VLÁKNA a TEXTIL

1

Volume 27.
March
2020

FIBRES AND TEXTILES

STU FCHPT

TECHNICAL UNIVERSITY OF LIBEREC
Faculty of Textile Engineering

Trenčianska univerzita Alexandra Dubčeka v Trenčíne
Fakulta priemyselných technológií v Púchove

VÚCHV

VÚTCH CHEMITEX

Spoločnosť priemyselnej chémie ZSVTS

CHEMOSVIT FIBROCHEM

Indexed in:
SCOPUS
Chemical Abstracts
World Textiles

ISSN 1335-0617
print version

ISSN 2585-8890
online version

Fibres and Textiles
Vlákna a textil

Published by

- Slovak University of Technology in Bratislava, Faculty of Chemical and Food Technology
- Technical University of Liberec, Faculty of Textile Engineering
- Alexander Dubček University of Trenčín, Faculty of Industrial Technologies
- Slovak Society of Industrial Chemistry, Bratislava
- Research Institute of Man-Made Fibres, JSC, Svit
- VÚTCH – CHEMITEX, Ltd., Žilina
- Chemosvit Fibrochem, JSC, Svit

Vydáva

- Slovenská technická univerzita v Bratislave, Fakulta chemickej a potravinárskej technológie
- Technická univerzita v Liberci, Fakulta textilní
- Trenčianska univerzita Alexandra Dubčeka v Trenčíne, Fakulta priemyselných technológií
- Slovenská spoločnosť priemyselnej chémie, Bratislava
- Výskumný ústav chemických vlákien, a.s. Svit
- VÚTCH – CHEMITEX, spol. s r.o., Žilina
- Chemosvit Fibrochem, a.s., Svit

Editor in chief *(Šéfredaktor)*: Anna Ujhelyiová

Executive editor *(Výkonný redaktor)*: Marcela Hricová

http://www.vat.ft.tul.cz

Editorial office and distribution of the journal
(Redakcia a distribúcia časopisu)

Ústav prírodných a syntetických polymérov
Fakulta chemickej a potravinárskej technológie
Slovenská technická univerzita v Bratislave
Radlinského 9, 812 37 Bratislava, SK
Tel: 00 421 2 59 325 575
e-mail: marcela.hricova@stuba.sk

Order and advertisement of the journal
(Objednávka a inzercia časopisu)

Slovenská spoločnosť priemyselnej chémie,
člen Zväzu vedecko-technických spoločností
Radlinského 9, 812 37 Bratislava, SK
Tel: 00 421 2 59 325 575
e-mail: marcela.hricova@stuba.sk

Order of the journal from abroad – excepting Czech Republic
Objednávka časopisu zo zahraničia – okrem Českej Republiky

SLOVART G.T.G, s.r.o. EXPORT-IMPORT
Krupinská 4, P.O.Box 152, 852 99 Bratislava, SK
Tel: 00421 2 839 471-3, Fax: 00421 2 839 485
e-mail: info@slovart-gtg.sk

Typeset and printing *(Sadzba a tlač)*

FOART, s.r.o., Bratislava

Journal is published 4x per year
Subscription 60 EUR

Časopis vychádza 4x ročne
Ročné predplatné 60 EUR

Evidenčné číslo MKCR SR Bratislava EV 4006/10

IČO vydavateľa 00 397 687

Fibres and Textiles (1) 2020
Vlákna a textil (1) 2020
March 2020

Content

TECHNOLOGICAL PECULIARITIES OF THE PRODUCTION OF A WEARABLE ANTENNA WITH INNOVATIVE TEXTILE MATERIALS

Snezhina Angelova Andonova

Department of Mechanical Engineering and Technologies, Faculty of Engineering, South-West University "Neofit Rilski", 66 Ivan Mihailov Str., 2700 Blagoevgrad, Bulgaria

andonova_sn@swu.bg

Abstract: *Essentially, textile materials are insulators. This is one of the main reasons to avoid their use in the fabrication of radiating elements of the antenna. Their extremely low value, the development of industrial technologies, as well as the need to design and build antennas on textile materials (embedded in clothing) are the main prerequisites for the ever-expanding use of textile materials (TM) for the fabrication of substrates of wearable antennas. Withal, many questions arise regarding technological factors affecting the effectiveness of textile materials application for antenna fabrication. Today, a number of new textile materials are very intensively developed. The subject of this work is the technological peculiarities of the fabrication of wearable antennas from a new TM registered with an invention patent in recent years.*

Keywords: *modern textile materials, wearable antenna.*

1 INTRODUCTION

The development of modern industrial technologies on a global scale is particularly intensive. Setting the scientific basis of problematic engineering tasks is especially important in view of their faster and more efficient solution for optimization of innovative technological processes. The process of application of textile materials for the fabrication of wearable antennas is an extremely up-to-date, interesting and innovative process, which is why its research and scientific analysis is the subject of this work.

Essentially, textile materials are insulators - they have very high electrical resistance. This is one of the main reasons to avoid their use in the fabrication of radiating elements for antenna. Their extremely low value (compared to other materials commonly used for antennas), the development of the industrial technology in recent years (however, electrical loads pass through textile materials), as well as the need to design and build antennas on textile materials (embedded in clothing) [1] are the main prerequisites for the ever-expanding use of textile materials to make substrates for wearable antennas. Wearable antennas made out of conductive fabric on textile substrates were reported in the past [2, 3]. Withal, many questions arise regarding technological factors affecting the effectiveness of TM application for antennas that have not been the subject of scientific treatment or have not been sufficiently and thoroughly studied.

One of the main criteria that determines the applicability of TM for antenna fabrication is its dielectric constant. Studies have been carried out to determine the effect of the degree of filling of capacitor plates with textile material, as well as the influence of the humidity and the temperature of fibers on the dielectric constant [4, 5]. Also, scientific research has been conducted in order to identify the influence of the frequency of the current supplied to the capacitor plates and the chemical structure of the fibers on the dielectric constant [4-6]. In recent years, however, a number of new textile materials have been developed and have entered into mass production. Each of them is with different properties according to its composition and structure. All this requires an expansion and deepening of the studies of dielectric properties of textile materials, taking into account the multicomponent nature of their chemical composition and the complexity of their structure. In the context of the above mentioned, the dielectric properties of an innovative TM (with multicomponent composition and complex structure) registered with an invention patent [7] in recent years, which have not been a subject of scientific research, are of a particular interest.

2 DISCUSSION AND ANALYSIS

The purpose of the present work is to investigate and analyze the dielectric constant of an innovative double woven fabric at different technological variants of operation. The double weaving technology enables the front side of the TM to have one type of structure and composition, and the backside of the TM - another type of composition and structure that meets specific requirements for the TM.

2.1 Conditions to execute the experiment

The textile material studied is a double woven fabric (for winter sports, hunting and tourism) "Hunter'12", produced by "E. Miroglio SA" – Sliven, Bulgaria. Flexible textile product is a fabric of multilayer weave type "double fabric". The considered pattern consists of 2 classical twills - 3/1 twill for the face fabric and 2/1 twill for the reverse fabric. Between the face fabric and the reverse fabric there is an intermediate bonding layer of chemical threads. The cross section of weaving contexture that underlies this complex fabric structure is given in Figure 1 [7, 8].

Pure cotton fibers (100%) make the face layer of the fabric and 100% wool fibers make the reverse layer of the fabric. The intermediate layer is made of chemical fibers - polyamide and viscose [8]. General fibrous composition of the face fabric is characterized by the linear density of warp threads (c: 1, 3, 5, 7, 8, 10, 12 and 14) Tt = 20.0x2 tex Sirospun, 70/18/7/5% Cotton/Viscose/PES/PA6, while the linear density of weft threads (t: 3 and 10) is Tt = 16.1 (8.3 + 7.8 Ply twisted) tex, 52/48% Viscose/PES. General fibrous composition of the reverse fabric is characterized by the linear density of warp threads (c: 2, 4, 6, 9, 11 and 13) Tt = 16.1 (8.3 + 7.8 Ply twisted) tex, 52/48% Viscose/PES, while the linear density of weft threads (t: 1 and 8) is Tt = 40x1 tex, 100% Wool.

It was the multicomponent composition, the complexity of the structure and the exceptional applicability of the above-described TM that aroused interest in exploring its potential for wearable antenna fabrication.

In formulating the conditions and methods for conducting the experiment, principles of the morphological method for analysis and synthesis of methods are applied [9]. The analysis of technological methods for the production of wearable antennas shows that the most common technological variants are with one layer and two layers of TM given in Figure 2. A wearable antenna can be made on a single layer of TM as given in Figure 2, positions 2 and 5.

A number of reasons may require the concealment of the wearable antenna. Therefore, this antenna can be inserted between the details of the sewing article. For example, between the base textile material and the outer sewn pocket (Figure 2, position 1) between the two layers of TM in the manufacture of connecting seams of the article (Figure 2, positions 3 and 4), between the two layers of TM in the manufacture of hemmed seams of the article and a number of others.

