of carding machine **b)** the web that created in output of the cross lapper consisted of 10 layers

Table 2: Parameters of carding machine

Components	Speed, m/min
Feed roller	18.2
Cylinder	97.0
Doffer	38.0
Worker-roller	14.5
Stripper	43.0

After the carding process, there are three needle punching processes (Figure 9). Among these manufacturing systems, three-dimensional needle-punching allows to produce complex net-shape preforms to be produced. The mechanical consolidation is provided by needling where the board containing a plurality of metal needle moved through the thickness direction so that the needles come pierce the mat to entangle the fibres. The shape and number of holes in nonwoven fabric depends on the number of needles in the needle board, the size of needles, advances per stroke and fibre type.

Pre-needling   Needle punching 1   Needle punching 2

Figure 8: Needle punching machines; Fehrer AG company

In the first step the web is feeding in pre-needling machine that create a physical entanglement between the fibres and make the layer compressed which increased the strength of the nonwoven. After that the layer is passed to the needle punching 1 machine (Figure 8 and 9). The layer passed the needle punching 2 machines which are needled from both sides (Figure 8 and 9). The properties of needle punching boards that used in current process are in Table 3:

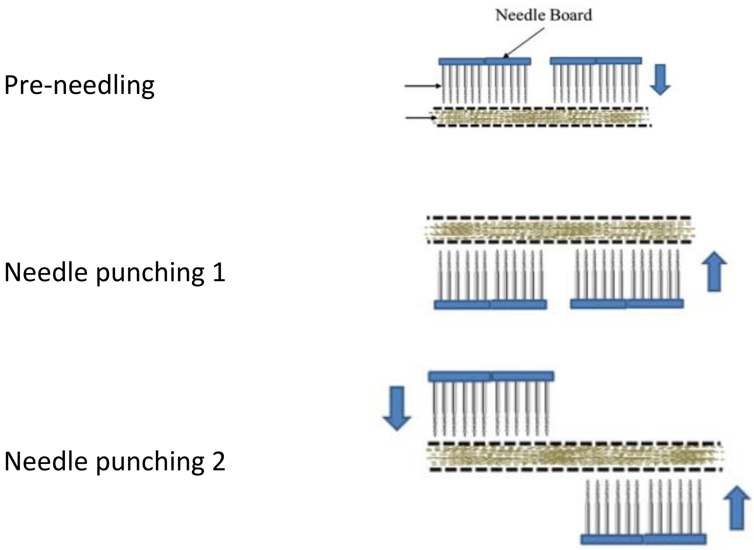


Figure 9: The strike's direction of needles in needle punching process

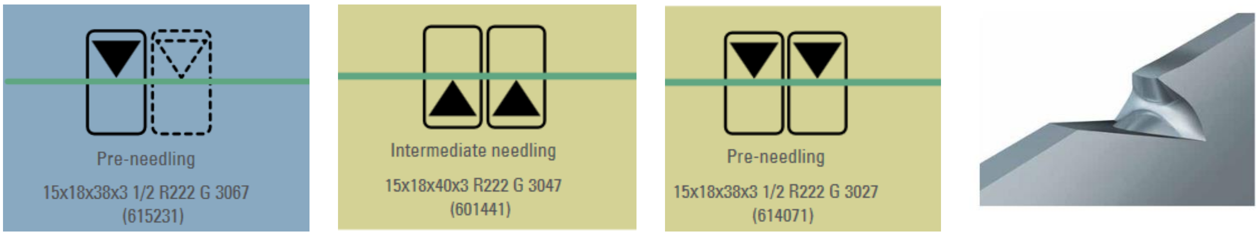
Table 3: Parameters of needling punching boards

Machine of needle punching	**Number of needle boards**	**Number of needles in each case**	**Properties of each needle***
Pre-needling	4	5000	15×18×38×3-R222-G3067
Needle 1	10	5000	15×18×40×3-M222-G3047
Needle 2	8	6000	15×18×42×3-R222-G3027
Explanation of each number:			a × b × c ×d -e f -G g hi

a	b	c	d	e	f	g	h	i
Needle thickness in the top point of needle	Needle thickness in the middle point of needle	Needle thickness in the down point of needle (Gauge)	Needle lengths (inch)	The interval between the barbs	The number of barb in each side	Rf is barb style	Height of the barb	The coating of the needle

* Needles are made by Groz Beckert Ltd.

The accentuated base of barb and the rounded edges in the undercut area have a positive impact on the wear characteristics and so guarantee a long service life of needle. The conditions of the needle punching process and the parameters for producing the raw layer are as below in Table 4:



a) Groz Beckert needles for each code b) needle barb for type RF

Figure 10: Scheme of Groz Beckert needles for needlepunching [10]

Table 4: Conditions of needle punching process

Machine of needle punching	Number of board of needles	Number of needles in each board	Input speed, m/min	Strokes, cm^{-2}	Stroke amplitudes, mm	Output speed, m/min
Pre-needling	4	5000	1.50	620	+10	2.58
Needling 1	10	5000	2.89	447	-5	3.01
Needling 2	8	6000	3.27	840	-7,+6	3.35

*In the stroke amplitudes minus sign showed the direction of the needles were penetrated to the nonwoven

In the next step for increasing the uniformity of the layer, the nonwoven fabric is passed through the thermal calendaring process (Figure 11). In the calendaring process the fabric is compressed by passing between three hot rolls under controlled conditions of time, temperature and pressure. They are three rollers of calendar (BOMBI MECCANICA) that oil heating is made externally to the calendar with a self-standing unit.it is possible to adjust the temperature independently in each roll that the data set as follow:

Table 5: Conditions of calendaring process

Temperature of heater 1, C°	Temperature of heater, C°	Temperature of heater 3, C°	Speed, m/min	Filler
155	167	155	3.05	0.1

a) The entrance part of calendar b) The existence part of calendar

Figure 11: The calendaring process

The calendaring process is done to regulate the filter media permeability and, hence, to improve its collection efficiency. After calendaring, nonwoven fabric has higher strength, higher modulus, stiffness and good recovery from bending. In the next stage the finishing process has been done that consist of chemical and physical finishing. In chemical finishing the nonwoven fabric is coating by SBR resin to fix the layer and improve the hardness properties that effects on modelling of the final air filter media. The concentration of the resin is 7%. The layer passed to the pan of the resin and coated by passing between rollers with the speed of 1.5 m/min. Then, nonwoven fabric was dried through the stenter and dryer machine at 180 °C with speed of 1.5 m/min. In this condition the resin is cured and leads to make the nonwoven hardness. After this step, the physical finishing is done by glaze singeing process. Singeing is a process that burns any loose or raised fibres on the surface of a textile fabric using a gas-fuelled flame or by infrared radiation to give a smooth surface finish. The height and size of the gas flame coupled with the machine speed regulates the extent of the burning effect on the fabric surface. The process carried out using a single-burner machine (Figure 12) depending on the requirements of the final product. In single-burner machines, it is usually possible to adjust the position of the burner to singe either the top or the underside of the substrate. Singeing technical fabrics increase the surface smoothness, and nonwoven fabrics, benefit from this treatment. For instance, the release of collected particle cakes in a fabric filter will be aided if the original fabrics are singed [11].

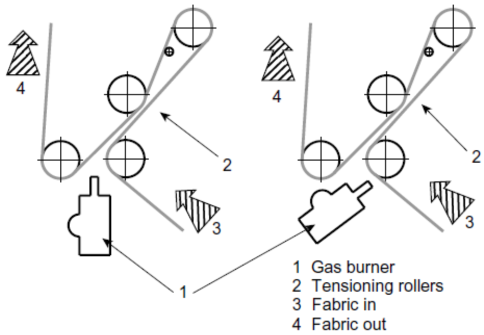


Figure 12: The Singeing process [11]

Raising and singeing processes are essentially used in the production of filter fabrics to facilitate both their dust holding and dust release capability. In this term a single-burner singeing machine is used by 25 m/min speed and the fillers are set on 10 mm to burning the surface of the nonwoven fabric that leads to decrease the thickness of the layer and make it uniformity. After the singeing process the thickness decreased, while the fabric density increases. The singeing process using pressure and fire for the bonding, caused decrease of fibre length and increase of fibre diameter within the nonwoven, improving the nonwoven media's surface smoothness.

5.3. Experimental part

The determination of the mass per unit area, thickness, tensile properties as well air permeability were done for all samples. The thickness of nonwoven fabrics was measured according to the standard EN 29073-1 (1992) using thickness gauge K-300 with measuring range (0 - 30 mm) and resolution of 0.1 mm. For measuring each parameter the samples are selecting as showed in Table 6 and the average of amounts in each side (left-middle-right) are reported in the results.

Table 6: Describing the selection of samples

3 types of nonwoven fabric		
raw	**coated**	**Coated and glazing**
5 samples in three sides of nonwoven (left-middle-right)	5 samples in three sides of nonwoven (left-middle-right)	5 samples in three sides of nonwoven (left-middle-right)
In total 15 samples	In total 15 samples	In total 15 samples

The nonwoven air permeability according to the standard method ISO 9237 by automatic air permeability tester GT-C27B (Figure 13) were done. Air permeability is an important nonwoven fabric characteristic when it's used in filtration at different thermal and chemical conditions of filtrate [6]. Air permeability of a nonwoven filter media is the measured as airflow through the sample area at a specified pressure drop. The air flow is constant where pressure drop is measured. Depending on the nonwoven structure with the void capacity through which the air can flow. The test consists on a volumetric rate of air flowing (L/dm^2.min) through the nonwoven of unit cross sectional area and at a certain pressure (the 200 Pa).

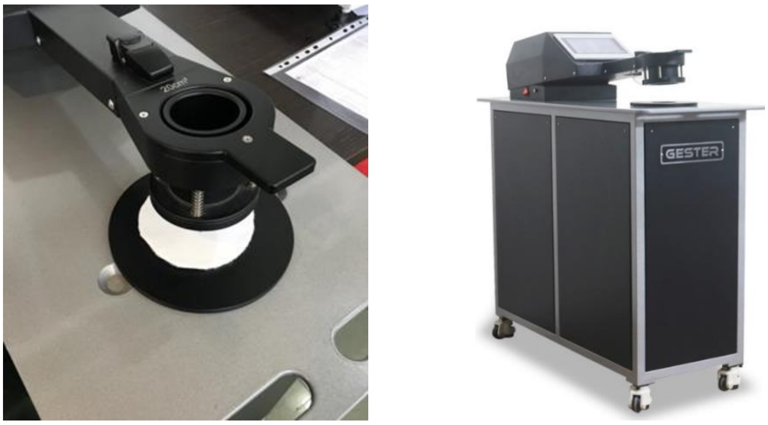


Figure 13: Automatic air permeability tester GT-C27B

The tensile properties for the nonwoven fabrics follows the standard EN ISO 9073-3 (1989) based on Constant Rate of Extension (CRE). Each nonwoven sample is selected from three sides of the layer (left, middle and right) cut in size of 5 cm x 25 cm. The samples were tested on an Instron tensile testing machine at a speed of 100 mm/min. The central section across the fabric width is clamped by jaws a fixed distance apart called gauge length and the interval between two jaws used was 10 cm. The data represent the averages and the standard deviations obtained from 3 measurements in each direction; machine direction (MD) and cross machine direction (CD).

6. Results and discussion

The mass per unit area and the thickness of nonwoven fabrics were measured in each step of production, i.e. raw layer, coated layer as well coated and glazing layer, where the results are presented in Table 7.

Table 7: Thickness and mass per unit area of the raw and coated nonwovens

Layer type in process	Layer side	Mass per unit area, g m^{-2}	Thickness, mm
Raw layer	Left	177.7	1.50
	Middle	199.6	1.52
	Right	214.0	1.54
Mean value		197.1	1.52
SD		18.3	0.02
CV, %		9.3	1.32
Coated layer	Left	235.7	2.04
	Middle	245.6	2.47
	Right	240.6	2.08
Mean value		240.6	2.20
SD		4.9	0.24
CV, %		2.1	10.81
Coated and glazing layer	Left	241.0	1.44
	Middle	239.3	1.54
	Right	238.8	1.44
Mean value		239.7	1.47
SD		1.2	0.06
CV, %		0.5	3.92

The nonwoven mass per unit area and thickness vary in different locations in the fabric which can be explain by the variation of local fibre packing density, fabric porosity and air permeability. These physical properties influence greatly the performance of nonwoven applications: tensile behaviour, shape forming, light opacity and air permeability. Indeed, the increase of the mass per unit area leads to the increase of the fibres' packing density consequently the nonwoven is less permeable. The coating process of the nonwoven leads to an increase in mass per unit area (about 40 g m^{-2}) and the thickness (increased from 1.52 mm to 2.2 mm). After glazing process the surface of layer become smooth and fibres are compressed where the thickness of the layer decrease from 2.2 mm to 1.47 mm. Obtained amount of thickness is suitable for moulding and forming of the final filter media.
The tensile properties of nonwoven fabrics were tested in both machine directions (CD, cross direction and MD, machine direction) where the results with statistical indicators are given in Table 8 and Figure 14.

Table 8: Nonwoven fabric breaking force, breaking elongation and air permeability at 200 Pa

Layer type in process	Layer side	Breaking force, N		Breaking elongation, %		Air permeability at 200 Pa, L/(dm²/min)
		MD	CD	MD	CD	
Raw layer	Left	471	585	192	178	1172.9
	Middle	465	541	218	190	1207.5
	Right	495	544	184	190	1187.4
Average		477	526.6	198	186	1189.27
SD		1.59	6.87	17.78	6.93	17.38
CV, %		3.33	13.04	8.98	3.72	1.46
Coated layer	Left	547	674	150	160	1009.4
	Middle	532	746	195	156	980.1
	Right	516	614	167	159	987.1
Average		531.6	678	170.67	158.33	992.2
SD		1.55	6.61	22.72	2.08	15.3
CV, %		2.99	9.75	13.31	1.31	1.54
Coated and glazing layer	Left	665	807	163	148	930.7
	Middle	520	861	182	143	908.5
	Right	600	962	165	178	942.2
Average		595	876.2	170	156.33	927.13
SD		7.26	7.87	10.44	18.93	17.13
CV, %		12.21	8.97	6.14	12.11	1.85

Breaking force as well the standard deviation of breaking force is larger in cross machine direction. Larger breaking force in cross machine direction can be explained by the manufacturing process where, after the carding and cross-lapping process, the fibres are more oriented in the cross direction of the nonwoven fabric. Larger standard deviation of breaking force can be explained with the higher variation of the local fibre density along with higher strain at break in the cross direction, in comparison to those in machine direction. The percentage of force increase in (MD/CD) in compered with row nonwoven fabric showed in Figure 14, from which is evident that by coating and glazing the layer, breaking force is increased in both directions, cross and machine directions.

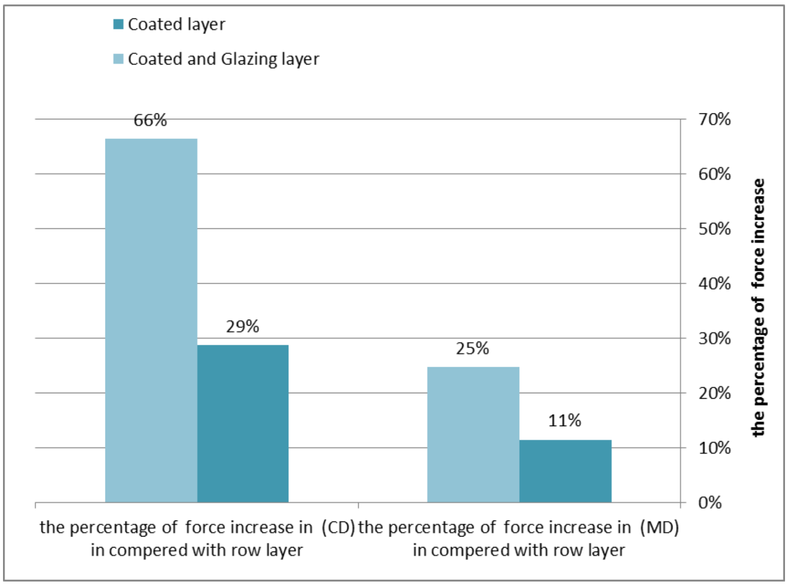


Figure 14: the percentage of force increase in (MD/CD) in compered with row nonwoven fabric.

For each layer type, air permeability at 200 Pa was measured. The results of the air permeability at 200 Pa showed that by coating and glazing the layer, air permeability will decrease. That is due to thickness decreasing and more entanglement of the fibres in the nonwoven fabric structure. The percentage of air permeability (at 200 Pa) decrease in compered with row nonwoven fabric is showed in Figure 15. The nonwoven fabric air permeability is inversely proportional to fibre packing density.

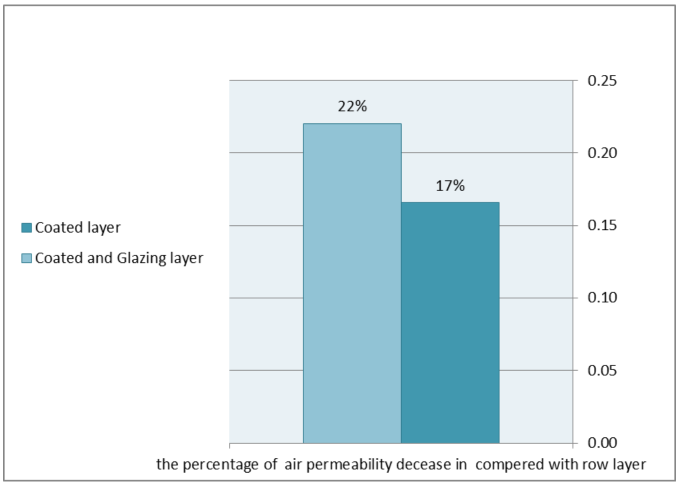


Figure 15: the percentage of air permeability (at 200 Pa) decrease in compered with row nonwoven fabric.

7. Conclusion

In this paper, an experimental study of the tensile properties, thickness and air permeability of nonwoven fabric for air filter media that is used in automotive industry is presented. Nowadays, for producing the filter media of engine cars, nonwoven filters are used. These types of nonwoven fabrics are made by special fibres such as bio component and hollow fibres or the spun bond layers. In this research, technology for producing air filter media is different. Nonwoven fabric was produced by carding and needle punching after which, in chemical finishing process, resin coating on the nonwoven fabric is used. By coating with resin, in addition physical finishing by signing and glazing the mass per unit area of the nonwoven fabric will increase. Increase of mass per unit area and more fibre packing leads to the increase of the breaking force. The results of the air permeability at 200 Pa showed that by coating and glazing the layer, air permeability will decrease which is related to the decreasing the thickness and more Flattening of the fibres in the nonwoven fabric. Thus using this technology of filter media production, due to the use of raw materials with lower prices and simpler production procedure is preferable to the usual methods of producing air filters media.

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Professional Paper

BE SMART. BE LIKE WILL. WEAR WOOL.
SOFT SCULPTURE DRESS WILL - INNOVATION IN TRADITION

Jelena ĐUKANOVIĆ[1]

[1] University of Donja Gorica, Faculty of Design and Multimedia, 81000 Podgorica, Crna Gora; sofsofjelena@gmail.com
* Corresponding author: sofsofjelena@gmail.com

Abstract: *Although fleece is deeply rooted in the cultural heritage of Montenegro, it is rarely processed nowadays, and the market potential of wool is underestimated. Up until a few years ago, wool was a precious raw material in the textile industry; it was bought back and processed by textile mills for their needs or export, but with the industry being shut down, it is not bought back any more nowadays, and is used sporadically in rural households, mostly for knitting warm winter socks or sweaters. Wool went from a precious textile material to an ecological challenge because cattlemen usually throw it away after sheep shearing and improperly dispose it in the nature. Climate changes, green energy sources, preserving resources of drinking water and ocean, environment friendly technology, recycling possibility, maintaining health taking into consideration more frequent allergic reactions to synthetic fibers and colors, are challenges presented by the modern era, and wool is the common denominator for each of them.*
Keywords: *fleece, ecological problem, environment friendly technology*

1. Introduction

In Montenegro, a mountainous country with a tradition in livestock farming, most commonly type of sheep that can be found is pramenka. *Jezero*, *piva* and *sjenica* types produce rough and sharp wool, and this type of wool is generally not used for fine clothing and fabrics. Wool, as historically predominant textile material, from the Neolithic to the mid-20th century was used for the most of the clothing, ambient textile and textile for any other purposes' production, in rural households of the continental and mountainous part of Montenegro. Textile items for everyday use were made by household members, and the art of the production was passed down from generation to generation, most often from grandmother to granddaughter [1].

Sheep shearing was done by men once a year, while all other textile activities were in the hands of women. Wool washing, classification of fibers by length and quality, combing with hands and combs and then spinning wool were preparatory actions for the final shaping of useful items. The weaving technique was used for making numerous usable and clothing items, starting with the simplest cloth and linen, bags, sacks and saddlebags were also woven; various robes, raincoats and aprons; towels, pillow cases, tablecloths, various bedspreads, decorative rugs, carpets and more, both for everyday and holiday use. Knitting is a technique used for making wool products mostly, often very lavishly embroidered and skilfully and artistically shaped. This technique was mostly used for making socks, toe covers, then mittens or gloves, and not as often-other clothing items too, such as knitted woollen sweaters, overalls, undershirts, underpants, petticoats, etc., [2].

Clothing items for everyday use were usually made of white – uncolored wool, and the decorative effect on those items was achieved by a combination of natural hues of white, grey, and black wool and yarn dyed in natural plant dyestuff until the beginning of the 20th century when starts the production of synthetic dyes.

Wool yarn was dyed black with black ash leaves and bark, brown with walnut leaves and fruit, pink with quince leaves, green with peach leaves, red with broccoli, yellow with onion peel, etc. Plant dyes were used until the beginning of the 20th century, when synthetic dyes took over, and the dyeing technology itself fell into oblivion. Every woman tried to weave her own inspiration to show her skills and imagination, but also to transmit their experience and skills to younger generations so that the tradition can be continued (3).

2. Experimental part

This paper presents the traditional way of wool usage in production of clothing items for everyday use. The creative challenge for creating a soft sculpture - Will dress in traditional wool material is inspired by an educational pictogram which, in addition to educating the public about the positive aspects of wool, raises awareness of the importance of using natural materials and environmental sustainability. The creative challenge for making the Soft sculpture – Dress Will in the traditional material – wool was inspired by a funny drawing floating on the Internet:

2.1 The methodology of Soft sculpture Dress Will production

The experimental part of working on the Soft sculpture Dress Will is carried out in four stages:

1. Analysis of the traditional clothing item - underwear traditionally named "fanjela";
2. Transferring the shape of cone, stable geometric shape into the form of Soft sculpture - Dress Will;
3. Selection of the woollen yarn obtained from domestic sheep soybean pramenka and technique of making Dress Will;
4. Selection of the location for shooting a model;

1. The traditional clothing item "fanjela" which is also called "džupa" is still used nowadays. It is a type of knitted woollen undershirt. It has two halves, no sleeves and with a hole for the head. It is mostly worn by elderly population of both genders of the continental and mountain part of Montenegro, directly to the body, both in the conditions of a harsh winter and hot summer months while doing agricultural work in the field. Thanks to the property of temperature regulation and humidity, wool is an excellent isolator. Due to crimps in wool structure, the air is trapped in fibers providing thermal barrier. Wool also absorbs humidity (up to 30% of its weight without losing isolation abilities) and perspiration of the body allowing it to breathe. It is not a fashion clothing item, led by functionality only, but as an anti-fashion clothing item which stands for a creative challenge for making sculpting or fashion forms.
2. Transferring the shape of cone, stable geometric shape into the form of Dress Will is done through a linen petticoat – crinoline embedded with concentric, metal rings. The structure of the selected knitwear and possibility of an elastic and plastic adjustment allows for application of form and re-composition of the form of the lower part of the dress. The shape of cone is often seen in the grasslands of Durmitor area – those are haystacks ready for winter feeding big and small cattle.
3. The selection of raw and uncolored knitwear allowed for keeping the authenticity of the material itself. The yarn is knitted – without reknitting; it has kept grassy residue and sheep scent; it is easily removed and soft to the touch. The technique is hand knitting (knit and purl) which allows for stretching the knitwear from left to right. The Soft sculpture Dress Will is composed on a mannequin of three rectangular knitted pieces size 0,6m x1,6m by hand stitching and binding elements with a cotton and woollen thread having in mind the petticoat in the form of crinoline. The direction and rhythm of knitwear stitches determines the direction of turning and wrapping. Openings created during this are added and highlighted with crocheting cones, bounded by crocheting ribbons determining their rhythm in space. Sleeves are knitted based on the knit and purl pattern, and then stitched to the dress, while crocheting ends are added to the ends of the sleeves in the shape of truncated cone with uneven fringes and tassels created by cutting, length of 12-14 cm. The texture of the crochet part was created by combining tightening, dropping or adding loops and thread winding around a crotchet while shaping the loop. The beanie Will is knitted based on the same pattern in the shape of rectangular size 45cm x30cm and bounded with a crotchet to the side. On top there is a tassel of uneven fringes length of 14-16 cm.
4. Soft sculpture Dress Will is shot on a model In situ. Grasslands at the foot of the highest Montenegrin mount Durmitor were chosen for taking photos. The glacial lakes of Durmitor are called "Mountain eyes" and are faced with extinction due to climate changes which is one more reason for the selection of a location on the banks of Fish Lake. The setting of a gloomy and cold winter day accentuates the superiority of wool and its inseparability from nature, this setting and space.

3. Results - Be smart. Be like Will. Wear wool.

Figure 1: Soft sculpture Dress Will; Photo: doc. Anka Gardašević ; Model: Sofija Đukanović

Figure 2: Detail of the sleeve and lower part of the skirt

Figure 3: Beanie Will

4. Conclusion

Research result is a realization of the soft sculpture Dress Will as a possible starting point for a fashion collection with the aim of creating objects for the purpose of creative industries along with mandatory design articulation. The paper points out the importance of returning wool to everyday use through a new aesthetic of self-sustainability, applied art and traditional craftsmanship (knitting, crocheting, embroidery and weaving) for which economically empowered women from the rural areas of Montenegro were hired. Through that process, a part of the intangible cultural heritage of Montenegro, anecdotes, legends, tales related to sheep farming and shepherd rituals as well as the techniques of processing and shaping wool have been preserved. The simplicity of the form of the original object allows the transposition and stylization of existing elements. Clothing, in the past used as part of the laundry and today would be used as "active laundry" due to the extraordinary thermal and waterproofing properties of wool. The paper points out the importance and justification of the reuse of wool in everyday use through a new aesthetic of self - sustainability, applied art and traditional crafts. Skills such as knitting, crocheting, embroidery and weaving were maintained thanks to women from rural areas of the mountainous part of Montenegro. Engaging unemployed women in wool processing and making items is an added value because it will contribute to their economic independence and empowerment. Through this process, a part of the intangible cultural heritage of Montenegro, anecdotes, legends, traditions related to sheep breeding and pastoral customs, as well as techniques of dyeing, processing and shaping wool will be preserved.

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Professional Paper

DIANE FRANCES SPENCER AS INSPIRATION FOR OWN INTERPRETATION OFTHE FASHION COLLECTION

Blaženka BRLOBAŠIĆ ŠAJATOVIĆ[1]; Diana BILUŠIĆ[1]; Irena ŠABARIĆ[1], Franka KARIN[1]

[1] Faculty of Textile Technology, University of Zagreb, Zagreb, Croatia; blazenka.brlobasic@ttf.hr, irena.sabaric@ttf.hr,franka.karin@ttf.hr
***** Corresponding author: blazenka.brlobasic@ttf.hr

Abstract: *The paper presents an analysis of clothing combinations by Diane Frances Spencer, who served as the inspiration for creating a collection of clothing items. The work of one of the designers whose collections were worn by Diane is described. In the experimental part, the process of making a certain garment from design, construction, modeling and its realization is presented.*
Keywords: *Diane Frances Spencer; clothing construction; modeling; design*

1. Introduction

Princess Diana, often called the princess of the heart with a lot of style violated the strict fashion rules of the royal court. Evening dresses, oversized jackets, unforgettable blouses and tops or pants that emphasize a slender waist, all this Lady Di wore in a unique way and everyone agrees that she rightfully bears the title of one of the greatest fashion icons of all time. High-waist jeans and jackets with accentuated shoulders, such as some fashionable icons of the new age, are worn with a lot of style today. Then 20-year-old Diana shone in a spectacular and one of the most famous wedding dresses in history that followed the fashion of the 80s. The fairytale wedding dress with puff sleeves and lace details, made of silk taffeta, was designed by David and Elizabeth Emanuel, a young couple chosen to support the British fashion industry. Over 10,000 pearls were sewn into the wedding dress. Perhaps the most striking part of the cut was the seven - and - a - half - meter - long veil, which went down in history as the longest veil worn at any royal wedding, Figure1 [1].

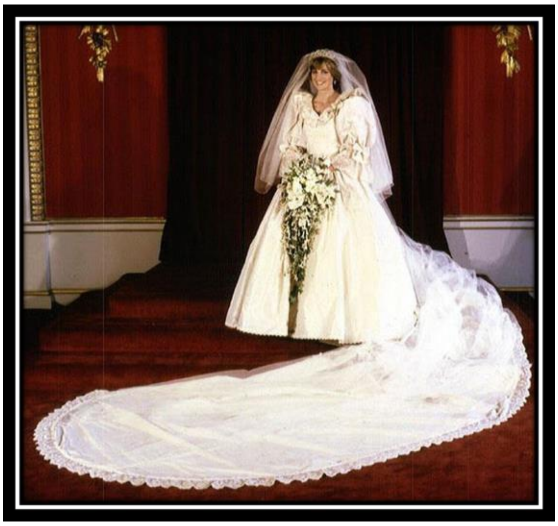


Figure 1. The wedding dress designed by David and Elizabeth Emanuel [2]

Figure 2. The shoes Diana wore to the wedding [2]

The shoes are made of a combination of satin and lace and are adorned with a total of 500 sequins and over 100 pearls, while the sole made of suede leather, just below the miniature heel imprinted with the initials of the newlyweds 'C' and 'D', between which is a small heart, figure 2. As we slowly return to the era of fashion trends of the 90s, fashion experts are very happy to remember her combinations, which can comfortably say that she was the most beautifully dressed person of the royal family. Now, 25 years after her death, Lady Di style is back on the catwalks and city sidewalks. She also inspired the cult designer Virgil Abloh, who embodied his entire appearance at Paris Fashion Week on a collection of paparazzo paintings by Lady Di from the 90s era. Proof of her thoughtful dressing was also in the fact that she wore a velvet dress on a visit to a hospital for the blind, so that the wards could feel her softness and warmth as they talked to her. She was very happy to wear velvet on special occasions, and I especially remember the black velvet dress, which she wore during a visit to the White House and in which she danced with actor John Travolta,figure 3 [3].