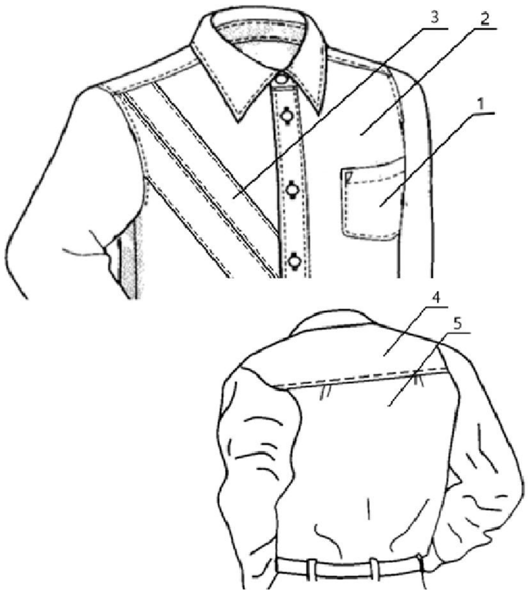


Figure 2 Scheme of an example placement of a wearable antenna on a men's shirt

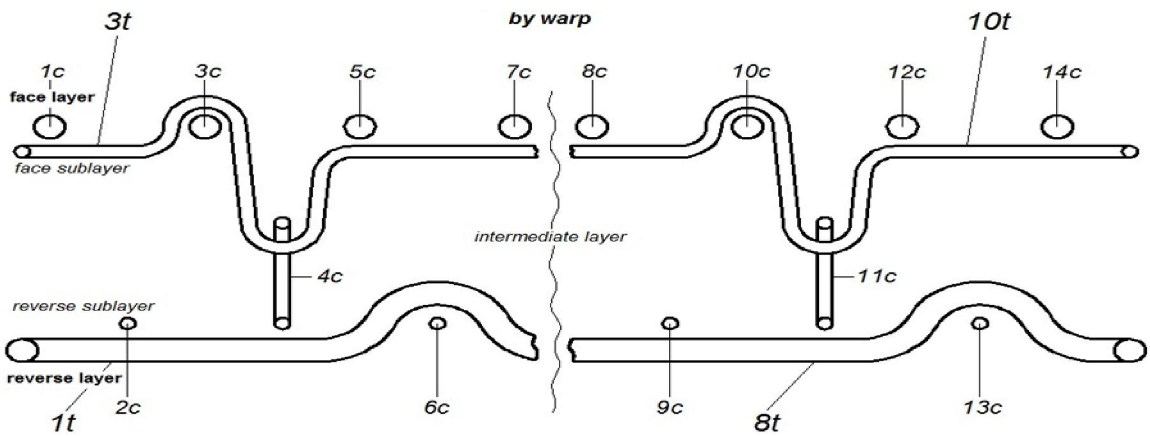


Figure 1 A cross section of weaving contexture that underlies a double woven fabric "Hunter'12"

Possible technological solutions are by using a special thread to connect the antenna to the basic TM or by using a polymeric binder. In this regard, two experiments were conducted to investigate the dielectric constant of the described TM. For each experiment, 2 variants were examined according to the number of TM layers - with one layer and two layers.

The tests in Experiment I were performed with TM without a polymeric binder.

The tests in Experiment II were performed with a TM with a polymeric binder.

The dielectric constant of the material was measured by the resonant perturbation method described in [10] at frequency of 2.564 GHz.

2.2 Experimental results

The results obtained from the implementation of Experiment I and Experiment II are given in Tables 1 and 2. It is important to note that in the initial conduct of two experiments, 3 repeated trials were made for each point in the experiment plan (m = 3). In doing so, it was found that the studies for Experiment II were not reproducible. This is why the number of repeated trials at one point in the experiment plan for Experiment II is increased to 4 (m = 4 for Experiment II).

Table 1 Results of conducted studies for dielectric constant for Experiment I

Study №, j	**Dielectric constant**		
Variant №, i, (number of layers)	***$DC_{i,1}$***	***$DC_{i,2}$***	***$DC_{i,3}$***
B_1 – 1 (one layer of TM)	1.963022	1.963875	1.964554
B_2 – 2 (two layers of TM)	1.929429	1.924141	1.923903

Table 2 Results of conducted studies for dielectric constant for Experiment II

Study №, j	**Dielectric constant**			
Variant №, i, (number of layers)	***$DC_{i,1}$***	***$DC_{i,2}$***	***$DC_{i,3}$***	***$DC_{i,4}$***
B_1 – 1 (one layer of TM with one layer polymeric binder)	1.893409	1.890665	1.892463	1.893318
B_2 – 2 (two layers of TM with two layers polymeric binder)	1.918928	1.919031	1.918903	1.917414

2.3 Discussion of experimental results

It is necessary to carry out a process reproducibility check, which is reduced [11, 12] to a variance perseverance check (by Cochran's C test):

$$G_C = \frac{S_{i\max}^2}{\sum_{i=1}^{B} S_i^2}; \tag{1}$$

$$G_T \begin{Bmatrix} f_1 = m - 1 \\ f_2 = B \\ r = 0{,}05 \end{Bmatrix} \tag{2}$$

where m is the number of repeated trials for each variant, B - number of variant, f_1 and f_2 - degrees of freedom, r - significance level.

The C test is used to decide if a single estimate of a variance (or a standard deviation) is significantly larger than a group of variances (or standard deviations) with which the single estimate is supposed to be comparable [11].

The results for the calculated and tabulated value of the Cochran's C test for Experiment I are:

$$G_{C,I} = 0{,}91798; \quad G_{T,I} = 0{,}9750 \tag{3}$$

Therefore, intra-group variance does not differ statistically and the study process for Experiment I is reproducible.

The results for the calculated and tabulated value of the Cochran's C test for Experiment II are:

$$G_{C,II} = 0{,}731019; \quad G_{T,II} = 0{,}9392 \tag{1}$$

Therefore, intra-group variance does not differ statistically and the study process for Experiment II is reproducible. Therefore, it can be summarized that the influence of the number of layers on the dielectric constant has been established. The results in Table 1 show that as the number of layers (without polymer binder) increases, the value of the dielectric constant decreases. The results in Table 2 show that as the number of layers (with polymer binder) increases, the value of the dielectric constant also increases.

As can be seen from the results listed in Tables 1 and 2, the investigated textile material exhibits low dielectric constant. Consequently, textile material can find application as a substrate in wearable antennas for off-body communications in the body area networks, because the low dielectric constant reduces the surface wave losses and improve the impedance bandwidth. From results of two experiments, it can be summarized that the most effective technological variant for making a wearable antenna is variant one (B_1) of Experiment II. This motivates the development of numerical and experimental models of a wearable antenna for this technological variant.

Figure 3 illustrates an example for a configuration of a wearable antenna with a substrate from the investigated textile material for one-layer TM with one-layer polymeric binder (variant B_1 of Experiment II).

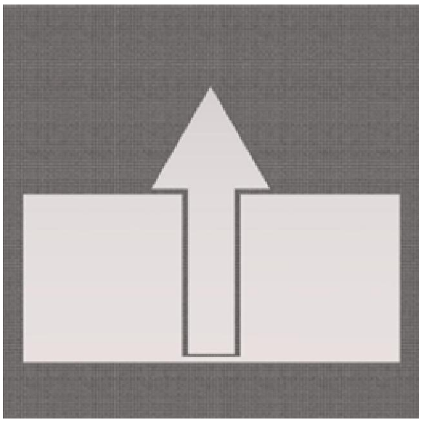


Figure 3 Configuration of a wearable antenna with a substrate from the investigated textile material

3 CONCLUSION

In the present work, the possibility of applying innovative double cloth to the elaboration of a wearable antenna has been investigated. Technological peculiarities for the design of a wearable antenna have been analyzed and considered when carrying out experiments.

The values of the dielectric constant of the investigated TM for different technological variants have been established. The reproducibility of studies carried out has been proven. The applicability of the investigated textile material as a substrate in wearable antennas for off-body communications in the body area networks has been established. A highly efficient technological variant for making a wearable antenna has been established. A configuration of a wearable antenna with a substrate from the investigated textile material has been created.

Researches and analyzes carried out lay on a scientific basis the solution of interdisciplinary engineering problems related to technological peculiarities for the production of a wearable antenna.

ACKNOWLEDGEMENT: This work was sponsored by the National Science Fund, Ministry of Education and Science, Bulgaria through a grant № KP-06-H27/11 from 11th December 2018 "Antenna technology for wearable devices in the future communication networks".

4 REFERENCES

1. Al-Sehemi A.G., Al-Ghamdi A.A., Dishovsky N.T., Atanasov N.T., Atanasova G.L.: Wearable antennas for body-centric communications: design and characterization aspects, ACES Journal 34(8), 2019, pp. 1172-1181
2. Monti G., Corchia L., Tarricone L.: Fabrication techniques for wearable antennas. Proceedings of the 43rd European Microwave Conference, 2013, pp. 1747 -1750, Nuremberg, Germany, DOI: 10.23919/EuMC.2013.6687015
3. Atanasova G., Atanasov N., Stefanov A., Andonova S., Avramov M., Kateva M.: Comparison of computed specific absorption rate induced in a homogeneous human body phantom using a wearable textile antenna for biomedical applications, Proceedings of 27th National Conference with International Participation "TELECOM 2019", 2019, Sofia, Bulgaria, pp. 94-97, DOI: 10.1109/TELECOM48729.2019.8994882
4. Kevorkjan A.: Textile Material Science and Testing, Technika, Sofija, 1977, pp. 172-175
5. Mitova B., Lazarov V.: Testing of Textile Materials, Technika, Sofija, 1987, pp. 85-86
6. Germanova-Krasteva D.: Textile Testing and Analysis, TU Sofija - University Press, Sofija, 2012, pp. 321-322
7. Rahnev I.: Patent for invention №66551/01.11.2016. BG 66551 B1, Double workwear fabric
8. Rahnev I., Rimini G.: Isotropy equilibrium of the double woven fabric with cotton face and wool reverse fibrous compositions, IOP Conference Series: Materials Science and Engineering 254(9), 2017, pp. 1-10, https://doi.org/10.1088/1757-899X/254/9/092003
9. Amudjev I.: Applying of the morphological method for analysis and synthesis of methods for finishing of external cylindrical surfaces by means of surface plastic deformation, Journal of Technical University, Gabrovo 34, 2007, pp. 19-25
10. Atanasov N., Atanasova G., Stefanov A., Nedialkov I.: A wearable, low-profile, fractal monopole antenna integrated with a reflector for enhancing antenna performance and SAR reduction, IEEE MTT-S International Microwave Workshop Series on Advanced Materials and Processes for RF and THz Applications (IMWS-AMP), Bochum, Germany, 2019, pp. 67-69, DOI:10.1109/IMWS-AMP.2019.8880142
11. Germanova-Krasteva D.: Textile Testing and Analysis, TU Sofija - University Press, Sofija, Bulgaria, 2012
12. Andonova S.: Investigation the influence of the cloth packs area on the temperature changes during the ironing process of cotton details, Textile and Clothing 1, 2006, pp. 17-19

METHOD OF PATTERN MAKING FOR SWEATING THERMAL MANIKIN FOR RESEARCH EXPERIMENT PURPOSES

Frederick Fung[1], Izabella Krucinska[2], Zbigniew Draczynski[2], Lubos Hes[1] and Vladimir Bajzik[1]

[1]*Department of Evaluation, Faculty of Textile Engineering, Technical University of Liberec, Studentska 1402/2, 461 17 Liberec, Czech Republic*
[2]*Department of Material and Commodity Sciences and Textile Metrology, Lodz University of Technology, Stefana Żeromskiego 116, 90-924 Lodz, Poland*
tassfashion@gmail.com, Izabella.krucinska@p.lodz.pl, zbigniew.draczynski@p.lodz.pl, lubos.hes@gmail.com, vladimir.bajzik@tul.cz,

Abstract: *This paper is showing the technique, which was developed during the research of Redefining Men's Shirt Pattern[1], of making a tightly fitted shirt pattern for the sweating thermal manikin (model-Newton) for the usage of the research experiments. From supplies to the pattern making procedures are clearly reported with details. The finished shirt is closely fitted to the manikin with minimum air gaps and the pattern can also be graded into different sizes for research purposes. The goal of making this pattern set for the manikin is to understand the true effect of air gaps influenced on the thermal insulation (R_{ct}) and the evaporative resistance (R_{et}). With this method, the researcher will know the increase of the air gap that is built into the shirt from minimum to different sizes of the air gap. Hence, it will benefit the study of air gaps related to thermal insulation and the evaporative resistance rather than using the ready-to-wear shirt which will only give the size labels without knowing the air gap distance that is built in the measurements of the shirt.*

Keywords: *shirt pattern, thermal insulation, evaporative resistance, grading, ready-to-wear, sweating thermal manikin.*

1 INTRODUCTION

Using shrink-wrap or duct tape [1, 2] to create a fitting mannequin for clothing is a common method in the fashion industry. However, it is difficult to trace back who is the first one to use this technique nor since when shrink-wrap/duct tape technique has been used. The shrink-wrap or duct tape technique (seems like a molding method in casting sculpture) is mostly used to clone oneself's own body for his/her fitting or to use it as the duplicated self to create clothing for his/herself. Because of this reason, the finished body part can only fit the person who has been duct-taped or shrink-wrapped to create the molding. More, shrink-wrap or duct tape is directly applied onto a lightly clothed person; no detailed or analytical measurements are recorded. The goal of this cloning technique is to obtain "another self" for easy fitting and creating fashion for oneself.

Thermal insulation and evaporative resistance are two major factors influencing wearing comfort. A lot of research had been done by using thermal manikin putting on ready-to-wear garments. For examples: Chen, Fan, Qian & Zhang [3-4] were using thermal manikin to find out the interactions between air gap and thermal resistance, as well as moisture vapor resistance; Jintu Fan & Tsang [5] investigated clothing thermal properties on sweating manikin; Qian & Fan [6] used Walter – the sweating manikin to predict the thermal insulation and moisture vapor resistance. Also, a lot of articles are related to using textiles and ready-to-wear clothing on the thermal manikin to find out the heat and mass transfer related to clothing protection and comfort [7-10]. All of these experiments, even though the results were quite similar that was when the air gap distance increase, the insulation or water vapor resistance increase. However, most of the researchers were using ready-to-use textiles or clothing. For clothing, researchers are relied on the company's size label to determine the dimension (air gap size) of the clothes but each company's standard of sizing system may not be the same and it is difficult to compare the results from one company to another. To solve this problem, the method of preparing a clothing pattern for sweating thermal manikin model of any kind was developed during the research of the Redefining the Man's Shirt Pattern1 (F. T. Fung, A. Havelka, 2017 - 2018). It is the adaptation of combining the shrink wrap and duct tape techniques, with accurate measurements and marking systems to ensure the accuracy of the patterns so that the finished pattern set can be transferred to another laboratory for repetitive research purposes.

The goal of the closely fitted manikin pattern set is to standardize the clothing size (which is the air gap size that is built-in the clothing) just only for the experiment purposes but not for the selling. Hence, results can be compared between different materials and garment sizes from different researchers' experiments.

2 METHODS

2.1 Supplies and tools

Supplies and tools are commonly used stuff that can be found in any supermarket or stationery store. The quantity and their purposes are given in Table 1.

2.2 Techniques and procedures

In order to develop a closely fitted shirt for the sweating thermal manikin model - Newton, the process is divided into 2 parts: Part 1 is the torso, part 2 is the sleeve. The following are the procedures:

Part 1: The torso

Step 1: Using small stickers as reference points and marked on the thermal manikin (Figure 1). Then the distance of each of the position points was recorded by tape measure (Tables 2 and 3).

Step 2: Plastic shrink-wrap was used to wrap around the entire upper body of the thermal manikin for the prevention of accidental damaging the manikin and for easy unmolding. Also, the reference points could be easily seen through the clear plastic film.

Step 3: Silver duct tape was taped along the contour of the manikin's torso on top of the plastic wrap and at the same time the reference points were transferred and marked on the silver tape by a marker.

Step 4: Cut lines were drawn by connecting the reference points along the contour of the manikin. Carefully cut along the drawn lines using a pair of round point scissors.

Step 5: 3D pattern pieces were unmolded.

Step 6: Pressed down the 3D pattern pieces on top of a piece of brown paper and traced the outlines of each piece.

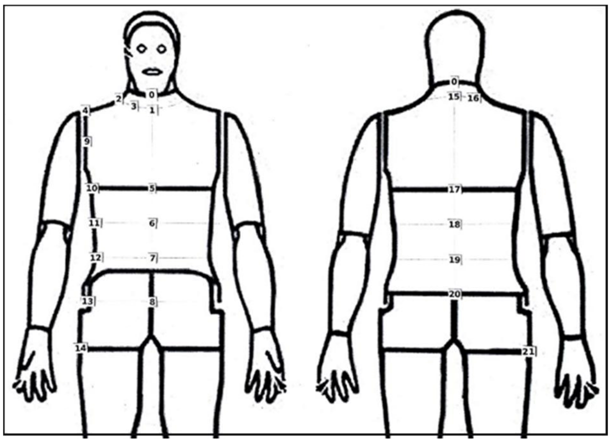


Figure 1 Thermal manikin was marked with reference points from 1 to 21

Table 1 Details of materials, quantity and the purpose of the shirt making procedures

Supplies and tools	Quantity	Purpose
Shrink-wrap	1 roll – any dimension	to protect the manikin from scratches
Duct tape	1 roll – wider the better	to create the 3D pattern from the manikin
Small sticker	1 package – smaller the better	for marking on the manikin
Marker	1 Black, 1 Red, 1Blue	for transfer marks and marking on the manikin
Tape measure	1 roll	to take measurements for confirmation
Scissor	1 pair	for cutting materials to fit the manikin and cutting pattern pieces
Pen and writing pad	1 each	for taking records
Camera	1 piece	for taking photo records
Brown paper	1 roll – wider on the width	for converted 3D patterns to 2D pattern pieces
Pencil and eraser	1 each	for pattern pieces transferring
Curve rulers	1 set	for truing the pattern pieces

Table 2 Reference points and their position chart

Number	(X, Y) [cm]	Description	Number	(X, Y) [cm]	Description
0	(0, 0)	center front neck	11	(0, 10)	from point 10
1	(0, 5)	5 mm down from center front neck 0, 0	12	(0, 10)	from point 11
2	(12, 5)	from center front neck 0, 0	13	(0, 14)	from point 12
3	(-7.5, 5)	from point 2 to point 1	14	(0, 14)	from point 13
4	(0, 10)	from point 2	15	(0, 5)	5 mm down from center back neck 0, 0
5	(0, 22)	from center front neck 0, 0	16	(-6, 5)	from point 15 to point 2
6	(0, 33.5)	from center front neck 0, 0	17	(0, 24.5)	from center back neck 0, 0
7	(0, 42)	from center front neck 0, 0	18	(0, 35.5)	from center back neck 0, 0
8	(0, 56.5)	from center front neck 0, 0	19	(0, 44.5)	from center back neck 0, 0
9	(0, 14)	from point 4	20	(0, 59)	from center back neck 0, 0
10	(25, 5)	from point 5	21	(-48, 0)	from point 14