Figure 3. The black velvet dress [4]

2. Designer Catherine Walker

Catherine Walker was a French designer. She opened her own design house in Chelsea in 1977, and began working with Diana a few months after her marriage to Prince Charles. At the time, Diana was still struggling to find her fashion foothold, and Catherine did her best there. Catherine Walker died in 2010, and the company continues with her second husband at the helm. Many other royal families, including Lady Helen Taylor and the Duchess of Cambridge. Catherine Walker has designed more than a thousand pieces for the Princess of Wales, including many of her cult pieces (like the "Elvis" dress). She also designed daywear and evening pieces for Diana, and was even buried in a black Catherine Walker dress in 1997. According to information from the exhibition, Catherine Walker began designing for the princess when she was pregnant and needed modern maternity clothes. They continued a lasting partnership, and Catherine Walker was struck by the princess's lightness and modesty. Figures 4a, b, c and d, show only some of the creations that the mentioned designer created for Diana [5].

a)

b)

c)

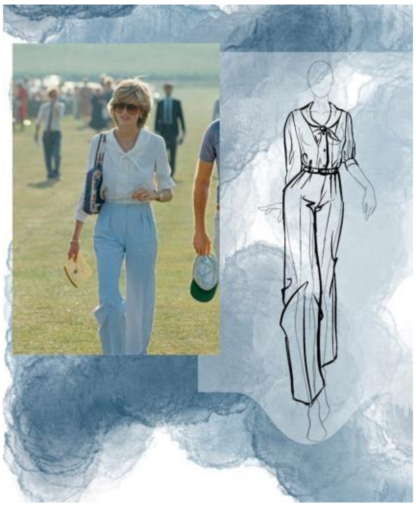
d)

Figure 4. Catherine Walker designer created for Diana [6]

3. Development of collection inspired by Princess Diana's clothing combinations

A collection of clothing items, based on Princess Diana's clothing combinations is shown figures 5a, b, c and d [7].

a)



b)

c)

d)

Figure 5. Collection of clothing items, based on Princess Diana's clothing combinations [8]

As inspiration for creation was her white midi-length dress-coat,dress-coat and the designer is Catherine Walker. Considering that studies most of Diana's clothing combinations, she preferred to wear so- called "dress coats". Through developing the idea, the conclusion are to make a two-piece set, more precisely a women's jacket and skirt, with our own ideas and design. The modeled upper part of the jacket is an abbreviated version of the classic jacket, and the modeled classic cut of the folded skirt in a mini folding skirt with one pocket cover and three buttons. The material was also selected by a detailed examination of Diana's clothes, in order to find a rich material in appearance and quality. It is a " tweed" fabric, and the lining is sewn from Viscose. Tweed (fabric) is a material consisting of woolen fibers of linen or diagonal weaving. The material is pleasant to the touch and soft. The chemical composition of wool is keratin (a protein of natural origin). Wool has long been a subject of British national pride and was highly prized. According to old technologies, the base of the fabric was made in one color, and the weft thread could be multicolored. At first, the fabric was rough and tough, but sometimes it served more than one generation of families. Today, other threads are added to the material, which significantly diversifies the color scale and improves performance. But connoisseurs still prefer handmade fabrics. Even today, canvas shape experts can determine in which part of England it is made, focusing on the interweaving of the thread, the color scheme, the default pattern. Tweed is suitable for many types of clothing. Fabrics are produced in many types, from heavy and dense to light and relatively thin. He used it mostly for tailoring outerwear and costumes. The classic style of this genre is considered strict English style for men, insulated jackets and coats are very popular. For many companies, a tweed suit or jacket has become part of corporate culture and mandatory dress code. Viscose is pleasantly soft and smooth.

4. Results

Viscose fabrics are mostly used for making business and elegant costumes, dresses, linings and the like. Thinner fabrics are used to make summer clothes, shirts, scarves, scarves, baggy pants and the like, Figure 6 [8].

Figure 6. Model based on Princess Diana's clothing combinations [8]

Figure 7 shows the construction, modeling and cutting parts of the female suit model.

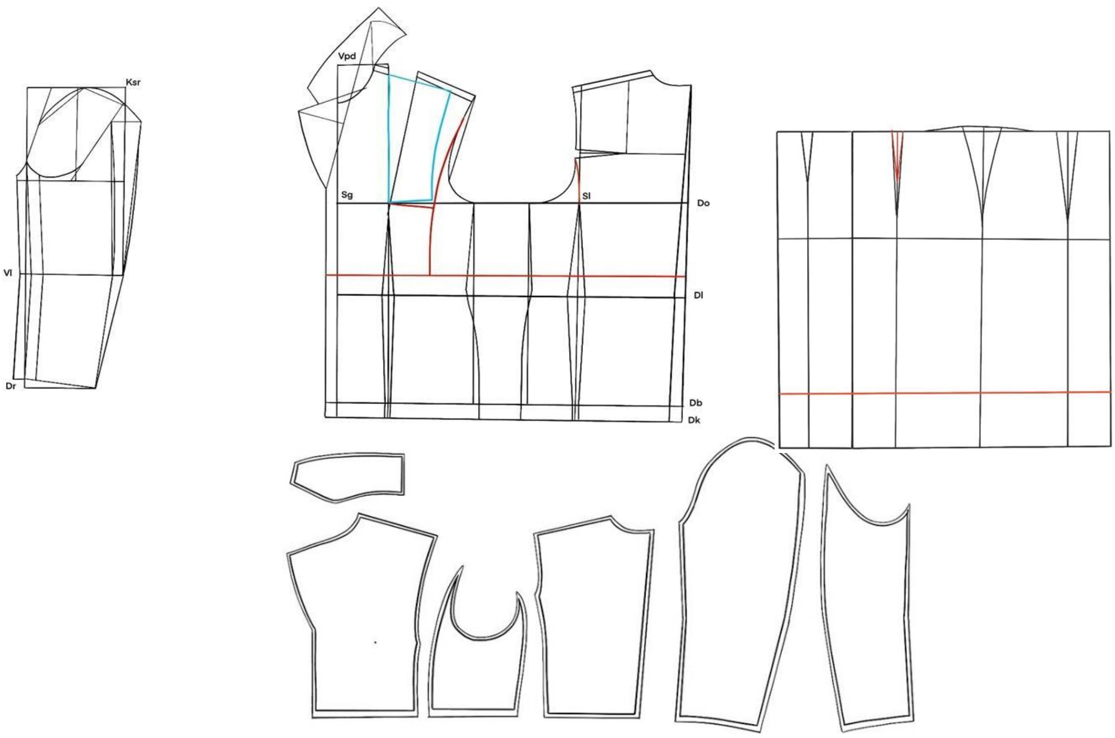


Figure 7. Clothing construction, modeling and cutting parts of the female suit model

The presented model is realized, which is shown in Figure 8.

Figure 8. Realized model

5. Conclusion

Despite his prestige and his wealth, Diana's whole life was like a constant struggle. Initially, Diana was an innocent schoolgirl who took care of her own parents and their divorce while dreaming of dreams of marrying a prince. After her wish came true, she realized that even the life of a princess was not perfect. Diana's personal experiences in the world have led her to a lot of self-discovery. Her struggle to overcome an eating disorder, her work with AIDS patients and her compassion for mine victims have proven to her and the rest of the world that she had special talents and a big heart. Her actions and travels are the focus of every charity. Although her relationship with photographers, journalists and editors was weak and often stressful, Diana even established connections with the media. In fact, if it weren't for so many photos and not being the center of attention not only because of generosity but also the ability to dress we might not have today most of the trends we have thanks to Diana. Princess Diana, through her way of dressing, always expressed her inner self, which was full of self-confidence, kindness and generosity. Diana became a confident woman with a strong presence and the ability to indulge in others who had far greater needs than her own. That is why this work is a mirror of Diana's fashion awareness, rich blue as the color of her eyes, complete with the insertion of her own design of cut parts gives a real look of a confident and successful woman like Diana herself was.

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Professional Paper

SYNERGY OF FASHION AND MURALS - A DISPLAY OF MERGING THE INCOMPATIBILE IN A CONTEMPORARY CLOTHING COLLECTION

Darija BREŠKI[1]; Irena ŠABARIĆ[2]; Franka KARIN[3] ; Daniel DOMOVIĆ[4]

[1] University of Zagreb Faculty of Textile Technology, Zagreb, Croatia, darijabreski@gmail.com
[2] University of Zagreb Faculty of Textile Technology, Zagreb, Croatia, irena.sabaric@ttf.unizg.hr
[3] University of Zagreb Faculty of Textile Technology, Zagreb, Croatia, franka.karin@ttf.unizg.hr
[4] University of Zagreb Faculty of Textile Technology, Zagreb, Croatia, daniel.domovic@ttf.unizg.hr
* Corresponding author: franka.karin@ttf.unizg.hr

Abstract: *Fashion, technology and art have always been closely linked. If we take into account that most clothes, in addition to aesthetics, must also meet functionality in everyday life, it is quite clear that production must be linked to the latest technologies and scientific research in order for the finished product to be representative. Many designers do not think in a conventional way, some of them want to send a strong message to society through fashion. In that case, the inspiration for fashion experiments is often unpredictable and inexhaustible. Designers often use the advantages of modern technologies in their work, which are advancing day by day, thus facilitating the realization of creative ideas in order to better present their vision. By using various computer programs for drawing and pattern making, they only make the process of making a collection easier and faster. The paper briefly describes the work of Alexander McQueen who created fashion ahead of his time and successfully manipulated design and technology in his work, with an emphasis on one collection. Along with it, the work of the versatile artist James Goldcrown is described, who with his murals put Street art in the rank of an artistic direction. In the experimental part of the paper, individual segments of the work of these two, seemingly incompatible designers were selected for inspiration, with the aim of creating a new hybrid collection of clothes based on the work of both artists, but without copying their work. The results show a women's clothing collection based on the work of fashion designer Alexander McQueen and fashion photographer James Goldcrown, who have strengthened the world of fashion with their distinctive work. The collection is shown by computer-generated drawings. One model of the dress was selected and developed and shown in the photos. The results of the work show how to present a collection inspired by seemingly incompatible designers without a literal interpretation, copying the work of the artist, but at the same time using their recognizable elements respecting the work of both artists.*
Keywords: *Alexander McQueen, James Goldcrown, fashion, graffiti, murals, technology*

1. Introduction

New technologies are constantly advancing and bring innovative and good solutions in the research process, but also make it easier for the designer to create his clothing collection. Who, for example, uses various software in the production of clothing, mainly for modelling patterns, making patterns, for printing and sewing garments, for detecting errors in weaving. Graphic programs such as Adobe Photoshop, Adobe Illustrator and Coral draw are used to create fashion illustrations and designs [1]. Design thinking is a process that begins with inspiration for the upcoming season and is often in line with current fashion trends and with competition research. It is necessary to determine the theme of the collection, the number of models in the collection, the types of materials to be used and the target group for which the collection is intended. Computer technologies such as sketch and pattern drawing programs, prepress and similar, have significantly improved and accelerated clothing design process and are increasingly applied in all fields of textile and fashion industry. Particularly talented designers express themselves in their own way without respecting conventional approaches, and often shock the audience. An example of such a designer was Alexander McQueen. In this paper one of his most significant collections "No.13" from 1999., which inspired the Arts and crafts movement and combines technology and fashion will be presented [2]. This collection is the main inspiration for the collection shown in the results of the work. The elements of asymmetry, contrast, drama and volume from the mentioned collection have been completely refined and as such used for further elaboration of the collection. The work of James Goldcrowne whose murals are being adorn on the streets of New York and Los Angeles were also used as inspiration in the making of the collection. His heart motives and color palette served as a starting point for the elaboration of the textile pattern design used on the fabric in this paper.

2. Alexander McQueen's No.13 collection as an example of design in line with Alexander technology

Alexander Mcqueen was one of the best fashion designers of the late 20th and early 21st century. He has always attracted attention with dramatic performances and thus secured his place in the history of fashion industry. He studied and was a great lover of fashion literature. At the age of sixteen, he began learning about the art of tailoring and making clothes in Anderson & Sheppard workshops. At the age of twenty, he got his first job in Milan, where he had worked for the famous fashion designer Romeo Gigglio. In 1992. he completed his studies at the prestigious Central Saint Martins at the University in London. Thanks to the development and progress of technology, fashion shows had been turning into performances and were focused on extending the limits of the fashion world [3]. The No.13 spring / summer collection is one of the most famous fashion shows in the world for which Alexander McQueen found inspiration in the Arts and crafts movement. In the collection, he presented 75 models in which achromatic colors and futuristic types of materials predominated. With the collection he presented his vision of the future. In avant-garde models, asymmetrical forms that emphasize the female body predominated [4]. The fashion show had a unique ending and was particularly remembered by the final exhibited model, a white dress that had a, hybrid A and X silhouette. The strapless dress was fastened in the chest area with a wide leather strap in beige. It was worn by former ballerina Shalom Harlow, who took a place in the middle of the stage between two large robotic arms that painted the dress by spraying paint, leaving traces of black and yellow on the dress, as the model spun dramatically in a circle. With this performance, McQueen left a big impact in the fashion world and announced the usage of technology in synergy with design, thus setting high standards in the future of fashion. He combined art, fashion and technology in an unprecedented way and predicted that the future of designer lies in combining technological advances and their own creativity. His celebrated dress was the result of a combination of modern technology and human hands which complemented each other. Purified elements and forms predicted the future of fashion and the impact of technology [5].

Figure 1: Collection No.13, dress painting

3. The art of graffiti and murals

Graffiti art or Street art is an independent art direction that is accepted either as art that conveys a strong message or as vandalism, with both interpretations being equally represented in society. Graffiti art reflects social problems that prevail in society and expresses attitudes, creativity, emotion and worldview [6]. Many media outlets impose an "ideal world", change trends and enter our subconscious, while on the other hand they deny us the exchange of information and encroach on copyright. It is graffiti through art that creates resistance to such an approach to the media and changes the way we look at everyday life. The artistic direction that belongs to Street art are murals. The main difference between murals and graffiti is technique and intent. Murals are made purposefully in collaboration with a sponsor, specific brands or the local community and are considered works of art. The goal of mural images is to attract and satisfy the masses, while graffiti appears mostly in textual form with the aim of expressing the attitude of an individual who opposes the masses. Today, the trend of making murals is growing, as they are accepted in society. They attract attention through social networks and become tourist attractions, and leave a dynamic and energetic impression on observers [7].

3.1. James Goldcrown

James Goldcrown is a British artist and fashion photographer who has always been fascinated by the art world, which is why he started working in photography and achieved a world-famous career as a fashion photographer. Apart from the world of fashion, he has also achieved great success in the field of humanitarian work and is one of the most famous mural painters. He gained popularity for his unique murals "Bleeding Hearts" and "Lovewall" which adorn the walls of the streets of New York, Los Angeles and Japan. His murals are recognizable by heart motifs in various intense colors such as red, pink, green, blue, yellow, purple and black. His murals emerge from his subconscious and as a reaction to what is happening around him, and he successfully combines fashion photography and Street art. Due to the frequent use of black contour lines in his work, the influence of pop art culture is visible. Intense colors, freedom of movement and spontaneity in the making of the drawing result in a strong energy emanating from his murals. James Goldcrown's latest collaboration was with the American company Skechers. He enriched the line of sneakers with his design and colorful heart motifs [8].

Figure 2: James Goldcrown, “Love Murals” around New York, 2015., spray paint, NoMo SoHo - New York City,

Figure 3: James Goldcrown, “Love Murals” around NewYork, 2015., spray paint, Cycle House - Studio Califonia

4. Experimental part

The clothing collection is inspired by the work of two seemingly incompatible artists, Alexander McQueen and James Goldcrown. Both artists have successfully balanced between art and fashion. To avoid copying the collection and literally conveying the artist’s work, some elements that characterize certain collections of Alexander McQueen’s were used such as: asymmetry, contrast, volume, oversize, and luxury with a theatrical note. Elements of stylized hearts and characteristic colors from murals were used from the work of James Goldcrown, which were the inspiration for the print on the fabric from which the collection is made. All elements have been made to successfully merge into a new hybrid collection without copying the work of both artists. During the making of the sketches and the elaboration of the idea, 10 models that make up the collection and a pattern for printing on fabric were selected [9].

4.1. Designing a collection of clothes inspired by the works of Alexander McQueen and James Goldcrown

After making the sketches, 10 project drawings of the model were made, and the collection was named "Return of Persophone". This is how the hybrid collection was obtained. The collection consists of maxi length slip dresses, thin straps, mini dresses, oversized coat and jacket. The collection is dominated by achromatic colors, black and white, while the prints on the fabric are inspired by the color palette of James Goldcrown [9]. For making the project drawings and illustrations; as shown in Figure 4, it is necessary to use vector graphics programs such as Adobe Illustrator or CorelDraw where it is applicable. By using graphic programs complex designs from simple lines and shapes were made and enriched with the use special effects to add patterns in order to make the impression as true as possible to the created model. The output file is in vector format since the drawn shapes are saved in memory using mathematical formulas instead of pixels as in raster graphics. The advantages of these computer programs include saving time and providing the possibility of easy and reliable design adjustments. For example, designers can easily make multiple models of the same design in different colors and quickly make adjustments to each of the models, and the quality of the drawings will not vary when enlarging or reducing a single sketch segment due to vector format [1].

Figure 4: Conceptual solutions for the collection "Return of Persephone"

5. Results

The results shown in Figure 5 represent the created textile design inspired by James Goldcrown murals. The selected pattern were made by computer in order to improve the quality of textile printing. The print on the selected fabric was made by the company "Caspar-design". The selected pattern is printed on 3 meters long polyester satin. Figures 6 and 7 show a realized model from the collection - slip dresses. The lower part of the dress and the ruffle are made of fabric with a print. They are cut at a 45-degree angle because the dress is designed to follow the body line, but without seams. The upper part of the dress is made of black satin and is cut in the direction of the base. The dress has an open back and has thin straps that are tied, also cut at an angle of 45 degrees [9].

Figure 5: Print on fabric **Figure 6:** Realized model 8

Figure 7: Dress from the “Return of Persophone” collection

6. Conclusion

Nowadays, with technologies that are rapidly evolving, fashion collections can be seen in every corner of the world in the moment they are shown at a fashion show . Therefore it is hard not to notice numerous copies of clothes and fashion accessories of famous brands. Work of the world-famous artists Alexander McQueen and James Goldcrown has been selected as an inspiration for the creation of the fashion collection created and presented within the scope of this paper. At the first glance, their interests - fashion and murals may seem incompatible but their work in different areas, has served as foundation for the collection made and presented in this paper. In the experimental part of the paper, one can see how work of these artists has served as an inspiration, while their heritage and legacy have been interpreted in a new and different way. The results obtained in this paper serve as a proof on how it is possible to create a contemporary collection for which the inspiration is based on the work of globally known artists without copying or appropriating other people's ideas.

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Professional Paper

CREATIVE CONSIDERATION OF THE UPCYCLING METHOD IN FASHION DESIGN

Belma KAPIĆ[1] & Dejla RAMIĆ[2]

[1] Faculty of Technical Engineering, Bihać, Bosnia and Herzegovina; gutlic.belma@gmail.com
[2] Faculty of Technical Engineering, Bihać, Bosnia and Herzegovina; dejlaramic.tfb@gmail.com
* Corresponding author: gutlic.belma@gmail.com

Abstract: *Due to the alarming level of greenhouse gases in the environment, the rapid depletion of natural resources and the increasing level of industrial waste, each individual production activity has come under sustainable control. In recent years, with the improvement of environmental concepts, sustainable fashion has achieved better development in related industries. From spinning, weaving, dyeing, finishing to fashion design, clothing production, retail, use and disposal, effective actions can be taken to reduce the consumption of natural resources and reduce environmental pollution. This research is focused on the upcycling method. With this method, by reconstructing and redefining textile waste, this paper aims to promote the principles of sustainable fashion. The method is defined through the process of creating a new and functional garment, women's jacket, with the remaining textile waste materials from furniture upholstery production, procured from a local company, and unusable garments that might otherwise be dumped in landfills. The ecological, economic, and sociocultural advantages of applying the upcycling method in clothing design are listed, as well as the various disadvantages and obstacles of this process in different contextual situations.*
Keywords: *sustainable fashion; upcycling method; fashion design; fashion waste*

1. Introduction

The phenomenon of fast fashion has revolutionized the clothing industry in the last decade [1]. The change in the attitude of consumers towards the consumption of clothing, associated with cheap production has led to a culture of impulsive buying. Improved look, greater diversity and limited editions, and especially the availability, make this industry attractive to many consumers. Fashion itself is considered new and vibrant. Fashion designers combine different values into garments; one is freshness, the next is a novelty, and then trendiness. In the existing, linear system, garments are produced, consumed and then disposed of, often on landfills, causing environmental problems [2]. Sustainability has become recognized as an important issue, with increasing demand for environmentally sustainable products [3].

Sustainability has been emphasized by many different proponents since the Brundtland report in 1987 popularized the term "sustainable development" with its well-known definition of "meeting the needs of the present without compromising the ability of future generations to meet their own needs" [4]. Among the various advocates of sustainable development and in the discipline of fashion design, various research topics have emerged that often overlap. Among such diverse approaches, one way to create sustainable fashion is sustainable consumption by extending the life cycle of a garment or optimizing the life cycle of industrial waste by the upcycling method. This paper uses the upcycling method in relation to other existing methods, by modifying the materials used to create a product that is of equal or higher quality than the constituent elements [5]. This method, despite its simplicity, is challenged by the negative perception of manufacturers about the longer life cycle of products in terms of potential reductions in sales and profits; customers who are more concerned with style and image and less with costs or environmental issues; due to durability which for many consumers is not the main priority in the purchase decision. For example, the high cost of labor relative to resources in most industrialized countries makes waste optimization less cost-effective than the traditional process. On the other hand, upcycling emphasizes that a good, functional design does not have to include exclusively "virgin" material in a new product to meet the requirements and necessity of its function. The concept includes creative reuse, repair and refurbishment, as well as sustainable product design and personalization [6].

This qualitative work takes an approach that social phenomena, such as the emergence of sustainable fashion, arise from the social interaction of the groups and individuals involved, and are in a state of constant revision. The primary research conducted in the paper provided new information and provided an understanding of special considerations related to sustainable fashion. As part of the analysis of the upcycling method, research processes are documented by observing professional and own upcycling practices and examining the literature related to sustainable fashion design and production process.

2. Upcycling method as a solution for accumulated textile waste

The term upcycling is relatively new, originated, and can be traced back to an interview with Riner Pilz. Pilz, in the context of architecture and interior design, introduced upcycling as a better solution than recycling [7]. According to Pilz, the upcycling method involves giving used products a new meaning and is a process of creative transforming old and used products into something completely useful in a way that loses a significant part of existing characteristics while the item undergoes mechanical or chemical processing. On the other hand, the primary goal of the upcycling method is to reduce waste, re-creating the product life cycle during the product planning, consumption and production process [8].

Others similarly define upcycling as producing new products with greater values or qualities and more sustainable nature; the reshaping or conversion of waste, used materials, or products; reusing items in a new way without degrading the material while reducing unnecessary expenses. In other words, upcycling is basically a non-traditional method in which post-industrial or post-consumer waste is treated as source material. New patterns cut on such materials require more flexibility, as minor adjustments in construction are often required to create standard-size garments [9].

Research has shown that discarded materials still have significant potential usability embodied at the time they are discarded. The upcycling method seeks to optimize the processes of an otherwise inefficient industrial system and ensure the transition to future circular systems. One of the strong proponents of the circular economy, the Ellen MacArthur Foundation offers models and case studies aimed at accelerating the transition to the circular economy [10]. Case studies show that their focus is mainly on the upcycling method, re-examining who does what, when, where and how, and examining how (un)successful it is. The circular economy "is gaining increasing attention in Europe and the world as a potential way for our society to increase prosperity while reducing dependence on primary materials and energy" [11]. This corresponds to sustainability where upcycling improves the environmental impact and restores the natural ecosystem. In the principle of sustainable design, it is also necessary to consider the design to achieve the re-circulation of materials, while minimizing the process of maximum use of the original functions.

"Trashion" could be one of the successful examples for both amateurs and professionals, with the upcycling method being an opportunity for designers to take advantage of the many opportunities of textile waste produced to meet the constant demand for fashion clothing as technological development progresses towards sustainable production [12]. Consumer appetite for novelty has led to the current situation of overproduction and consumption resulting in the rapid rejection of clothing and large amounts of textile waste. There are currently a large number of independent designers in the world who successfully use textile waste as a largely underused source of supply to the fashion industry. The role of designers within large companies often does not involve further involvement in the production process but focuses on collecting and applying market data and trends to current styles. Also, in large companies, the designer is involved only in the research and development phase of the concept, where it is unlikely to influence the development of events outside these points. Limited participation makes it impossible for designers in their ability to consider, request, or implement sustainability criteria. In contrast, by applying the upcycling method, designers take on a highly centralized role in which they either directly supervise or actively perform all duties from procurement, design, and production, to promotion and retail. Designers are then the centerpiece of all operations; meet the criteria of a sustainable design strategy at every stage of the process [13-14].

The results of this study show that there are significant advantages of the upcycling method compared to traditional production and research processes. The advantages include the use of waste as source material, its diversion from local landfills, which reduces the negative impact on the environment. By using waste materials from local sources, labor, and skills, involving the public in activities related to sustainable consumption, the upcycling method can enable greater participation of crafts in the production of high-quality sustainable clothing than in mass production. Thus, this approach directly solves the problem of textile waste and offers opportunities to localize economic growth by presenting opportunities for the development of the fashion industry in the direction of setting international standards for sustainable practice. In addition to economic benefits, the fashion industry must understand the importance of effectively implementing environmental strategies as a critical factor for future competitiveness in the global marketplace. Designers can create and propose more imaginative, bolder fashion using sustainable materials as a way to gain a competitive advantage.

3. Implementation of the upcycling method in creating a woman jacket

The upcycling method embodies the strategy of "sustainable design to minimize waste" above all others. It is often assumed that the design idea begins with sketching. As in each of the examined studies from the literature, the process began with a short summary, which outlined the project task or problem. This was followed by market research and gathering and analyzing information to gain insights of textile waste problems in our area. The designs were created using traditional fashion design techniques, sketches, mood boards, and pattern making.

The first design to appear on paper contained suggestions of shapes and details. It was a time to think through drawing without limiting potential. During this process, areas of weakness in design became apparent and negotiations on design aspects followed to re-establish the power of ideas. This form of renegotiation has become a real shaping process.
Once the process of thinking through drawing resulted in “concrete” visualization, one stepped out of the interior space and sought expert advice so that technical elements as an integral part of the design could be considered. Targeted design interventions, innovating in the field of upcycling methods to create a woman’s jacket that will at the same time surpass the offer with more attractive design than already established sustainable design codes was a challenge that required considerable initial information.
At this design stage, the central issues of consistency, integrity, and internal coherence have been considered. Small changes have been made with reference to more detailed technical - aesthetic issues. After a series of drawings of the potential design as shown in Figure 1, the selected fashion drawing progressed to the second phase of development.

Figure 1: Fashion drawings as a possible solutions

Through the creative process, the designer must think about which materials are appropriate for the design and currently available. Accordingly, this project started by putting the design concept on paper at an earlier stage to think carefully about the type of consumer. The approach became more technical as the details were fine-tuned with regard to the cutting elements and construction required for the next phase. The result of this process was the technical drawing shown in Figure 2.

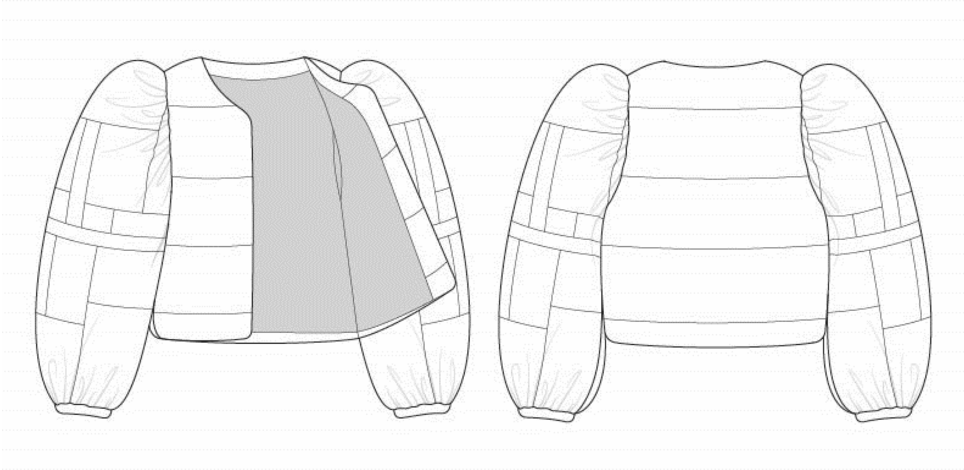

Figure 2: Technical drawing

The fashion designer's resources for technical research, the external elements needed to create the finished product were obtained and sampled before the design process continued. The search for textile materials is an aspect of the procurement phase that involved a visit to a local company to inspect the textile waste they had in stock. The key issues in procurement were consistency, quality, quantity, and sorting of favored textile waste. In this way, design decisions were made on how to best use the given quantities of such material waste in clothing design and production planning. After long moves through what would be appropriate and available, a couple of samples were selected that were considered to work well. Although the first choices were relatively conservative, a wider selection of fabric in the form of a pattern was also chosen, to be retained for later consideration.
There seems to be a great variety of waste transformation techniques. A technique like a patchwork has created smaller pieces of cut patterns to make the best use of available waste materials. This cutting technique also allowed for greater flexibility, meaning that material waste from production was fully utilized in line with strategies for sustainable design. It is known that the manipulation of waste materials, available techniques of application on the surfaces of materials, contributes to other branches of art and help the designer to achieve greater aesthetic value in the production process. Often, traditional hand techniques can be innovatively adopted to create new visual or textural effects and turn waste material into a modern product. The redefinition of fabric texture can be expressed by tearing, reshaping, superposition, and contrast between different materials. The whole work is concentrated on redefining the texture of the fabric that can be used in creative clothing design.

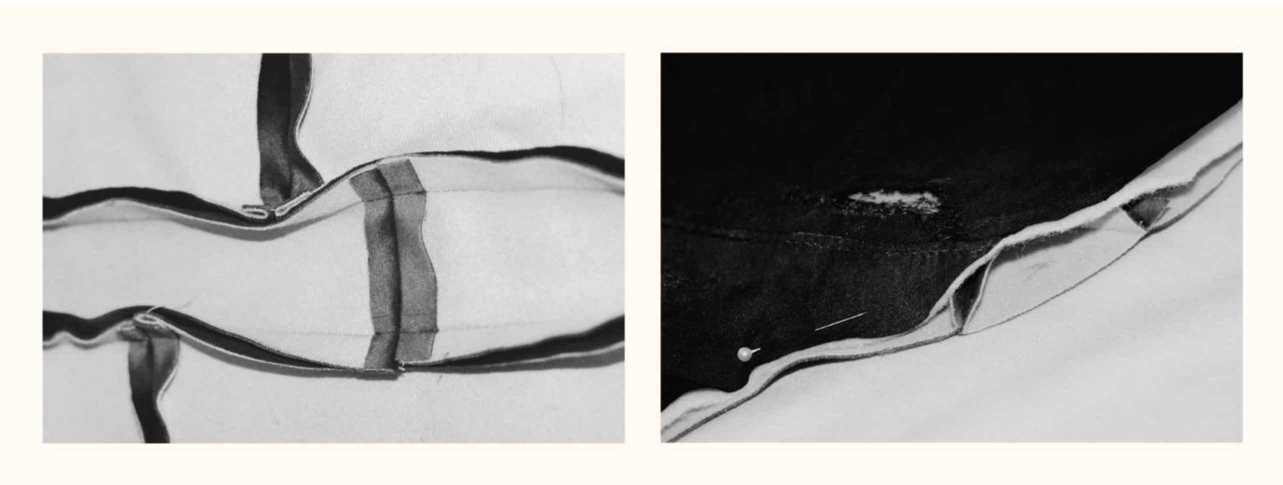

Figure 3: Process of joining the materials

This method of redefining materials by joining small pieces into one big material and stitching by the line of seam has created a new texture that greatly increased the value of textile waste as shown in Figure 3. In this case, the stitching effects reflected the dynamic flow of the material that reconstructed the three-dimensional space. Such application on the surface of the material has significantly improved the performance of the design. Due to difficulties in production, spatial materials are relatively rare in the clothing industry. Texture reconstruction in this paper focuses on the use of basic materials and other auxiliary materials to create a spatial form in which the design development phase is crucial and requires time to observe how clothing moves and adheres to the body. It also assesses how successful the design details are. The dialogic process that developed during the drawing continued as a method of assessing and testing movement through this phase of the work. In connection with this design, it is purified by moving back and forth between the concept and the outcome, testing ideas and purifying in incremental steps. The outcome, therefore, was not a fixed manifestation of a pre-solved problem. Each new outcome became the bearer of all the accumulated information and problem solving until it reached the stage where it was ready for its final form. The final form of the garment produced using the upcycling method, through fashion photographs, is shown in Figure 4.