Table 3 Confirmation of the measurements between reference points

Description	Connected numbers	Total measurement [cm]	Description	Connected numbers	Total measurement [cm]
half front neck	1-3-2	8+7.5=15.5	side-mid-waist to waist	11-12	10
shoulder	2-4	10	side-waist to hips	12-13	13.5
half front chest	5-10	24.5	half back neck	15-16-2	6+6=12
half front mid-waist	6-11	22.5	half back chest	17-10	21
half front waist	7-12	20	half back mid-waist	18-11	18
half front hips	8-13	24	half back waist	19-12	17
mid armhole	4-9	14	half back hips	20-13	24
under armpit	9-10	14.5	center front length	1-5-6-7-8	17+12+9+14=52
side-chest to mid-waist	10-11	10.5	center back length	15-17-18-19-20	20+9.5+10.5+14.5=54.5


a)
The torso of the manikin was wrapped around by shrink-wrap


b)
Silver duct tape applied on the manikin to obtain the tightly fitted 3D body shape measurements


c)
The unmolded half of the right front side of the 3D molding which was cut open along the center front and the center backline


d)
Half of the right side back 3D body molding


e)
After transforming from 3D pattern pieces to 2D pieces by using confirmation of measurement table to correct the dimension of each piece of the 2D pattern and 1 cm of seam allowance is added around each pattern piece for sewing purpose


f)
The first test shirt was made from the 2D pattern pieces with minimum air gaps between the manikin and the shirt

Figure 2 The procedures of the molding method for the torso pattern development

Step 7: Using reference points and the recorded position tables to confirm the dimension of the 2D pattern pieces were accurately drawn when they were compared to the 3D molding pieces. Using a curved ruler set to perfect the outline of each piece of the pattern. Figures 2a - 2f are showing the procedures of the process.

Step 8: To finish the pattern set, one centimeter of seam allowance (for joining pattern pieces together) is added around each pattern piece.

Part 2: The sleeve

The steps were similar to the torso. Figures 3a - 3f are the procedures for arm pattern development:

a)

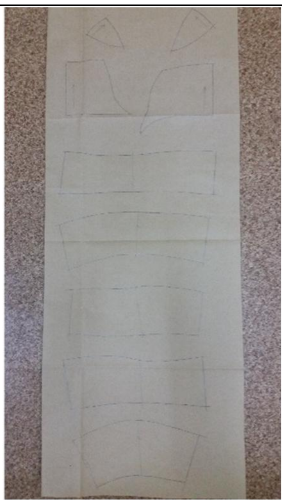
Sticker marked the center point of the upper arm which was wrapped by shrink-wrap

b)

Silver duct tape covered shrink wrap and markings were transfer to duct tape

c)

3D molding was flattened and ready to be traced onto the brown paper



d)

3D molding traced the outline on brown paper

e)

Finalized 2D pattern pieces ready to be used for making a sleeve

f)

First fitted sleeve sample with minimum air gaps

Figure 3 The procedures for arm pattern development

Table 4 The total increase in each sample's circumference and the increase in each sample's front and back pattern pieces

Sample number	Radius increase and total increase in sample's circumference	Equal amount increases in the front piece and back piece
sample 1	r = 144.8 mm (no increase), 910 mm	0
sample 2	r + 3 mm = 147.8 mm, 928.65 mm	18.65 mm/2 = 9.3 mm
sample 3	r + 5 mm = 149.8 mm, 941.22 mm	31.22 mm/2 = 15.61 mm

3 GRADING SAMPLE TO DIFFERENT SIZES

Assuming the cross-section of the thermal manikin is a geometrical shape of a circle (Figure 4), hence; the following equation applies to any cross-section of the manikin's torso:

$$\text{Manikin Body Circumference (MBC)} = 2.\pi.r \qquad (1)$$

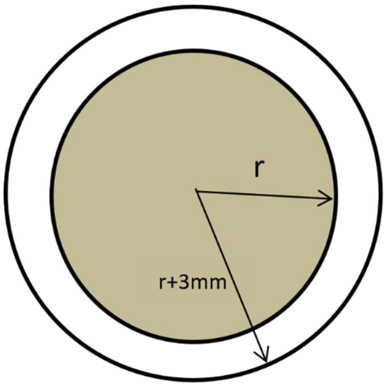


Figure 4 Assuming the grey part is the geometrical shape of the body. The white part is the air gap between the body and the clothing sample. Increase in radius affects the sample size increase, hence; air gap sizes increase

By tape measure, the chest circumference of the manikin is 910 mm, hence; using equation (1) the radius of the chest is 144.8 mm. Based on the clothing pattern of the first sample with minimum air gaps, the clothing pattern of other sizes each will have an increase in the radius of the manikin body circumference. For example, the increase in the radius is 0; 3 and 5 mm and so on. Hence, the total increase of the pattern sizes is calculated as follow:

$$\text{Grading Size of Shirt} = 2.\pi.(r + i) \qquad (2)$$

where: *i* is the increase of the radius: 0; 3 and 5 mm and so on.

The increase of the body circumference from each of the samples will be divided equally and distributed to the front and back on the pattern pieces as shown in Table 4.

4 CONCLUSION

The technique of making the closely fitted shirt pattern for the sweating thermal manikin is a simple and effective method for the researchers. It is because the researchers not just knowing how much the air gaps are built in the garment, also they can decide the air gap size to suit their needs for the experiment. More, this technique can be applied to any model of sweating thermal manikin: male, female, child, hand, head or leg, and the finished clothing can be transferable to other labs for repetitive experiments or for comparison verification.

ACKNOWLEDGMENT: Deeply appreciated the Politechnika Lodzka for the permission of operating the sweating thermal manikin. A great thank to Dr. Ing. Ewa Skrzetuska and Dr. Ing. Agnieszka Komisarczyk for their assistance.

5 REFERENCES

1. 'DIY Mannequin - YouTube'. Accessed Nov. 3, 2019, https://www.youtube.com/watch?v=p6a9Sodvm7E
2. 'DIY MANNEQUIN | XOHANN - YouTube'. Accessed Nov. 3, 2019, https://www.youtube.com/watch?v=wHYKxHVCPEQ
3. Chen Y.S., Fan J., Zhang W.: Clothing thermal insulation during sweating, Textile Research Journal 73(2), 2003, pp. 152-157, https://doi.org/10.1177/004051750307300210
4. .Chen Y.S., Fan J., Qian X., Zhang W.: Effect of garment fit on thermal insulation and evaporative resistance, Textile Research Journal 74(8), 2004, pp. 742-748, https://doi.org/10.1177/004051750407400814
5. Fan J,, Tsang H.W.K.: Effect of clothing thermal properties on the thermal comfort sensation during active sports, Textile Research Journal 78(2), 2008, pp. 111-118, https://doi.org/10.1177/0731684408080046
6. Qian X., Fan J.: Prediction of clothing thermal insulation and moisture vapour resistance of the clothed body walking in wind, The Annals of Occupational Hygiene 50(8), 2006, pp. 833-842, DOI: 10.1093/annhyg/mel050
7. Wang F., Gao C., Kuklane K., Holmer I.: Determination of clothing evaporative resistance on a sweating thermal manikin in an isothermal condition: heat loss method or mass loss method? The Annals of Occupational Hygiene 55(7), 2011, pp. 775-783, DOI: 10.1093/annhyg/mer034
8. Ueno S., Sawada S.: Correction of the evaporative resistance of clothing by the temperature of skin fabric on sweating and walking thermal manikin, Textile Research Journal 82(11), 2012, pp. 1143-1156, https://doi.org/10.1177/0040517511427966
9. Kim J-H., Powell J.B., Roberge R.J., Shepherd A., Coca A.: Evaluation of protective ensemble thermal characteristics through sweating hot plate, sweating thermal manikin, and human tests, Journal of Occupational and Environmental Hygiene 11(4), 2014, pp. 259-267, DOI: 10.1080/15459624.2013.858820
10. Dlugosch S., Hu H., Chan A.: Thermal comfort evaluation of equestrian body protectors using a sweating manikin, Clothing and Textiles Research Journal 31(4), 2013, pp. 231-243, https://doi.org/10.1177/0887302X13506110

Note [1] "Redefining Men's Shirt Pattern" is an ongoing project by means of four major parameters: thermal insulation, water vapor permeability, air permeability and movement; to redefine the traditional men's shirt pattern that was developed hundreds of years ago through draping techniques or try and error method but with no strong scientific data to prove that how the sizes and shapes of the pattern pieces can provide warmth and wearing comfort.