Figure 4: Fashion photographs

4. Conclusion

The upcycling method offers fashion designers textile waste as a resource, thus encouraging their creativity through critical thinking in creating an innovative and inventive outcome and insists that designers consider "out of the box" and outside their comfort zone. In this case, the upcycling method involves creativity in integrating existing textile waste into new and "fresh" garments and the original function of its basic form has been completely neglected and abandoned. Creating a new product is one thing; creating a functional product is a whole new level. Recommendations for the application of the upcycling method should be a base of design schools and encourage students to influence the sustainability of garments when designing. In relation to this factor, there does not seem to be a particular rule in design methodology, as the design is always perceived as subjective in nature, dependent on design creativity and imagination. Consumer preferences can be included in the implementation of designers' guidance on the use of certain quantities of textile waste. Today, consumers value more eclecticism and the use of materials with the right note of creativity that still maintains the aesthetic values of each item of clothing. The upcycling method has the potential to combine two or more different aspects that will make the design very distinctive and rare. An upcycling garment can sometimes become more of a sculpture than a garment - showing how much the new product design goes beyond its actual function. The most important thing is to educate designers to save nature because they lead the trend and can create and raise awareness. As a resource is a key to creating consistent designs, a network of information for designers outlining the location, quantity, quality and composition of source materials would allow for a more efficient and less time-consuming sustainable fashion process. This would ensure the implementation of the upcycling method as a new approach to sustainable design in the fashion industry. Implications suggested by these findings include strategies for more efficient resource discovery in textile waste as key to adapting business models. In addition to setting targets for textile waste, the paper considers creative measures to provide motive for the application of the waste hierarchy, such as extended producer responsibility, and seems to introduce a change in the concept of increasingly treated waste as a resource with significant impact on the fashion industry. Despite the encouraging development of sustainable clothing, sustainable clothing is mostly thought of in an environmentally friendly context, but the evaluation and territory of sustainability are huge and covers areas such as fair production structure, economic vitality and quality growth, and rational consumption. There is no single simple answer to moving to a business model that will ensure the sustainability of clothing, but what this paper highlight is one of the key challenges - improving the longevity of garments and giving solutions for post-industrial textile waste problems. And we should produce according to sustainable methods, without harming the environment. Although the interventions proposed in the paper require testing, they provide opportunities and a plan for future research.

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Review

THE CURIOUS CASE OF WOMEN'S POCKETS

Belma KAPIĆ[1]; Kristina VINČAR[2]; Dejla RAMIĆ[3]

[1] Faculty of technical sciences, Bihać ,Bosnia and Herzegovina; gutlic.belma@gmail.com
[2] Faculty of technical sciences, Bihać ,Bosnia and Herzegovina; kristina.vincar@gmail.com
[3] Faculty of technical sciences, Bihać ,Bosnia and Herzegovina; dejla.ramic@unbi.ba
***** Corresponding author: e-mail gutlic.belma@gmail.com

Abstract: *The subject of this paper is researching the issue of inadequate pockets and, in some cases, the lack thereof in women's clothing articles. Going in depth of as to why pockets on women's garments are non-functional and more of an accessory, this paper touches upon subjects of history and technological aspects of the reasons behind this problem and ways of fixing it. While they have been a crucial part of people's everyday lives for centuries, pockets have changed a lot in both shapes and sizes. They have also had a great impact on society, shifting from being seen as just parts of clothes, most notably pants and jackets, to a symbol of equality and independence for women around the world.*
Keywords: *pockets, poaches, fast fashion*

1. Introduction

Pockets are, undeniably, one of the most important parts of any article of clothing. Throughout history, they have evolved in both shape and size, but their function remained the same - they are utilitarian portable compartments for items the wearer is able to carry on themselves. Pockets have been spotted in almost every part of the ancient world, all similarly designed and almost identically carried around. Usually, when one thinks of a pocket, they think of an envelope-like piece of textile that is fastened to a garment or some other baglike item. But in a historical sense, pockets didn't become such add-ons as they are now well until the 17th century when the first pockets getting started sewn into men's breaches. Since their invention during the ancient times, pockets were recorded on people of every class, all serving the same purpose as a very personal garment. What is believed to be one of the world's oldest known iteration of the pocket was found on the Alpine mummy known as Otzi, aka "the Iceman", who lived around 3300 BCE, in which he carried what are presumed to be his most essential items: a scraper, drill, flint flake, bone awl, and a dried tinder fungus. While simple in their design and function, pockets carry with them a long history in which they became a political symbol for independence, equality, and women's rights.

Modern women's pockets have often times been called insufficient and seen more as a fashion accessory rather than a functioning compartment. In 2018 Jan Diehm & Amber Thomas concluded a research based on 80 pockets from different brands, both male and female, on skinny and straight jeans all boasted with a 32 inch (81.28 cm) waistband. In their research called "Women's Pockets are Inferior", Diehm and Thomas go in-depth as to why and how women's pockets lack in function, stating that they are approximately 45% smaller and 6.5% narrower than average pockets found on men's jeans. Furthermore, they state that only 40% of women's front pockets found on jeans are able to completely fit one of the three leading smart phone brands, with 43% of them being able to carry wallets specifically designed to be put in the front pocket. While noting that skinny jeans by proxy have smaller pockets to more closely fit the body, their research showed that female skinny jean pockets were 3.5 inches (8.89 cm) (48%) shorter and 0.3 inches (6%) narrower than men's skinny jeans. For straight jeans, Diehm and Thomas have found that women's pockets were 3.4 inches (0.76 cm) (46%) shorter and 0.6 inches (1.52 cm) (10%) narrower. With back pockets being fairly similar in size, women's pockets were still up to 0.4 inches (1.02 cm) (7%) shorter and 0.1 inch (0.25 cm) (2%) narrower. Brands that were found to have the biggest pockets on women's jeans were: Abercrombie, Lee, and Ralph Lauren, while those with smallest were Guess, Gap, H&M, and J. Crew. [1]

2. Women's pockets throughout history

Before they were instilled into clothes like they are today, pockets were first made as entirely separate garments known as pouches that were tied around the wearer's waist, either concealed by the over tunic or a cloak, or simply left untouched on display. During the middle Ages, pouches were often made by any material available, be it wool, leather, or linen, they were made with either horizontal or, the more popular, vertical slits. Pouches were found in many different sizes and shapes, with almost all of them embroidered with scenes from the persons everyday life,

certain shapes and initials or flower motifs, while it wasn't rare for them to be entirely made in the patchwork technique because materials were handmade and every piece of unused textile that was leftover from sewing garments was later used in the making of the pocket.
Pockets were fairly unchanged during the most part of history, up until the 17th century was the first recorded sewn-in pockets were found in men's breeches. [2] Women, on the other hand, still carried pockets that were tied around the waist, but this time they were concealed underneath petticoats and reached through slits, which made it more secure from the possible pick pocketing or being cut off, something that was a prevalent problem regarding pockets that were tied on. These pockets were much bigger than an average modern day pocket: many were 40cm long and 30cm wide. [3] By the start of the 18th century, wide hips became a very fashionable look for Western women, something they achieved by boned strays known as panniers. Women of that time used the width the panniers created in their advantage, with some women having what is known as the pocket hoop, which were wide enough to carry live chickens in them, used both by aristocratic women and peasants.

Figure 1: An example of the 18th century tie-on pocket [3]

Women's pockets were met with an incoming change. In lieu of the French revolution that was happening during late 18th century, women started wearing incredibly small and almost fully decorative handbags known as reticules. Hardly able to fit a handkerchief and a couple of coins, they were a way to expose woman's belongings as to avoid possible concealment and sharing of revolutionary materials. The way reticules were presented to women of the Regency period was by making this small handbag into a status symbol, it meant that their husbands were rich and were carrying all the essentials needed with them, while also being an important part of the then-fashionable assembles. [4] The shape of their gowns was now slick and Grecian looking; making any and every bulge highly noticeable due to such a high waistline that gives a shapeless look to the dress. In-garment pockets were still achievable, but they were far less spacious than the ones of the rococo era. Peasant women and merchants still kept their classical poaches and pockets, because they couldn't afford the fashionable dresses of that era and thus continued to wear a layered and more convenient type of clothing. The other reason that ties closely to the French revolution as to why European women ditched the bigger pockets that were beneath their undergarments was a fairly simple one: due to the pure decadence of the aristocratic class of the 18th century, the wider dresses were a symbol for such power and, those who wielded it, would end up on the guillotine. [4]
While reticules were slowly evolving into the handbags of today, they weren't the definitive change for pockets, as they had their comeback in the Western world during the middle of the 19th century. With the fashionable dress shape now being achieved with crinolines and many layers of skirts, pockets found their way back into women's clothing. Introducing, the sewn-in pockets for women. With manuals such as the Work Women's Guide for how to sow one's own pocket into any garment, women used the new fashionable shape to their own advantage, sewing pockets in various different places of the skirt. [5] While poaches were still in use, because of the rapid urbanization and industrialization, they weren't as secure as the pockets that were found inside of clothes, as those that were tied on were more susceptible to theft. These pockets resembled the ones found in menswear, but because one had to take in mind the balance of the skirt, as much as the whole gown, women's pockets were found in a much smaller number and couldn't go above a certain size limit as it would create a noticeable bulk while also making the dress uncomfortable for the wearer. Even though most of the pockets were found in the side seams of skirts, it was a fairly common practice to hide pockets in places such as the centre back seams of the garment, mostly found in Edwardian

dresses, beneath drapes of a layered skirt or in the front. Chatelaines, on the other hand, were a way for women to carry and to be able to access essentials that were put on display, without having to search for them as they were attached to the waist and had multiple chains to hold small items on such as keys, whistles, coin purses, or for a working woman such as a nurse, thermometers and safety pins. [6] But much like the reticules were at the beginning of the 19th century, chatelaines were more of a status symbol than a way to compensate for pockets, because most of them were made by jewellers. So, pockets were still as important as ever and didn't have a solid alternative as an average woman's pocket was big enough to carry books, tools, and, in some cases, guns.

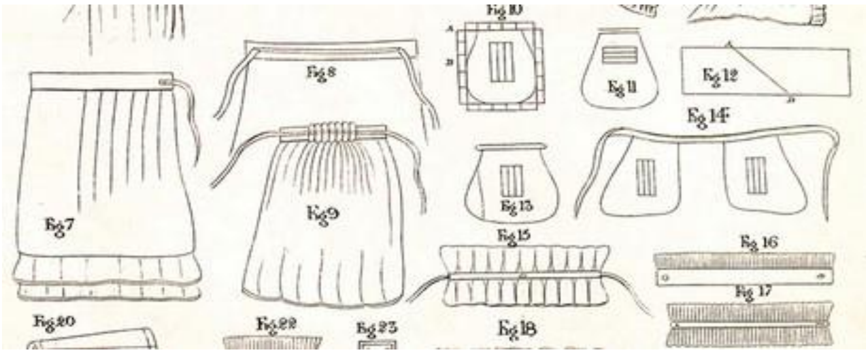

Figure2: Different types of tie-on and sewn-in pockets

By the turn of the 20th century, pockets for women became a political statement. Women were now fighting and protesting for their independence, making pockets as one of the symbols of inequality that they were facing every day. [4] With the founding of the feminist organization known as the Rational Dress Society, a public plea for more comfortable clothing for women without boned strays and tight fitting corsets, as well as for more pockets, was published around the late Victorian period as a way to reform the restrictive fashion trends for those of the fairer sex. Radical feminist organizations of the time all had one part of the clothing as an essential to achieve, if not equality, then something close to it, citing how men could fit up to 13 different pockets on their whole outfits, while women had their freedom taken away from them with the maximum of one pocket per garment that they had to sew in themselves. The 1910 "Suffragette Suit" was the new "feminist" dress that had around 7 to 8 pockets, all that were easily accessible, practical and visible in plain sight even to the wearer. [7]

Around WWI, dresses became shorter and slimmer, with more of them sporting up to 2 pockets each. As the fight for equal rights for women was still going strong, the rebellion was visible in even bigger pockets that were now included into their skirts. Coco Channel, the rising fashion designer of the Roaring Twenties, used the jersey material to design her pieces, taking inspiration from sportswear and WWI soldier uniforms; she made sure that all of her designs include spacious pockets for women, both in skirts and pants. [8]

With World War II deploying more men into war than ever before, women found themselves working jobs that were usually deemed as masculine. Working in factories, in fields and taking care of the jobs left behind those who were on the battlefield; overalls became the new popular woman's garment, being worn in and out of working places. They were the new liberating clothes for women, brimming with pockets that proved to be useful in every aspect of their lives. Such newfound independence didn't last for long, as soldiers returned back to their homes and felt an unease seeing women in roles that were once thought to be male. [9] Enter Christian Dior's 1950s "New Look" that swept both America and Europe off their feet. Glorious dresses with small waists and big skirts that had no places for pockets, leaving them as a luxury only men could have, was the reaction to the shift in gender roles that were creeping upon the Western man who wasn't ready for such a change. As Dior he reportedly said in 1954: "Men have pockets to keep things in, women for decoration." [10] Still, a lot of things have changed since the fifties, and so the modern woman wears pants of different shapes and sizes, almost all that include some type of pockets.

3. Smaller pockets for the modern woman

Taking in mind the whole history of fighting for bigger and more sufficient pockets, the 21st century woman finds herself having pockets that, as one study finds, are 45 per cent smaller and 6.5 per cent narrower than those found in menswear, especially jeans. [1] One argument as to why that is states that in the age of fast fashion, trend cycles that change what the fashionable shape and colour of garments is last much shorter by the year, making the production of bigger pockets on women's pants costlier and more time consuming. With trends lasting up to three months on average, not counting the surge of numbers in micro-trends that have appeared in the age of social media and influencers, female fashion doesn't only change by the year but during the year as well, deeming some garments or

shades as "démodé". Not only that, but the biggest fast fashion factories produce up to a staggering 100 billion garments yearly, with many of those clothing garments ending up as waste during the same year they were made. So to cut on time and resources, women's clothes, especially pants and jackets, come with small or fake pockets as fashion and trends in the female department change more rapidly in every aspect of clothing, opposed to men's where trends last longer and stay similar in design during the year. [11]
Other argument says that bigger pockets in women's clothing would hurt the handbag industry, as bags compensate for the lack of space average women pockets provide. As bags are viewed as essentials for women, but their prices put them in the luxury department, retail sales for handbags in US alone are estimated to be above 10 billion dollars yearly, while worldwide they produce no less than over 60 billion dollars of profit, a number that is constantly growing every year. To be able to sell them to an average working class woman, they are marketed as better and bigger than pockets that are already insufficient to hold all of the key items of the modern man, while also providing more space for the things almost every woman needs, be it make-up or gadgets, while also making it a fashion statement. [12]
The third most common argument as to why women's pockets are so small is that bigger pockets in jeans would ruin the female silhouette, creating weird folds around the waist. This is the result of skinny jeans and pants that are form hugging around the thigh area. Many fashion designers believe that clothes should be, above all, appealing to the eye, putting functionality in the second place. To achieve such a silhouette, pockets are either shut tight so the consumer would have a more appealing shape of the garment they are buying, a practice also seen in men's clothing such as blazers and suits also having the "no pocket" problem, or completely left out, either in the form of fake pockets or no pockets at all. Because of that, the construction of the modern women's skinny jeans lacks pockets altogether, creating the illusion of a slimmer figure and making the garment more appealing on the wearer. To conceal the pocket and the bulk created by the things inside of it would be nearly impossible without creating an awkward shape in such clothing pieces.

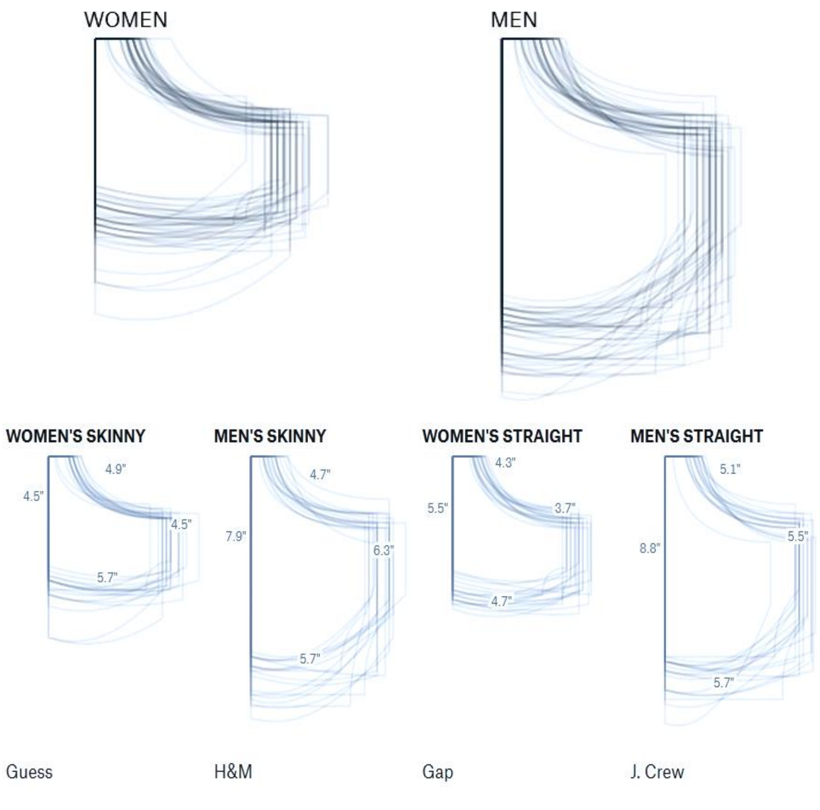

Figure3: Comparison taken in the Diehm and Thomas research between the average women's and men's pocket sizes and how that reflects on the fast fashion brands [1]

Still many of these and other claims can either be debunked or easily fixed by different practices and better constructions. For starters, the myth of the slimmer fit pants for women, while in some aspects is true, can't be seen as the end all be all reason as to why feminine garments lack sufficient and deeper pockets as the male ones do, because in the 21st century the skinny jeans trend wasn't exclusive to women and has seen improvements as to how create a more form fitting design for their male counterparts. [13] These designs have been seen put into practice for women's skinny jeans in some luxury and fast fashion brands, but are far from becoming the norm in women's clothes production. Other aspect of this problem comes from the fact that not all female clothes are meant to create the illusion of a skin-tight look. As trends change, so does the ideal body shape change with them, making it so that clothes such as loose or bulky cargo pants or shapeless dresses come in and out of fashion in a matter of less than a decade. Yet still, such garments lack pockets that are big enough to satisfy the modern consumer. On the other hand, the argument regarding the cost cuts in fast fashion factories to create such large amounts of clothes is part of a much larger problem. The inherent problem of fast fashion is both ethical and environmental, with the best way of fighting it being buying from slow sustainable fashion brands or second-hand, rather than buying what's trendy. [11] Still there is a dispute in regard as to why fast fashion brands produce female garments with such compartments because one of the leading problems of these factories is the pollution they produce by throwing out pieces of textile they deem as waste, which brings up the question of whether or not these textiles could be used to make bigger pockets, thus creating less non-biodegradable garbage. Were the average customer aware of the power their choice in shopping for garments holds, they would have been able to be more wary of what practices they choose to support and which ones they should as consumers boycott. With the rise of public awareness about certain problems that are caused by the fast fashion industries, as well as the workers' rights violations that are happening within these factories, there has been a rise in second-hand and thrift shopping, which is by many considered a very needed step in the right direction, while also liberating the costumer in a certain degree of following the trends and silhouettes imposed by such industries, thus getting to choose what fits them the best, and what pocket sizes they prefer.

3. 1. The return of the DIY culture

While the questions as to why exactly women have to spend more to have enough space for the things they need while on the go stay unanswered, 21st century sees a resurgence of people taking matters in their own hands rather than waiting for the fashion industry to change. With the COVID pandemic making many people home-bound, those who had more time in isolation started searching for ways to survive without the constant need for industrially made products, as shelves became emptier from hysteria shopping and non-essential stores and businesses were either shut down or put on a halt. Sewing and tailoring came to be one of the most popular skills that resurged, with some sewing machine stores reporting a spike in traction going up to 30 per cent. [14] Learning more how to work on their own garments and how to make masks for themselves, people got more environmentally educated about the problems of the "ready to wear" industry. By doing so, more people started fully sewing their garments, relying less on outside forces to produce the things they need. With such, skills like patchwork became the perfect way of achieving bigger pockets in feminine clothing, similar to how women did in the 19th century. Sewing in or simply enlarging the already existing pockets are the most common types of refinement of feminine wear, making them more useful to the wearer. To enlarge a pocket without jeopardizing the garment itself came to be a very simple job, seeing as one only needs a pair of scissors to cut the seams and a piece of any clothing to attach to it. Depop, one of the biggest second-hand online stores as of 2021, has under lockdown seen a surge in sales, with its community producing, up-cycling and selling more than ever. On Depop, there's a large proportion of garments in the almost 20 million items that are listed as customised, up-cycled or reconstructed, and as such have seen a 40 per cent increase in listings and 65 per cent uptick in sales for March in comparison for the same month during 2019, with traffic on the app up 74 per cent. [15] Environmentally charged individuals also see this as the zero waste alternative in the sense of reusing already existent textiles that would have been seen as waste. This is also a part of what some argue to be "quiet activism" [16], a resurgence of anti-capitalist practices in which one creates for themselves, against the norms. Knitting, up-cycling, re-shaping are just some of the few methods one can artistically express themselves through fashion, while also creating garments that suit specifically their tastes, such as pocket sizes and silhouettes. A trend that resurfaces every so often, especially after the rise of the punk subculture in the 70s, up until today, it prioritizes the craft of creating something new, and protesting against the unfriendly environments fast fashion circles create. DiY culture of the 21st century also focuses on breaking very gendered stereotypes against "amateur" sewing and garment-production, making it easier for people of all genders to make conscious decisions on what they want to wear, not burdened by the thought of what they can afford.

4. Conclusion

The historical dilemma of women's pockets has still not come to a conclusion. Individual ways of improving ones pocket take time and effort, which in this age of speed and technology is something not many people have, makes it harder for everyone to make pockets as functional as they were intended. Yet, changes are happening in the world. With smaller and sustainable businesses' getting more traction as a reaction against the fast fashion industries, many designers and tailors have found that using less gendered approach in making these pants and pockets is better as they generate more profit from the satisfied customers. By making all pockets in factories on the same mold, in a unisex type of way, less waste is generated from the throw-away materials and the time spent on constructing a special pocket for feminine clothes is noticeably reduced. Still, this is a practice not many expect from luxury and fast fashion brands, as their main goal is to produce as much profit as possible, a reason why non-functioning garments are still thriving in this consumerist environment. Simply put, the moment equal pocket sizes become a more profitable norm in the fashion world is the moment people start thinking more sustainable.

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Original Article

DEFORMATION OF ELASTIC KNITTED FABRICS UNDER CYCLIC LOADING

Tea JOVANOVIĆ; Željko PENAVA; Zlatko VRLJIČAK

Faculty of Textile Technology, University of Zagreb, Pr. b. Filipovića 28a, 10000 Zagreb, Croatia
Corresponding author: teajovanovic81@gmail.com

Abstract: *The article describes the application of elastic knitted fabrics in socks, sports and recreational clothes, swimsuits and various flat ribbons used in clothes production. A force/elongation diagram is described for uniaxial tensile load of the knitted fabric. Conditions prescribed by the standard for conducting cyclic loadings are provided. Measurements of cyclic loadings were conducted on four different types of knitted fabric: knitted fabrics of different density used in the production of fine women's stockings, knitted fabrics intended for recreational and sports clothes, swimsuits and elastic ribbons. Force drop and residual deformation were analysed in all the measurements. A special emphasis was placed on the analysis of the hysteresis curve index, which ranged from 0.000 to 0.920 in the conducted measurements. The index was the lowest in the highly porous knitted fabric of a fine women's stocking lying on the leg under the crotch: usually 0.000 to 0.100. The hysteresis index in knitted fabrics designed for recreational clothes was 0.3 to 0.7, and in elastic ribbons used in clothes production 0.8 to 0.95. Further research is needed on the elasticity area of highly stretchable knitted fabrics.*

Keywords: *elastic knitted fabrics, recreational and sports clothes, hysteresis curve, hysteresis index*

1. Introduction

Compared to woven fabrics, knitted fabrics are much more stretchable textile materials. In classic woven fabrics, elongation in the weft direction is 5 to 20 %, while in knitted fabrics it is considerably larger and varies significantly. It is usually much greater in the course than wale direction. For example, the elongation at break of plain single jersey cotton knitted fabrics used in the production of summer shirts or vests is 150 to 250 % in the course direction, and 50 to 150 % in the wale direction. In principle, such knitted fabrics can elongate twice as much in the course direction (transversely) than in the wale direction (longitudinally). Similar plain double jersey knitted fabrics are predominantly used to make male winter underwear and have the elongation at break in the course direction of up to 400 %, and in the wale direction around 100 %, meaning they are approximately four times more stretchable in the course than in the wale direction. Chain knitted fabrics made on warp knitting machines from elastane yarns and intended for swimsuits have approximately the same elongation in the course direction (transversely) and in the wale direction (longitudinally). Each weave in the warp provides a different structure and therefore knitted fabric elongation properties. For example, if the goal is to decrease knitted fabric elongation in the course direction, the kind of yarn knitted into the knitted fabric structure will be the kind which does not form loops but "falsely" lays the weft in a different rapport. In certain combinations, by knitting in such a yarn or more yarns, tensile properties of the knitted fabric (fleecy) are closer to woven fabric properties and are very hard to differentiate in certain structures. All the knitted fabrics described are intended for classic garments and in most cases casually lie on the human body [1].

In the modern world, there is an increasing demand for elastic knitted fabrics which comfortably lie on the body and often press on it with a certain force. Such knitted fabrics are usually made with two yarns. The first one is ground, usually of natural fibres, and the other is elastane. In the production of recreational clothes, polyamide (PA) or polyester (PES) multifilament yarns are used instead of cotton. Single cotton yarns have the elongation at break 3 to 8 %, PA or PES 20 to 40 %, and elastane 400 to 900 %. Adequate elongation amounts are obtained by different yarn combinations, structures and density. These are coordinated with the garment construction, which results in the desired pressure on the body, Fig. 1. In recreational clothes which lie on the body directly, garment pressures are often 5 to 15 hPa (5 to 15 g/cm^2), [2]. Such elastic knitted fabrics form a basis in the production of classic and compression socks. Fine women's stockings are usually made from PA multifilament yarns in the counts 20 to 80 dtex and exert compression on the leg 2 to 8 hPa (1 to 6 mmHg). This is a small compression and is therefore not stated on the manufacturing label. However, if in addition to the PA multifilament yarn, an elastane yarn in the count of 33 or 44 dtex is inserted into every second or third course, the obtained knitted fabric structure is such that it presses on the leg more, usually from 8 to 15 hPa (8 to 15 g/cm^2; 6 to 13 mmHg), [3]. Young women happily wear these stockings on special occasions. If, in addition to the PA multifilament yarn, an elastane yarn in the count of, for example, 33 to 60 dtex is knitted into each course, the obtained structure is such that the knitted fabric presses on the leg even more, and the compression is 13 to 24 hPa (13 to 24 g/mm^2; 10 to 18 mmHg). Such stockings are classified as preventive compression stockings and are gladly worn by pregnant women. Medical compression stockings (therapeutic compression stockings) exert the compression on the leg from 24 to 65 hPa (24 to 65 g/cm^2, 18 to 49 mmHg) and are used according to doctor recommendation and supervision [4,5].

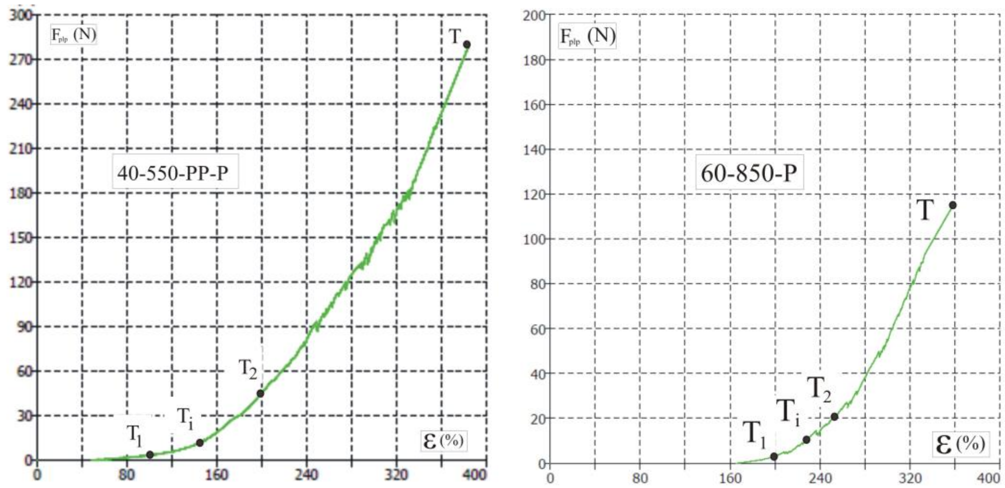
a. b. c. d. e. f.

Figure 1: Different forms of compression preventive products: a) women's preventive pantyhose, b) maternity preventive pantyhose, c) compression knee-highs, d) long compression underwear, e) sports long underwear, f) compression recreational set

All the described elastic knitted fabrics stretch severalfold during use. A very frequent complaint about these materials is that the pressure on the body can drop by 30 % after around ten washes [6]. For example, a medical compression stocking which exerts compression on the leg around 60 hPa (Class III, high compression, 60 g/cm2; 45 mmHg), drops to 42 hPa, or 42 g/cm2 after around 10 washes. The stocking is therefore classified as a lower class, which means it is not possible to achieve the desired therapy in the venous system. This is caused by three factors: yarn structure, knitted fabric structure and relation between knitted fabric elongation and compression [7,8].

2. Uniaxial tensile elongation of knitted fabric

In the analysis of knitted fabric tensile properties, 50 mm wide linear or strip samples were cut out from the knitted fabric and stretched to break on a tensile tester thus recording the force/elongation. These measurements are usually called static and are acceptable in the production of textile materials. The force/elongation diagram can basically be divided into three parts, Fig. 2, [9]. The first part of the diagram spanning from 0 to T_1 is considered linear and is assumed to represent the elastic area. The second part of the diagram is from point T_1 to point T_2 and represents the elastic-plastic knitted fabric area, where point T_i is also located. Some knitted fabric structures are elastic up to this part as well. The third area starts at the beginning of the second linear part of the diagram (T_2), which is assumed to be the beginning of knitted fabric plastic deformation or permanent deformation.



a. *b.*

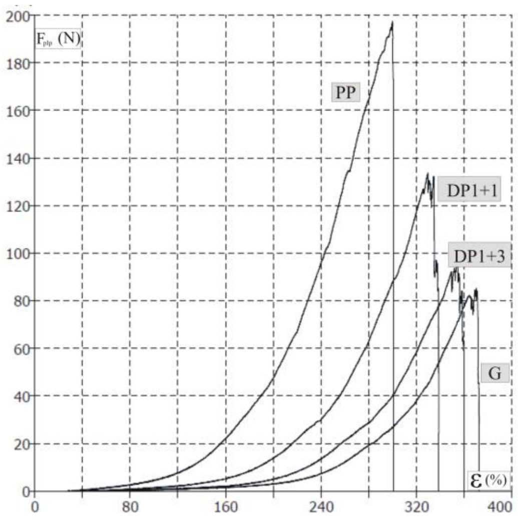
Figure 2: Force/elongation diagrams of two different structures of elastic knitted fabrics: a) more massive, condensed knitted fabric of a smaller elasticity, b) lighter, more porous knitted fabric of a larger elasticity

These three points are often used as a basis during repeated knitted fabric loading in research of its elongation properties during use or on a tensile tester in cyclic measurements. In certain knitted fabric structures, these three points represent different knitted fabric deformations. The results of cyclic measurements at the given points point to a more precise analysis of used yarns and its compatibility with the applied structure in order to be able to explain the drop in compression at a particular knitted fabric elongation.