AIR PERMEABILITY, WATER VAPOUR PERMEABILITY AND SELECTED STRUCTURAL PARAMETERS OF WOVEN FABRICS

Marie Havlová

Technical University of Liberec, Department of Textile Evaluation, Liberec, Czech Republic
marie.havlova@tul.cz

Abstract: *This paper is primarily focused on the description of the relationship between the structural parameters of woven fabric and its permeability for air and for water vapour. There are significant differences between the two phenomena. Consequently, there are also differences in the relationship between the structure and each of these phenomena. In this paper the influence of the weave type is eliminated by using only fabrics with a plain weave, and influence of material is eliminated by using only polyester fibres. Then two parameters of the fabric – the fineness of the yarns used and diameter of inter-yarn pores – are shown to play a very important role. With the use of the multivariate linear regression method equations for predicting air permeability and relative water vapour permeability have been proposed on the base of the structural parameters of the woven fabrics – yarn fineness and inter-yarn pore diameter. The correlations between calculated and measured values were high.*

Keywords: *air permeability, relative water vapour permeability, woven fabric, porosity, inter-yarn pore.*

1 INTRODUCTION

Air permeability and water vapour permeability are very important properties of textile materials, which significantly contribute to the physiological comfort felt by a dressed person. Both the properties are due to the porous structure of textile materials. However, the number, size, shape and distribution of the pores in the fabric may be varied within a wide range. The aim of a number of research papers [e.g. 1-15], therefore, is to identify the relationships between structural parameters of textile material and its air permeability or water vapour permeability. Understanding these relationships can lead to a targeted designing of clothing materials with very specific comfortable properties (e.g. sports, outdoor, medical or professional clothing). Some studies indicate that there are differences in relations between the structure of the fabric and its permeability for air or for water vapour [e.g. 12-15].

2 AIR PERMEABILITY

Air permeability (*AP*) of textile materials is generally understood as the ability of air-permeable fabric to transmit air under the well specified conditions given. Permeability measurement is carried out according to the standard ISO 9237. Air permeability *AP* [mm/s] is expressed as the speed of air flowing through the sample of fabric given. The measurement conditions have to be defined properly, namely the clamping area of sample S [cm^2] and the pressure difference Δp [Pa]. Standard measurement devices create a negative pressure inside the device, which leads to sucking air through the tested fabric. The air permeability of fabric is closely connected with the structure of the given textile material. Therefore, a number of contributions [e.g. 1-10, 12-15] are focused on finding the relationship between the structure and air permeability of fabrics.

In these works, the structure of the fabric is usually characterized by its porosity [1, 3, 4, 6-10, 12, 13]. In the case of woven fabrics, a number of authors also discuss the effect of weave on air permeability of the fabric [e.g. 1-5, 7]. An even a very small change in the structure of the fabric causes a change in the air permeability. This fact can be used in assessing the quality of fabrics. In earlier papers [8, 10] it was shown that air permeability measurement can be used for detection of fabric structure irregularities. There is also an assumption [1] that if the inter-yarn pores in woven fabric (i.e. pores between the yarns – see Figure 1) are large enough and the air has enough space for free passage, it will mostly flow just in that way. Based on this assumption, most authors dealing with the air permeability of fabrics consider yarns as an impermeable body. The question of whether it is right to consider yarns in fabric as impermeable body was also addressed in an earlier paper [9]. In this paper, for most of the evaluated knitted fabric, this assumption was confirmed as possible.

The conclusions of the contributions that deal with the relationship between the structure of the fabric and its air permeability are fairly consistent. According to them, the air permeability is very closely associated with properties such as porosity or the average size of one inter-yarn pore (e.g. diameter, area, perimeter) – regardless of whether it is a woven or knitted fabric [1-4, 6-7, 9, 10, 12, 13]. These properties, such as the porosity of the fabric or the size of the individual inter-yarn pores in the fabric, depend on its constructional parameters and on the production technology used.

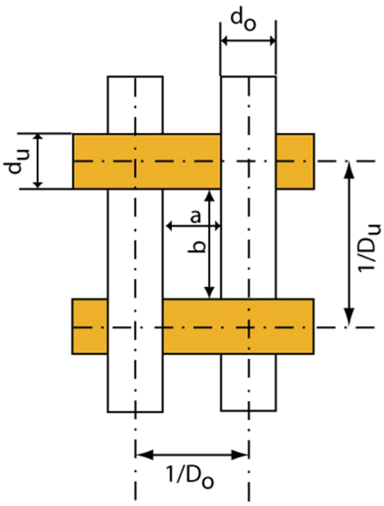


Figure 1 Scheme of dimensional characteristics of the one inter-yarn pore in woven fabric

3 WATER VAPOUR PERMEABILITY

Water vapour permeability (*WVP)* of textile materials is generally understood as the ability of permeable fabric to transmit water vapour through textile structure – usually expressed in units [g/m^2/24h]. Water vapour permeability measurement can be carried out according to the cup method [14, 15], or according to the standard ISO 11092. Similar procedure to that given by this standard is measurement using a PERMETEST apparatus, which measures the amount of heat passing through the thermal model of human skin [16, 17]. Relative water vapour permeability *RWVP* [%] of textile sample is a non-standardized but useful parameter that represents the relative heat flow responsible for the cooling of the body [16, 17], in the isothermal steady state is measured by the given equation:

$$RWVP = \frac{q_S}{q_0} \times 100 \tag{1}$$

where q_S [W/m^2] is the heat flow passing through the measuring head covered by the sample and q_0 [W/m^2] is the heat flow passing through the measuring head without sample.

Unlike air permeability, water vapour permeability is significantly influenced by the material composition of fabric. There are different ways for transfer of water vapour through fabrics. One of them is transfer of water vapour through the void spaces in the fabric – intra-yarn and inter-yarn pores, and the other one is the diffusion through individual fibres [11, 12, 14, 18]. In the case of hygroscopic fibres (cotton, wool, viscose etc.) water vapour transfer also occurs by diffusion through the fibres themselves. So, the water vapour permeability is much more closely connected with the properties of the fibre material itself [11, 12, 14] than the air permeability. The geometrical parameter, which appears to be the most significant for the water vapour permeability, is the fabric thickness [11, 15].

Lee and Obendorf [11] searched relationship between the structural parameters of woven fabrics and their water vapour permeability using a statistical modelling. They tested fifteen woven fabrics with various fabric thickness, weight, fabric construction and fibre material. Statistical analysis revealed that it was fabric thickness, fabric cover factor, mean flow pore diameter of fabric, and moisture regain of fibre that proved to be significant parameters affecting water vapour transmission through woven fabrics. The yarn twist factor and yarn packing factor were found to be insignificant.

A number of authors investigated the influence of fabric constructional parameters on both of these comfort properties. For example, Polipowski et al. [12] confirmed the above mentioned that a strong correlation with the thickness of the woven fabric was obtained for the water vapour resistance and very strong correlation of the air permeability was found with the channel clearance area. At the same time, it was stated that there is a lack of correlation of air permeability with fabric thickness. The correlation between air permeability and water vapour resistance was only 0.44.

The attention of a number of papers, which are focused on evaluation of comfort properties, is paid to knitted fabrics [e.g. 13-15]. The reason is practical because the knitted materials are very often intended for garments that are in direct contact with human skin (e. g. underwear, sportswear). Wilbik-Halgas [13] and similarly Bivainyte [14] investigated the air and water vapour permeability of double-layered weft knitted fabric. Wilbik-Halgas [13] shows that air permeability, contrary to water vapour permeability, is a function of the thickness and surface porosity. The vital lack of correlation between water vapour permeability and the thickness and surface porosity is accounted for by a different character of media transport by free convection and by generally high porosity of knitted fabrics. Similarly, Bivainyte [14] established that knitting structure parameters, such as the loop length, area linear filling rate and pattern have a significant influence on the air permeability. It is the raw material that has the main influence on the water vapour permeability. To predict water vapour permeability using the loop length or area linear filling rate is impossible. There is no correlation between water vapour permeability and air permeability because the water vapour permeability depends on the structure of knits in the order different from air permeability. Coruh [15] examined single jersey knitted fabrics. His investigation shows that an increase in the loop length of the fabric investigated increases its permeability for air and for water vapour, likewise an increase in the linear density of yarns decreases its permeability to air and water vapour.

Based on the above mentioned facts, water vapour transport through porous textile materials is governed by various factors. Diversity and complexity of the involved parameters makes it hard to describe moisture vapour transport in relation to these factors [11]. In order to investigate the influence of individual structural parameters, it is necessary to eliminate the influence of others. Therefore, our experiment is focused only on woven fabrics with plain weave made of 100% polyester staple yarns. The influence of fibre composition, as well as the effect of the type of weave is eliminated.

4 STRUCTURAL PARAMETERS OF FABRICS

One of the main aims of this research is to discuss the possibility of predicting the air and water vapour permeability of fabrics on the basis of their structural parameters. The basic structure of the woven fabric may be described as follows: the weave, weft and warp diameter or the linear masses of these yarns, the density of the warp and weft, the thickness of the product or its surface mass [12, 20]. The fabric structure parameters can be divided into primary and secondary parameters [2]. Primary parameters of fabric structure are dependent variables, where the choice of one parameter influences the effect of the others – it is yarn thickness, density of yarns, type of weave. All others fabric structure parameters depend on primary parameters. These are secondary parameters. In our experiment the following primary and secondary structural parameters are considered:

- D_O, D_U [1/m] – setts of warp and weft yarns, respectively
- T_O, T_U [tex] – fineness of warp and weft yarns, respectively
- t [m] – fabric thickness
- W_P [g/m^2] – planar weight.

Porosity P [-] expresses the proportion of air voids contained in the textile. It can be considered as a secondary parameter of fabric structure. The porosity inside textile materials is usually divided into inter-yarn porosity (includes pores between the yarns from which the fabric is made) and intra-yarn porosity (includes pores inside the yarns, which are formed between the fibers) [4, 5, 11, 19].