Sizes of knitted fabric elongation, and therefore also elasticity can be obtained in different ways. The method used depends on the purpose of the sample. In the production of fine women's stockings or pantyhose, the most suitable method of changing the amount of knitted fabric elongation is changing the sinking depth. The stocking leg is made with one yarn, i.e., one yarn is knitted into a single course. The part of the knitted fabric which lies above the ankle should be the narrowest, and the part lying on the leg under the crotch should be the widest. Leg circumference above the ankle is usually 20 to 25 cm, around the calf 30 to 40 cm, and under the crotch 45 to 60 cm. In comfortable use, such a fine stocking stretches 30 to even 300 % so the width of the tubular knitted fabric lying above the ankle is around 8 cm x 2, the one lying on the calf 9 cm x 2 and under the crotch 11 cm x 2. Larger tubular knitted fabric width and elongation are obtained by applying a larger sinking depth. The mentioned knitted fabric widths stretch differently depending on the leg part [10,11].

Another method used to produce a knitted fabric of different elongations is to use plated and partially plated structure in different combinations [1,12,13]. In the production of a plated knitted fabric, one course is formed by two yarns. If the goal is to obtain a fuller and therefore more massive knitted fabric structure, the knitting is done with two equal yarns. However, if the goal is to get a knitted fabric with different elongation properties, two yarns of significantly different elongation properties are used, e.g., the ground yarn is cotton or polyamide, and the other or plated yarn is elastane. Further combinations are to knit different structures or counts of ground and elastane yarns. Combining plated and partially plated structures and different yarns and sinking depths results in a wide palette of multi-purpose elastic knitted fabric structures. Instead of using a plated or in addition to a plated structure, additional combinations involve a tuck structure with the mentioned or different yarn combinations. A particular combination will depend on product function and machine construction.

Fig. 3 shows tensile properties of four structures of double jersey knitted fabric intended for men classic and winter underwear. The results were obtained by stretching the knitted fabric sample to break. Sample strips, which were 50 mm wide and 200 mm long, were cut out from the knitted fabric, while the spacing between the tensile tester clamps was 100 mm. The yarn used for knitting was ground cotton single yarn in the count 20 tex, and the plated was PA multifilament in the count 44 dtex. In such knitted fabrics, transverse elongation, i.e., in the course direction is more significant than longitudinal elongation, i.e., in the wale direction. In plain knitted fabric (G) the elongation at break in the course direction or transversally is around 380 % and the knitted fabric remains elastic up to 200 % elongation. Such large elongations at break classify the structure as a hyper-stretchable and hyperelastic material.



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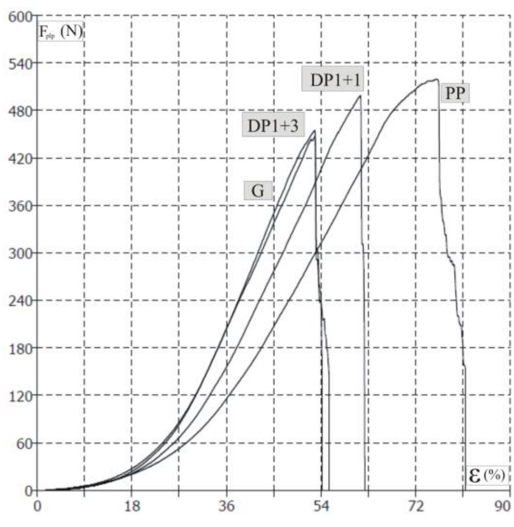


b.

Figure 3: Force/elongation diagrams of four different structures of elastic double jersey knitted fabrics made by plating: a) transverse elongation, b) longitudinal elongation. Structures: G – plain, DP1+1 – partially plated 1+1, DP1+3 – partially plated 1+3, PP - (completely) plated

By knitting a plated thread into every fourth course (DP1+3), elongation at break and elasticity decrease. In a completely plated knitted fabric (PP), both yarns are knitted into each course and the elongation at break drops to around 300 %, and elasticity even more, i.e., 80 %. Elongation at break in the wale direction is significantly smaller, ranging from 55 to 80 %, and is not so relevant for use properties of such a knitted fabric. This example demonstrates how different combinations of plating can impact knitted fabric elongation properties and elasticity. The given samples have a commercial purpose and are very often used to produce men clothes for colder climates, recreational clothes and hiking underwear [14].

3. Cyclic loadings

In order to observe knitted fabric behaviour during use it is purposeful to load it cyclically. The standards recommend conducting five continual measurements per elongation area and then identifying the difference between one-time static and cyclic results [15,16]. It is not necessary to conduct more than five cyclic measurements or five loops, because in most materials, the results after only the third elongation or third loop differ less than 5 %, and in the fifth loop less than 1 %. The three previously mentioned points obtained in the diagram of knitted fabric force/elongation at break are of interest for different textile materials, especially elastic knitted fabrics. If a knitted fabric is five times cyclically loaded for elongation, e.g., to point T_1 or the assumed end of plastic deformation, what can be noticed is a drop in force and residual deformation of knitted fabric. Similar changes can be observed if these measurements are repeated for the curve vertex point (point T_i). Point T_2 represents the beginning of permanent deformation so the cyclic measurements can also be conducted and compared to the previous ones at this point. Further elongations to T_2 are unnecessary for knitted fabrics used to make classic garments. However, knitted fabrics which are used for special clothes or have technical purposes, are tested for cyclic loadings all until break. After five cyclic loadings, certain knitted fabric structures are expected to exhibit different force drops and residual deformation of knitted fabric. These differences depend on a series of parameters, primarily measurement conditions, i.e., speed of elongation and relaxation of a knitted fabric sample. The results obtained in cyclic measurements help to estimate knitted fabric elongation properties during use, especially in elastic knitted fabrics which must exert a certain compression on the human body.

4. Experimental

The experimental section deals with research of deformations in four different knitted fabric types after cyclic loadings. The first group contains finished knitted fabrics of fine women's nylon stockings of different structures. The second group contains knitted fabrics intended for elastic recreational and sports clothes. The third group of elastic samples consists of knitted fabrics intended for swimsuits, while the fourth group contains different ribbons used in the production of underwear and clothes.

4.1. Deformations of knitted fabric of fine women's stockings after cyclic loading

For this research, tubular 100 cm long samples of a uniform knitted fabric structure were knitted. The yarn used for knitting was PA multifilament yarn in the count 33 dtex f 10 s, which is very often used to make fine women's stockings in the European market. Four groups of samples with different knitted fabric density were knitted. The first sample group was knitted at the smallest sinking depth of 400 control units. The second sample group was knitted at a larger sinking depth of 550 units, the third group at a yet larger sinking depth of 700 and the fourth group at the sinking depth of 850 units. The knitted fabric made at a smaller sinking depth is fuller, more massive and narrower with a smaller elongation, while the knitted fabric made at a larger sinking depth is more porous, lighter and wider, with a significantly larger amount of elongation. Narrower, less stretchable tubular knitted fabrics are suitable for the leg part of a smaller circumference, above the ankle, while wider and more stretchable knitted fabrics are suitable for the leg under the crotch.

In all the measurements of knitted fabric tensile properties, 50 mm wide and 180 to 230 mm long samples were cut out from tubular samples and the spacing between clams was 100 mm. Base samples were stretched to break ($\mathcal{E}_t$, %) on the tensile tester. On their diagrams, points T_1, T_i and T_2 and corresponding elongations $\mathcal{E}_e$, $\mathcal{E}_i$ and $\mathcal{E}_p$, were determined, Tab.1. The cyclic loading method was used to determine knitted fabric deformation during use. Certain samples were cyclically stretched up to the three given points. The speed of elongation and recovery was 350 mm/min. After five continual stretches up to a determined point, the force drop (ΔF) between elongation of the first and fifth loop, residual deformation of knitted fabric ($\Delta\mathcal{E}_x$) and hysteresis index (H_x) were determined.

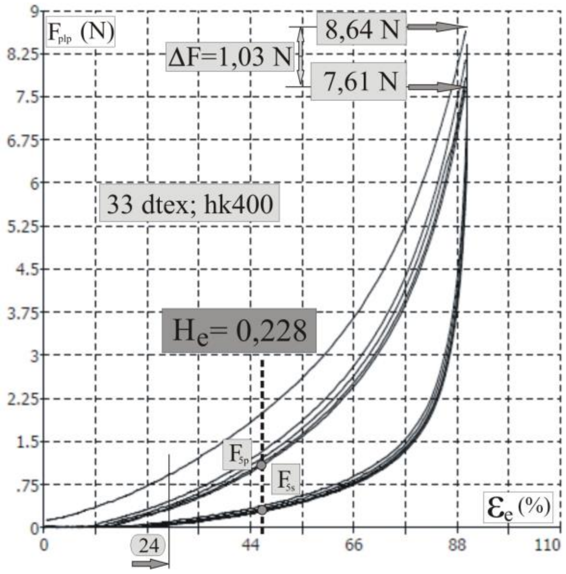
In the first knitted fabric, the densest knitted fabric structure which stretched the least to break (191 %) was obtained. The largest force in stretching to the end of the elastic area and forming of the first loop was 8.64 N, and in the fifth loop 7.61 N, i.e., there was a 1.03 N drop in force, Fig. 4a. After five elongation cycles, residual deformation of knitted fabric was 24 %, i.e., the knitted fabric length was 124 mm. Therefore, residual deformation of knitted fabric ($\Delta\mathcal{E}e$, %) occurring after cyclic loadings indicates that the knitted fabric is not elastic to the end of the linear part of the diagram, i.e., to T_1. In order to precisely determine the elasticity area in static and dynamic measurements, or their correlation, measurement methods must be coordinated or research must be deeper. In a very porous knitted fabric sample made at the sinking depth 850, the force drop was 0.32 N, and residual deformation of knitted fabric even 70 %, i.e., knitted fabric length was 170 mm. As the elongation length at cyclic loadings increases, the residual deformation also increases, especially in more porous knitted fabrics, i.e., knitted fabrics which lie on the upper leg.

Table 1: Tensile properties of knitted fabric of finished fine women's stockings under cyclic loadings

h_k	ε_e, %	ΔF, N	$\Delta\varepsilon_e$, %	H_e	ε_i, %	ΔF, N	$\Delta\varepsilon_i$, %	H_i	ε_p, %	ΔF, N	$\Delta\varepsilon_p$, %	H_p	ε_t, %
400	90	1.03	24	0.228	110	6.6	35	0.126	130	10.6	61	0.095	191
550	120	0.21	25	0.309	160	0.7	46	0.338	190	3	90	0.096	254
700	180	0.13	37	0.351	230	1.19	88	0.190	280	2.57	145	0.093	362
850	230	0.32	70	0.222	280	0.96	210	0.000	330	2.24	215	0.000	448

Where: h_k – sinking depth, ε_e – knitted fabric elongation to point T_1, %; ΔF – force drop after five cycles of loading and unloading, N; $\Delta\varepsilon_e$ – residual deformation of knitted fabric after five cycles of loading and unloading at point T_1, %; H_e – hysteresis index at point T_1; ε_i – knitted fabric elongation to point T_i, curve vertex, %; $\Delta\varepsilon_i$ – residual deformation of knitted fabric after five cycles of loading and unloading at T_i, %; H_i – hysteresis index at T_i; ε_p – knitted fabric elongation to point T_2, %; $\Delta\varepsilon_p$ – residual deformation of knitted fabric after five cycles of loading and unloading to point T_2, %; H_p – hysteresis index at point T_2; ε_t – knitted fabric elongation at the moment of break (at the largest elongation force), %;

The hysteresis index was analysed at the half of the set elongation. Figure 4b shows a sample made at the sinking depth 700 and point T_2, i.e., beginning of plastic deformation. Knitted fabric elongation to the beginning of plastic deformation was 280 %. At the elongation amount of 140 %, the hysteresis index was calculated by the relation of force measured in the fifth knitted fabric relaxation cycle after elongation (amount 0.05 N) and force at elongation (amount 0.54 N). The obtained hysteresis index was 0.093, i.e., the amount of force during knitted fabric relaxation made only 9.3 % of the amount of force during knitted fabric elongation (H_e = 0.05 N/0.54 N = 0.093). Knitted fabric structures obtained at certain sinking depths at certain points achieved different hysteresis indices, which ranged from 0.000 to 0.351.



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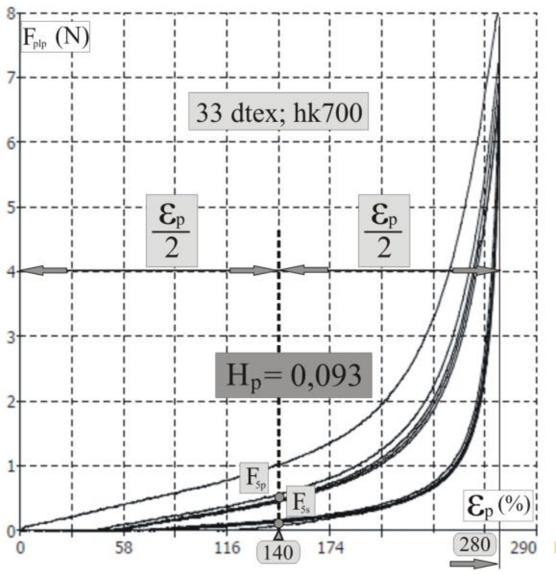

b.

Figure 4: Cyclic loading diagrams of a fuller and more porous structure of a plain knitted fabric in the production of fine women's nylon stockings knitted with PA multifilament yarns in the count 33 dtex f 10; a) more condensed knitted fabric, which stretches less and lies above the ankle, made at the sinking depth 400, b) more porous knitted fabric, which stretches more and lies on the upper leg part, made at the sinking depth 700

Plain knitted fabric structure in fine women's stockings is different in certain parts of the stocking leg. The densest knitted fabric lies on the leg above the ankle, a bit more porous on the lower part of the calf, more porous on the calf and the most porous on the upper leg part. Basically, along the stocking leg there are at least three, and sometimes even ten different knitted fabric structures. A particular structure in the shrunk knitted fabric should not be shorter than 50 mm. In such hyper-stretchable knitted fabric structures (usual elongation even up to 600 %) made from multifilament yarns, there is a great variation of results obtained after cyclic loadings, in both unfinished and finished knitted fabrics. The reason can be found in the amount of elongation, yarn structure and knitted fabric structure.

4.2. Deformations of elastic knitted fabric of recreational clothes after cyclic loading

Recreational and/or sports elastic knitted clothes include different forms of short and long pants and shirts. They are equally used by women and men, and a growing number of kids. Knitted fabric structures are adapted to certain sports. Such knitted fabrics are made from PA or PES multifilament and elastane yarns. Simpler knitted fabric structures are made in plated single jersey. The ground yarn is PA or PES in the count 70 to 220 dtex, and plated is elastane in the count 33 or 44 dtex. This research focused on the analysis of tensile properties of two elastic long pants, two shirts and one swimsuit. Research samples were cut out transversely (course direction) and longitudinally (wale direction). The sample width was 50 mm and length 250 mm. The spacing between the clams was 100 mm. As was the case with the samples of fine women's stockings, these samples were first stretched to break. Next, three characteristic points (T1, Ti and T2) with their corresponding elongations (Ɛe, Ɛi and Ɛp) were determined in the diagram and cyclic measurements were performed at them, Tab. 2. Yarn and knitted fabric properties are not given for the reasons of clarity.