There exist several different techniques for characterization of the idealized fabric porosity based on some constructional parameters of woven fabrics. Each of these techniques involves some simplifying assumptions. In our research the following will be considered:

Density based porosity P_D [-], which is calculated as [4, 10, 11]:

$$P_D = 1 - \frac{\rho_W}{\rho_F} = 1 - \frac{W_P}{\rho_F * t} \tag{2}$$

where ρ_F [kg/m^3] is the density of fibres and ρ_W [kg/m^3] is the volumetric density of the fabric, W_P [kg/m^2] is the planar weight and t [m] is the fabric thickness.

Porosity determined in this way indicates how much air is contained in the fabric, however, says nothing about its placement – the shape of pores, their size, distribution etc. It includes both types of pores – inter-yarn pores and intra-yarn pores.

Area filling base porosity P_S [-], which is calculated as [4, 6, 7, 10, 11]:

$$P_S = 1 - (D_O d_O + D_U d_U - D_O d_O D_U d_U) \tag{3}$$

where d_O, d_U [m] are the diameters of warp and weft yarn, respectively, and D_O, D_U [1/m] are setts of warp and weft yarns, respectively (see Figure 1).

The diameter of yarn can be determined by calculation or the experimental use of various methods. This model of porosity completely neglects the third dimension of the fabric and includes only inter-yarn pores.

As shown previously [6], two fabrics may have the same value of the surface porosity, however, their air permeability can be significantly different. Such fabrics may have a larger number of smaller pores or smaller number of larger pores. The value of the pore diameter is not well defined because pores do not have regular shapes. In a simple approach it is possible to assume that the diameter of a rectangular pore d_P [m] (see Figure 1) equals to an average of its width a [m] and length b [m]:

$$d_P = \frac{1}{2}(a+b) = \frac{1}{2}\left(\left(\frac{1}{D_O} - d_O\right) + \left(\frac{1}{D_U} - d_U\right)\right) \tag{4}$$

In an earlier paper [6] it was shown that the pore diameter d_P [m] calculated according to equation (4) can be considered as the characteristic dimension of the one inter-yarn pore of woven fabric. This parameter itself is well applicable to the prediction of the air permeability value in the case that fabrics are made from yarns of the same fineness, because there is a strong positive linear dependence between air permeability and the inter-yarn pore diameter value.

5 MATERIALS AND EXPERIMENT

In this research a set of 13 woven fabrics was used for the experiment. The yarns used were 100% polyester and were produced by the ring spinning technology. The fineness of yarns was 16.5, 25 or 40 tex. All fabrics were woven in a plain weave. A summary of some fabrics parameters is shown in Table 1.

Table 1 Parameters of used experimental fabrics

No.	D_O [1/m]	D_U [1/m]	$T_{O,U}$ [tex]	t [mm]	W_P [g/m^2]	P_S [-]	P_D [-]	d_P [mm]	AP [mm/s]	$RWVP$ [%]
P_1	2060	2020	25	0.326	108	0.288	0.760	0.263	1469	78.3
P_2	2820	2800	16.5	0.260	90	0.253	0.749	0.179	1680	83.0
P_3	1585	1510	40	0.415	132	0.279	0.770	0.342	1516	73.4
P_4	3060	2720	16.5	0.267	99	0.238	0.731	0.170	1252	82.8
P_5	2420	2160	25	0.334	119	0.230	0.741	0.211	1157	77.1
P_6	3040	3020	16.5	0.291	108	0.215	0.730	0.153	758.8	79.3
P_7	2420	2340	25	0.313	128	0.211	0.705	0.193	832.7	76.7
P_8	1940	1540	40	0.432	151	0.217	0.747	0.277	975.1	73.0
P_9	2560	2680	25	0.339	131	0.164	0.720	0.155	791.7	76.5
P_10	2060	1840	40	0.401	168	0.163	0.696	0.209	612.3	70.6
P_11	2880	2860	25	0.332	158	0.121	0.655	0.121	229.5	73.3
P_12	2020	2240	40	0.451	181	0.122	0.710	0.166	225.5	71.0
P_13	2260	2160	40	0.431	199	0.106	0.666	0.148	200.4	69.7

For each fabric D_O [1/m] and D_U [1/m] values were determined experimentally according to Standard EN 1049 – 2. The fabric thickness t [mm] was measured according to the Standard EN 5084 (1 kPa, 20 cm^2). The planar weight W_P [g/m^2] was measured according to the Standard EN 12 127. The air permeability AP [mm/s] was measured using a digital tester FX 3300 according to the standard EN 9237 (20 cm^2, 100 Pa). The relative water vapour permeability $RWVP$ [%] was measured with the use of apparatus PERMETEST (at 23.0±0.5°C), which is consistent with the Standard EN 11092. 10 measurements were always taken for each parameter, Table 1 shows average values.

The area filling based porosity P_S [-] according to equation (3), density based porosity P_D [-] according to equation (2) and diameter of one inter-yarn pore d_P [mm] according to equation (4) were calculated for each woven fabric. These values are also shown in Table 1. The values of yarn diameters $d_{O,U}$ [mm] were measured using USTER apparatus before weaving.

6 RESULTS AND DISCUSSION

The data were processed with the use of linear regression analysis (using software QC Expert). First, the correlation coefficients between the air permeability AP and selected parameters of woven fabrics structure and correlation coefficients between the relative water vapour permeability $RWVP$ and selected parameters of woven fabrics structure were determined. These results are shown in Table 2 (correlation coefficients in bold are significant at $p<0.05$).

Table 2 shows there is relatively high positive linear dependence (R=0.69) between $RWVP$ and AP. However, other correlation coefficients that are shown in Table 2 confirm differences in relations between the structure of the fabric and its permeability for air or for water vapour. A strong positive linear dependence is between air permeability and porosity of both the types – density based porosity P_D (R=0.87) and area filling based porosity P_S (R=0.95). In contrast to this, in the case of relative water vapour permeability these correlation coefficients are lower – R=0.50 for P_D and R=0.64 for P_S. And on the contrary, a strong negative linear dependence is between $RWVP$ and thickness of the fabric t (R=-0.92) and fineness of yarn $T_{O,U}$ (R=-0.91). In contrast to that, in the case of AP these correlation coefficients are low – R=-0.47 for t and R=-0.39 for $T_{O,U}$. A strong negative linear dependence is between AP and planar weight W_P (R=-0.82) and between $RWVP$ and W_P too (R=-0.95).

These results indicate that while the parameters of fabric that reveals information on the void spaces in the fabric are important for air permeability, the parameters indicating the filling of fabric by yarns are more significant for the water vapour permeability. It is a very interesting finding corresponding to the differences between the two phenomena described above. While in the case of passage of air through the fabric the assumption that the yarns are impermeable bodies and air flows predominantly through inter-yarn pores is accepted, in the case of water vapour permeability water vapour passes through the mass of yarns itself.

Table 2 Correlation coefficients between AP, $RWVP$ and selected structural parameters of woven fabrics

	AP [mm/s]	$RWVP$ [%]	$T_{O,U}$ [tex]	D_O [1/m]	D_U [1/m]	t [mm]	W_P [g/m^2]	P_D [-]	P_S [-]	d_P [mm]
AP [mm/s]	1	**0.69**	-0.39	-0.05	-0.15	-0.47	**-0.82**	**0.87**	**0.95**	**0.61**
$RWVP$ [%]	**0.69**	1	**-0.91**	**0.65**	**0.56**	**-0.92**	**-0.95**	0.50	**0.65**	-0.10

Very important information is also provided by spot diagrams shown in Figures 2 and 3. Figure 2 shows a comparison of the *AP* values and values of the pore diameter d_P. It is evident that the values can be divided into three groups: fabrics made with 16.5 tex, 25 tex and 45 tex yarns. Points in one group are spaced approximately along a straight line. This finding is consistent with the findings from the earlier paper [6] and shows that when the fabrics are woven from yarns of the same fineness, a strong linear dependence is between air permeability and the diameter of one inter-yarn pore (Figure 2 and Table 3).

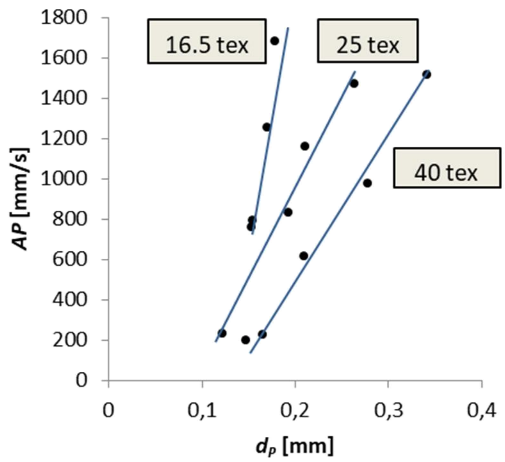


Figure 2 Relationship between *AP* and diameter of one inter-yarn pore d_P

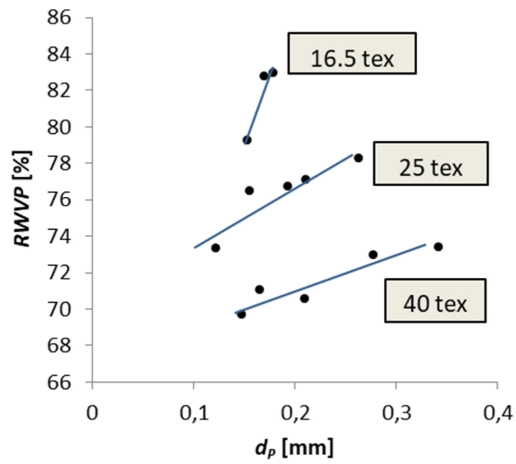


Figure 3 Relationship between *RWVP* and diameter of one inter-yarn pore d_P

Figure 3 shows a comparison of the *RWVP* values and values of the pore diameter d_P. It is evident that the values can be divided into three groups too: fabrics made with 16.5 tex, 25 tex and 45 tex yarns. This confirms the importance of yarn fineness value for the relative water vapour permeability. However, the value of d_P appears to be very well applicable to the prediction of *RWVP*, provided that the fabrics are made from yarns of the same fineness (Figure 3 and Table 3). In this case, a close linear relationship between *RWVP* and d_P is evident, as in the case of *AP*, but the slope and displacement of the individual lines on the y-axis are different. Table 3 shows the correlation coefficients between the air permeability and inter-yarn pore diameter values and between relative water vapour permeability and inter-yarn pore diameter values when evaluating individual groups of fabrics with different yarn fineness separately. The values of all these correlation coefficients are very high.