The analysis dealt with two structures of unused elastic pants intended for recreational running (H1 and H2). The knitted fabric elongation at break in the course and wale direction was 142 to 217 %. The first, linear part of the force/elongation curve was assumed to be elastic. When the knitted fabric was stretched in the course direction or transversely, it was 40 and 60 %, and in the wale direction it was smaller: 20 and 30 %. After five cyclic loadings to the first linear part of the force/elongation diagram, the drop in force was very small, from 0.08 to 0.18 N, and residual deformation of knitted fabric was 1.3 to 5.8 %. Only in one sample was this amount larger than 5 %, meaning that its elasticity area during use was somewhat smaller than shown by T_1. The criterion that could be accepted in the three remaining samples is that the first linear part of the diagram represents the elastic area. It should be noted that the hysteresis curve index for this area (H_e) was significantly larger than in the fine women's stockings and amounted from 0.692 to 0.720. The second round of cyclic loadings was performed when the knitted fabric was stretched to the vertex point of the force/elongation curve (T_i). This point is located from 30 to 80 % from the beginning of elongation. After cyclic loadings in this area, the force drop was somewhat larger, 0.06 to 0.33 N, as was the residual deformation of knitted fabric: 2.2 to 6.5 %. The hysteresis curve index was slightly higher and ranged from 0.672 to 0.755. A slight force drop and small amount of residual deformation indicate that it is necessary to research the elasticity area for such knitted fabrics, because based on these results, it can be concluded that the elasticity area stretches outside the first linear part of the force/elongation curve. Knitted fabric elongation to the beginning of plastic deformation was 40 to 115 %. For an optimal and functional use of knitted fabric, a larger elongation is not recommended. A knitted fabric is usually stretched up to this area during dressing and undressing. After a stretching like this one, the force drop after cyclic measurements was also very small and ranged from 0.05 to 1.1 N. However, the increase in residual deformation was more significant and ranged from 3.3 to 11.2 %, being larger than 5 % in three of the samples. In this elongation area, the hysteresis index (H_p) covered an even bigger span and ranged from 0.433 to 0.773. It should be noted that the hysteresis index does not follow any rule of change in relation to length and direction of cyclic knitted fabric elongations, (Fig. 5a-Fig. 5f).

The analysis of elongation properties of shirts also included the analysis of two unused knitted fabric samples (M1 and M2). In both samples, the knitted fabric stretched more in the course than wale direction. After five cyclic loadings, at the end of the elastic area (ε_e), the force drop (ΔF) was also small and somewhat larger than in the pants, from 0.03 to 1.02 N. Residual deformation of knitted fabric after cyclic loading ($\Delta\varepsilon_e$) was also larger than in the pants, 2.5 to 7.9 %. The knitted fabric hysteresis index of the first shirt was 0.378 and 0.473 and was significantly smaller than in the second shirt, where it was 0.625 and 0.706. In the first shirt, there was a large difference in knitted fabric elongation to break in the course direction (213 %) and wales (90 %) while in the second shirt, this difference was much smaller (142 and 162 %). These are some of the reasons why the hysteresis indices in this area significantly differ. After five cyclic loadings at knitted fabric elongation to the curve vertex (T_i), the force drop was small as in the previous cases and ranged from 0.03 to 0.26 N, while the residual deformation of knitted fabric slightly increased and ranged from 3.9 to 10.1 %.

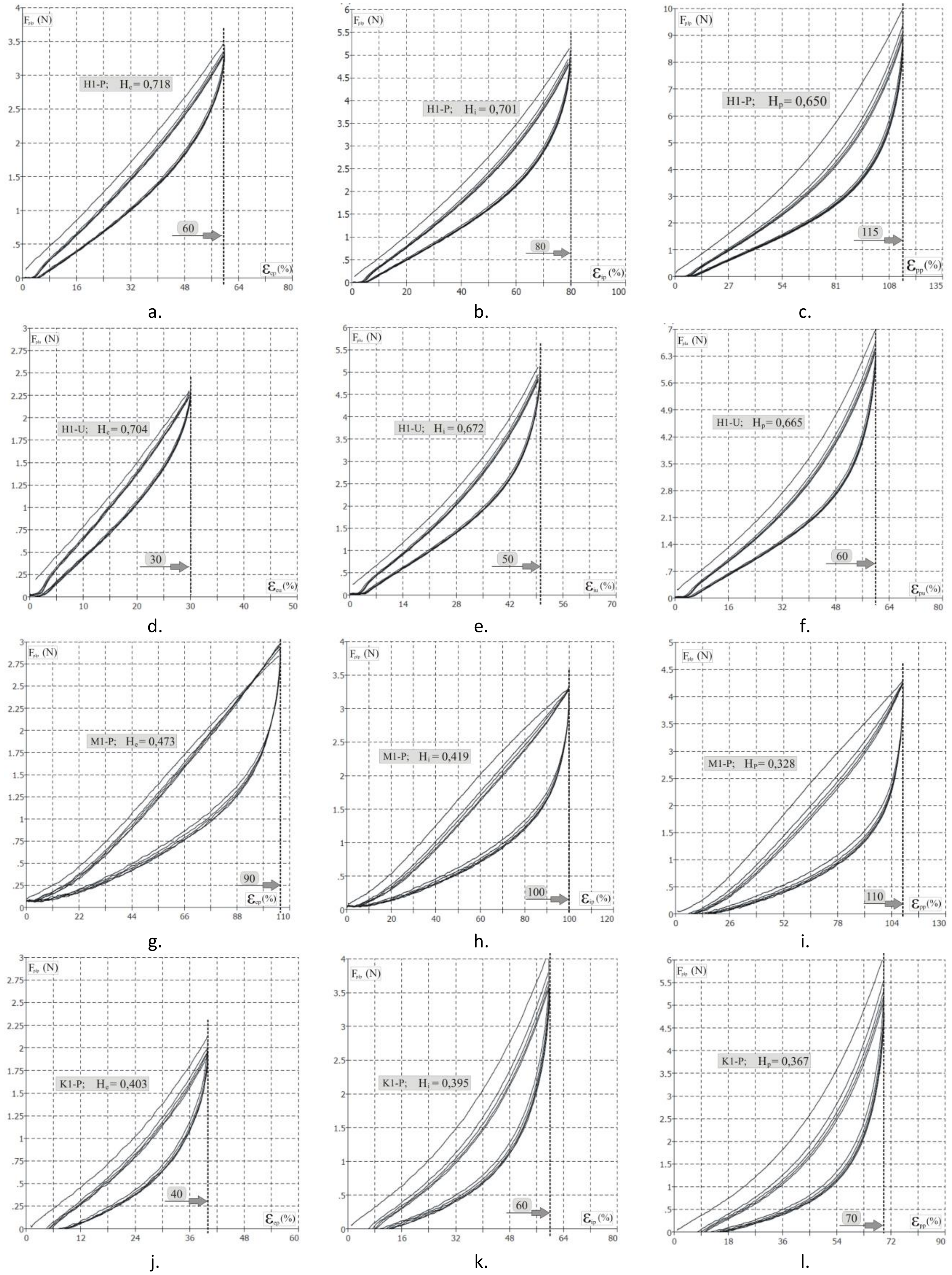

Figure 5: Diagrams of cyclic elongations of elastic pants, shirts, and a swimsuit

The hysteresis indices in this area for these two shirts were notably different and were larger in the second shirt. In the third elongation area, i.e., to the beginning of permanent deformation of knitted fabric, the force drop was again small, and the residual deformation of knitted fabric rose significantly, especially in the first shirt and transverse elongation and was 19.4%. It is interesting to compare knitted fabric deformation during transverse and longitudinal elongation of the first shirt (M1). In transverse elongation, already at the end of the assumed elasticity (point T_1 - ε_e), residual deformation was 7.9 % (more than 5 %), and at the beginning of permanent deformation (point T_2 - ε_p) 19.4 %. This points to a significant presence of permanent deformation. However, after cyclic loadings of the knitted fabric in the longitudinal direction, the residual deformation at all three points was lower than 5 % and ranged from 2.5 to 4.8 %. This indicates that in this direction there is no important length change in cyclic loadings to the beginning of permanent deformation. It can be concluded that it is necessary to research elasticity area in these knitted fabrics, because it is probably also present after knitted fabric elongation to point T_1. All the hysteresis indices of the analysed shirts gradually decreased from the end of elasticity towards the beginning of permanent deformation of knitted fabric. The hysteresis index increased only in longitudinal elongation of the first shirt, (Fig. 5g-Fig. 5i).

Knitted fabrics used in the production of swim trunks and swimsuits are usually produced on warp knitting machines with two groups of warp threads knitting in two different structures. Unlike weft elastic knitted fabrics, in which elongation in the course direction is significantly larger than elongation in the wale direction, in elastic knitted fabrics made on warp knitting machines, elongation is often approximately equal in the longitudinal and transverse direction. This research analysed one sample of a warp knitted fabric which was cut out from a swimsuit (K1) which was mostly used at the seaside for one tourist season (around three months). In this period, the swimsuit was used several times a day in sea water. It was washed by hand a few times and left to dry in summer weather. The results of tensile properties are provided in Tab. 2.

Table 2: Tensile properties of knitted fabric of elastic recreational clothes under cyclic loadings

Sample	ε_e, %	ΔF, N	$\Delta\varepsilon_e$, %	H_e	ε_i, %	ΔF, N	$\Delta\varepsilon_i$, %	H_i	ε_p, %	ΔF, N	$\Delta\varepsilon_p$, %	H_p	ε_t, %
H1-P	60	0.18	5.8	0.718	80	0.33	6.5	0.701	115	1.1	11.2	0.650	217
H1-U	30	0.08	4.3	0.704	50	0.32	5.0	0.672	60	0.58	5.7	0.665	200
H2-P	40	0.08	1.3	0.692	55	0.15	4.5	0.725	70	0.34	6.0	0.433	142
H2-U	20	0.12	1.6	0.720	30	0.06	2.2	0.755	40	0.05	3.3	0.773	158
M1-P	90	0.14	7.9	0.473	100	0.03	10.1	0.419	110	0.08	19.4	0.328	213
M1-U	10	1.02	2.5	0.378	15	0.11	3.9	0.429	20	0.13	4.8	0.504	90
M2-P	40	0.03	4.0	0.625	70	0.26	5.7	0.575	100	0.90	9.6	0.486	142
M2-U	40	0.07	5.5	0.706	55	0.23	8.3	0.632	75	0.38	11.1	0.569	162
K1-P	40	0.24	10.1	0.403	60	0.83	13.9	0.395	70	1.21	19.0	0.367	132
K1-U	60	0.75	7.8	0.494	70	0.82	13.0	0.441	80	1.15	17.4	0.414	171

Where: H – elastic pants, M – elastic shirts, K – swimsuit, P – transversely, U - longitudinally

The first interesting thing that should be pointed out in such a sample is that the elongation at break in the course direction or transversely (132 %) is much smaller than the knitted fabric elongation in the wale direction, which is 171 %. In unused knitted fabrics intended for swimsuits, hysteresis indices at the three analysed points are usually larger than 0.5. In this research and the used knitted fabric, the hysteresis index at all the three analysed points is smaller than 0.5, ranging from 0.367 to 0.494, and is always larger in knitted fabric elongation in the course direction and gradually decreases with the increase in elongation. The force drop is small, as in the previously analysed samples, and permanent deformation is always larger than 5 % and increases constantly from the end of elastic area to the beginning of permanent deformation, ranging from 7.8 to 19.0 %, (Fig. 5j-Fig. 5l).

4.3. Deformations of elastic ribbons after cyclic loadings

Elastic ribbons are used in clothes production and come in different models and widths which are usually approximately 10, 15, 20, 30, 35, 50 and 80 mm. They are made by different techniques: narrow weaving, gallon machines (warp knitting), warp knitting machines, knitting machines, etc. In this research, two ribbons of different widths and structures were used. The first ribbon had the width 15 (ED15), and the second 35 mm (EG35). Different elongation criteria were applied for these ribbons. The first cyclic loading was done at 50 % of ribbon elongation, second at 100 % and third at 150 % of ribbon elongation from the initial length, which was 100 mm between clams, Tab.3.

Table 3: Tensile properties of elastic ribbons under cyclic loadings

Sample	ε_{50}, %	ΔF, N	$\Delta\varepsilon_{50}$, %	H_{50}	ε_{100}, %	ΔF, N	$\Delta\varepsilon_{100}$, %	H_{100}	ε_{150}, %	ΔF, N	$\Delta\varepsilon_{150}$, %	H_{150}
EG15	50	0.11	0.5	0.896	100	0.24	6.0	0.920	150	0.42	13.3	0.914
EG35	50	0.31	5.1	0.887	100	0.53	8.2	0.903	150	1.27	12.9	0.907

The results of this research are given for comparison with previous results, especially through the hysteresis index, Fig. 6. In ribbons like these, the hysteresis index is much bigger than in the previous samples and is in the area between 0.887 and 0.920, i.e., the amount of force at loosening of the fifth loop at the half of the elongation length is 88.7 to 92 % of the fifth loop elongation force. Due to the small widths and method of ribbon use, measurements in the transverse direction were not conducted. As in the previous samples, the force drop is small and ranges from 0.11 to 1.27 N in all the measurements. The residual deformation increases with the amount of elongation from 0.5 to 13.3 %. For elastic ribbons, as was the case with some of the previous samples, it would be necessary to conduct special research to define the structure of the force/elongation curve, all until ribbon break and define elasticity areas and beginning of permanent deformation. These structures are probably not described by models of classical mechanics, and it would be necessary to use their altered and adjusted models, especially by applying Hooke's law.

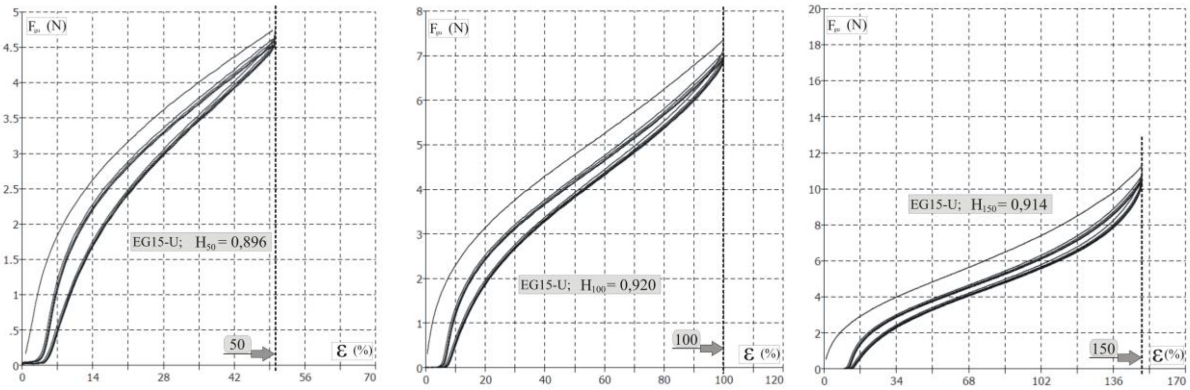

Figure 6: Diagrams of cyclic elongations of a 15 mm wide elastic ribbon used in clothes production

5. Conclusion

The subject of research are tensile properties of elastic knitted fabrics with a special focus on the hysteresis curve index. Four different elastic structures are used for the results analysis and comparison. The first knitted fabric structure is the simplest and comes from finished unused fine women's stockings. Four different knitted fabric structures with different density and stretchability which lie along the female leg from ankle to crotch are analysed. The curve hysteresis index in these knitted fabrics is between 0.000 to 0.400.

The hysteresis index of unused knitted fabric intended for recreational clothes is much higher than in fine women's stockings and ranges from 0.3 to 0.8. It is often different in longitudinal and transverse knitted fabric elongation. The factors that have an impact on the hysteresis index are knitted fabric tensile properties, structure and technique of knitted fabric production.

The hysteresis index of the swimsuit knitted fabric is analysed after a few months of use, washing and drying. The obtained index is in the area between 0.3 and 0.5. In unused knitted fabrics it is presumably much larger. The hysteresis index of elastic ribbons used in clothes production is the largest and ranges from 0.8 to 0.95.

In the analysis of indices of the obtained hystereses in certain areas, it is observed that future research should investigate elasticity areas which depend on knitted fabric structure and amount of elongation and are connected to the hysteresis index. The conducted research indicates that knitted fabrics with a smaller hysteresis index follow their own law of elasticity, while knitted fabrics with a bigger hysteresis follow a significantly different law of elasticity.

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