Table 3 Correlation coefficients between *AP*, *RWVP* and inter-yarn pore diameter values

	T=16.5 tex		*T*=25 tex		*T*=40 tex	
	AP	***RWVP***	***AP***	***RWVP***	***AP***	***RWVP***
d_P	0.99	0.96	0.96	0.90	0.99	0.94

Based on the findings described above the method of multivariate linear regression was used and model was tested in the shape:

$$y = a_1 * x_1 + a_2 * x_2 + a_0 \quad (5)$$

where air permeability *AP* [mm/s] was chosen as a dependent variable, and yarn fineness *T* [tex] and diameter of one inter-yarn pore d_P [mm] were chosen as independent variables.

Then, the predictive model in the form:

$$AP \approx -39.5 * T + 7517 * d_P + 543 \quad (6)$$

is suitable for prediction of the air permeability (R^2=0.86), see Figure 4. Similarly, the predictive model in the form:

$$RWVP \approx -0.46 * T + 23.5 * d_P + 84.5 \quad (7)$$

is suitable for prediction of the relative water vapour permeability (R^2=0.92), see Figure 5. The method of the least squares was used, all tests were performed at a significance level 0.05. Both models – (6) and (7) were identified as significant, all parameters in equations (6) and (7) were identified as significant.

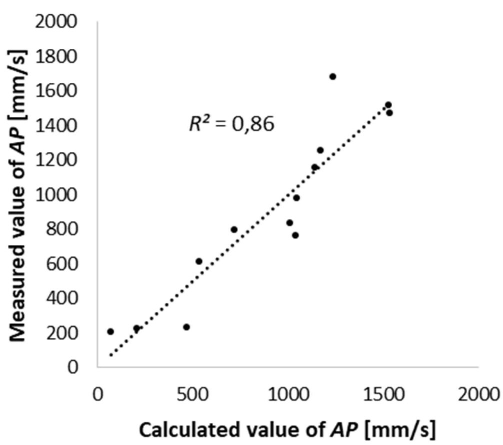


Figure 4 Relationship between calculated and experimental values of *AP*

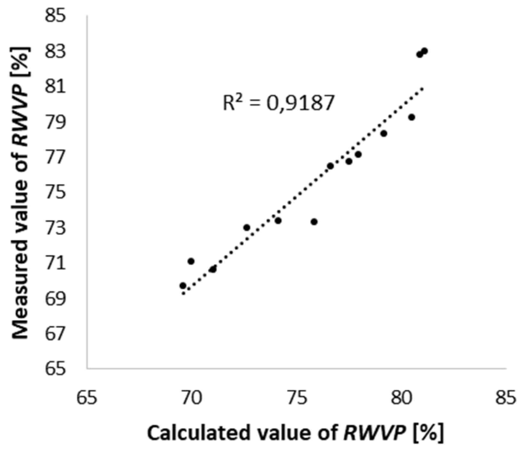


Figure 5 Relationship between calculated and experimental values of *RWVP*

7 CONCLUSIONS

The main aim of this paper was to demonstrate and discuss the relationship between fabric structure and its permeability for the air and for the water vapour using woven fabric made of polyester staple yarns. Some important differences between the two phenomena were discussed. Both phenomena – air permeability and water vapour permeability – are based on the porous nature of textile materials and, therefore, both closely related to their structure. However, apparently each of them in a different way. In the case of air permeability, the yarn is usually considered as an impermeable body and only the pores between yarns are considered as important. Then conclusions of many published works are quite consistent. Air permeability is very closely associated with inter-yarn porosity of textile materials, which can be determined by various methods. In the case of water vapour permeability significantly less publications aimed at studying the relationship between water vapour permeability and the structure of textile material are available, and their findings are not always consistent. It is obvious that an important role is played by the material of the fibres themselves. However, the role played by the inter-yarn pores and intra-yarn pores is still a matter of discussion.

In our research the set of 13 woven fabrics with plain weave was chosen for experiment. Fabrics were made of polyester staple yarns. For these fabrics the air permeability and relative water vapour permeability were measured as well as some other parameters of structure. Subsequently, the mutual relations were evaluated:

- Relatively high linear dependence was found between air permeability and relative water vapour permeability. The correlation coefficient was *R*=0.69.
- In the case of air permeability, the strongest linear dependence was demonstrated with planar weight of fabric (*R*=-0.82), with density based porosity (*R*=0.87) and with area filling based porosity (*R*=0.95). This indicates that the information about void spaces in the fabric is very important for air permeability. This conclusion is consistent with previous findings of other authors.
- In the case of water vapour permeability, the strongest linear dependence was demonstrated with planar weight of fabric (*R*=-0.95), with thickness of the fabric (*R*=-0.92) and with yarn fineness (*R*=-0.91). This indicates that the information about the filled spaces is very important for relative water vapour permeability.
- It was further demonstrated strong linear relationship between each of the properties – *AP* and *RWVP* – and the inter-yarn pore diameter values in the case when the yarns used are of the same fineness.
- Using the multivariate linear regression method enabled equations for prediction air permeability and relative water vapour permeability of fabric to be proposed based on the yarn fineness and inter-yarn pore diameter values.

In our experiment some important factors of the fabric structure were eliminated by using only fabric with plain weave and polyester fibres. It allowed showing the important aspects of relationships especially between relative water vapour permeability and the structural parameters of woven fabric such as yarn fineness, inter-yarn pore diameter and porosity.

ACKNOWLEDGEMENT: *This work was supported by the Ministry of Education, Youth and Sports of the Czech Republic and the European Union – European Structural and Investment Funds in the frames of Operational Programme Research, Development and Education – project Hybrid Materials for Hierarchical Structures (Hyhi, Reg. No. CZ.02.1.01/0.0/0.0/16_0000843).*

8 REFERENCES

1. Robertson A.F.: Air porosity of open-weave fabrics, Part I: Metallic Meshes, Textile Research Journal 20(12), 1950, pp. 838-844, https://doi.org/10.1177/004051755002001203
2. Dubrovski P.D., Žiberna-Šujica M.: The connection between woven fabric construction parameters and air permeability, Fibres & Textiles in Eastern Europe 11(4), 1995, pp. 37-41
3. Gooijer H., Warmoeskerken M., Wassink G.: Flow resistance of textile materials, Part I: Monofilament fabrics, Textile Research Journal 73(5), 2003, pp. 437-443, https://doi.org/10.1177/004051750307300511
4. Zupin Ž., Hladnik A., Dimitrovski K.: Prediction of one-layer woven fabrics air permeability using porosity parameters, Textile Research Journal 82(2), 2011, pp. 117-128, https://doi.org/10.1177/0040517511424529

5. Fatahi I., Yazdi A.: Predicting air permeability from the parameters of weave structure, Fibres & Textiles in Eastern Europe 20(3), 2012, pp. 78-81
6. Havlová M.: Air permeability and constructional parameters of woven fabrics, Fibres & Textiles in Eastern Europe 21(2), 2013, pp: 84-89
7. Havlová M.: Model of vertical porosity occurring in woven fabrics and its effect on air permeability, Fibres & Textiles in Eastern Europe 22(4), 2014, pp. 58-63
8. Havlová M.: Detection of fabric structure irregularities using air permeability measurements, Journal of Engineered Fibers and Fabrics 9(4), 2014, pp. 157-164, https://doi.org/10.1177/155892501400900419
9. Havlová M., Špánková J.: Porosity of knitted fabrics in the aspect of air permeability - Discussion of selected assumptions, Fibres & Textiles in Eastern Europe 25(3), 2017, pp. 86-91, DOI: 10.5604/01.3001.0010.1695
10. Militký J., Havrdová M.: Porosity and air permeability of composite clean room textiles, International Journal of Clothing Science and Technology 13(3/4), 2001, pp. 280-288, https://doi.org/10.1108/09556220110396533
11. Lee S., Obendorf S.K.: Statistical modelling of water vapour transport through woven fabrics, Textile Research Journal 82(3), 2012, pp. 211-219, https://doi.org/10.1177/0040517511433145
12. Polipowski M., Wiecek P., Wiecek B., Pinar A.: Analysis of the effect of chanel parameters between filaments and single fabric parameters on air permeability, water vapour resistance and thermal resistance, Fibres & Textiles in Eastern Europe 25(5), 2017, pp. 79-86, DOI: 10.5604/01.3001.0010.4632
13. Wilbik-Halgas B., Danych R., Wiecek B., Kowalski K.: Air and water vapour permeability in double-layered knitted fabrics with different raw materials, Fibres & Textiles in Eastern Europe 14(3), 2006, pp. 77-80
14. Bivainyte A., Mikučioniene D.: Investigation on the air and water vapour permeability of double-layered weft knitted fabrics, Fibres & Textiles in Eastern Europe 19(3), 2011, pp: 69-73
15. Coruh E.: Optimalization of comfort properties of single jersey knitted fabrics, Fibres & Textiles in Eastern Europe 23(4), 2015, pp. 66-72, DOI: 10.5604/12303666.1152728
16. Boguslawska-Baczek M., Hes L.: Effective water vapour permeability of wet wool fabric and blended fabrics, Fibres & Textiles in Eastern Europe 21(1), 2013, pp. 67-71
17. Hes L., Araujo M.: Simulation of the effect of air gaps between the skin and a wet fabric on resulting cooling flow, Textile Research Journal 80(14), 2010, pp: 1488-1497, https://doi.org/10.1177/0040517510361797
18. Das B., Das A., Kothari V.K., Fanguiero R., Araújo M.: Moisture transmission through textiles, Part I: Processes involved in moisture transmission and the factors at play, AUTEX Research Journal 7(2), 2007, pp. 100-110
19. Benltoufa S., Fayala F., BenNasrallah S.: Capillary rise in macro and micro pores of jersey knitting structure, Journal of Engineered Fibres and Fabrics 3(3), 2008, pp. 47-54
20. Szosland J.: Identification of structure of inter-thread channels in models of woven fabric, Fibres & Textiles in Eastern Europe 7(2), 1999, pp. 41-45

EFFECTS OF VARIOUS HOME DRYING PRACTICES ON SMOOTHNESS APPEARANCE, SHRINKAGE, HANDLE AND OTHER PROPERTIES OF WOVEN FABRICS

Rim Cheriaa, Imed Ben Marzoug and Faouzi Sakli

University of Monastir, Laboratory of Textile Engineering (LGTex), Iset Ksar Hellal–BP 68-5070 KSAR HELLAL, Tunisia
cheriaar@yahoo.fr; imedmarzoug@yahoo.fr; faouzi.sakli@isetkh.rnu.tn

Abstract: *The main goal of this study is to examine drying practices in order to make an objective evaluation of fabric properties after one and five cycles of washing-drying. Light and medium weight wool, cotton and polyester weave fabrics are tested to compare fabric behavior in terms of weight and also in terms of fiber nature under different drying practices. Smoothness, shrinkage, mechanical properties related to fabric handle and other physical properties were measured after machine, drip line, flat and line drying. As results, special drying effects reveals more important in the case of cotton and wool fabrics, and tumble drying method affects more the measured properties especially after successive cycles of washing-drying.*

Keywords: *Drying methods, repeated laundering cycles, smoothness appearance, fabric handle.*

1 INTRODUCTION

Although the topic of laundering cannot be considered innovative, researchers need to continue to re-examine and report current trends and practices to teach consumers textile maintenance. Especially on the light of increasing costs of apparel, laundering equipment, energy, consumer time, but also fabric compositions, structures, and finishing treatments. To be truly satisfactory the garments should be able to be washed and dried in a household dryer or hanged in the open air without crease retention or loss of desired hand and physical properties.

According to previous studies, fabrics appear smoother after machine drying than after line drying. In fact, the heated air of the clothes dryer allows the fibers to relax and recover from deformation. Machine-dried fabrics tend to have a softer hand than those that are lines dried. This also could affect consumer acceptance [1]. The shrinkage potential of knitted fabrics depends on the conditions of drying during the finishing process. In a tumble-dryer, the knitted fabrics shrink the most [2]. Other authors have shown that reproducible and complete relaxation will only occur after cotton knitted fabrics have been washed and tumble dried five times [3, 4].

Previous works have also confirmed the need to use tumble drying as opposed to line or flat drying to facilitate total relaxation and hence maximum shrinkage [5]. It was also demonstrated that tumble drying plain single Jersey, Interlock and Lacoste cotton weft knitted structures under a normal cotton cycle causes significant length and width shrinkage. The amount of shrinkage increases sharply in plain single Jersey and Lacoste [6]. Tumble drying causes greater levels of shrinkage compared to line drying of plain woven cotton fabrics. Tumble drying reduces the level of wrinkling. Over drying increases the level of shrinkage in woven cotton fabrics and also improves the appearance of the fabrics [7]. In another work, the effect of sunlight and drying methods on the strength of real wax printed cotton fabrics produced in Ghana was studied. Sunlight caused the specimens to lose more strength in the sun than in the shade. The effect is more severe on the specimens dried on a flat surface than those on the clothesline [8]. The reference [9] has shown that tumbling in the dryer is effective in removing wrinkles from garments of the hydrophobic fibers. The reference [10] has shown that line-dried cotton and polyester fabrics were significantly stiffer than machine dried fabrics

In our previous works, we reported the effect of laundering conditions (machine load, spinning speed and repeated cycles) on fabric properties of three woven cotton fabrics. Spinning speed and machine load have significant effects on dimensional, on mechanical tactile and on clothing properties of woven cotton fabrics [11]. The use of overlaid contour plots via experimental design allowed the determination of optimum spinning conditions for selected fabrics.

On the other hand, we studied the behavior of the same cotton fabrics under industrial ironing conditions. We focused on using Taguchi method coupled with desirability function analysis for solving multicriteria optimization problem. Experimental results have shown that different optimal ironing conditions may be applied on different woven cotton fabrics [12].

The main goal of this study is to examine the effect of drip line drying, flat drying, line drying and tumble drying on fabrics' properties. Light and medium weight wool, cotton and polyester woven fabrics are tested for good comparison and conclusion. Smoothness appearance, shrinkage, physical and mechanical properties were evaluated.

2 EXPERIMENTAL

2.1 Description of test fabrics

The investigation has been carried out with nine types of weaved fabrics going from light to medium weight. Basic characteristics of the selected fabrics are shown in Table 1. Samples 60x60 cm were cut from each fabric for laboratory laundering procedures according to ISO 6330: 2003: Domestic washing and drying procedures for textile testing.

2.2 Fabric characterization

Washed and dried samples were tested according to the following test methods.

- Smoothness appearance following AATCC 124: 2009.
- Recovery angle following ISO 2313: 1972.
- Dimensional change in warp and weft directions according to ISO 3759: 2007 and ISO 6330: 2001.
- Air permeability following ISO 9237: 1995.
- Siro FAST system was used in all measurements of the following mechanical properties:
  - Thickness T_2 [mm], measured at 196.12 Pa pressure using FAST 1: compression meter,
  - Surface thickness *ST* [mm],

$$ST = T_2 - T_{100} \tag{1}$$

where T_{100} is the thickness measured at 9.8 kPa.

  - Bending rigidity B_i [μNm],

$$B_i = W \times C_i^3 \times 9.807 \times 10^{-6} \tag{2}$$

where *W* is fabric mass area [g/m²], C_i is the bending length measured on FAST 2: bending meter, *i*: 1/2 respectively warp and weft direction.

  - Extensibility, *E100-1* [%] and *E100-2* [%] is extension in warp and weft direction respectively at a fixed force of 98 N/m, measured using FAST 3: extension meter.
  - Shear rigidity *G* [N/m],

$$G = 123 / E5\_B \tag{3}$$

where *E5-B* [%] is the extension in the bias direction (45°) to warp or weft at 4.9 N/m.

Measurement methods are clearly described in previous studies [13, 14].

All experimental tests were carried out under standard atmosphere for conditioning and testing textiles following ISO 139: 2011.

2.3 Methods

Washing method was adapted to simulate five repeated home laundering practices in washer-extractor machine "Electrolux Wascator FOM 71 MP-Lab", following ISO 6330: 2003.

In order to study the effect of drying method on fabric properties, 4 drying methods described in Table 2 are tested. Fabric dried until fully dry out; 5% of residual humidity for cotton and wool fabrics and 2% for polyester fabrics.

All experimental tests were carried out under standard atmosphere for conditioning and testing textiles, according to ISO 139: 2011.

Table 1 Basic structural parameters of unwashed fabrics

Fiber content	Cotton (100%)			Polyester (100%)			Wool (100%)		
Fabric code	**CO1**	**CO2**	**CO3**	**PES1**	**PES2**	**PES3**	**WO1**	**WO2**	**WO3**
Weave design	Plain	Twill 3/1	Twill 3/1	Plain	Plain	Twill 3/1	Plain	Plain	Twill 3/1
Mass per unit area [g/m²]	138.4	228.1	344	75.1	124.2	241.5	146.6	204	262
Thickness [mm]	0.322	0.562	0.796	0.274	0.3	0.589	0.326	0.598	0.721

Table 2 Description of drying modes

Mode	Description	Conditions
Mode 1	Drip line dry: The wet fabric is carefully depressed and hanged on a line in wale direction thus fully dry out.	20 ± 2°C
Mode 3	Flat dry after spinning: The thoroughly wet fabric is carefully depressed, spread on a flat, smooth surface and drains thus fully dry out.	
Mode 2	Line dry after spinning: The thoroughly wet fabric is carefully depressed and hanged on a line in wale direction thus fully dry out.	
Mode 4	Tumble dry after spinning: The thoroughly wet fabric is carefully depressed and drains in a tumbler dryer (Electrolux T4130)	20 minutes at 60°C

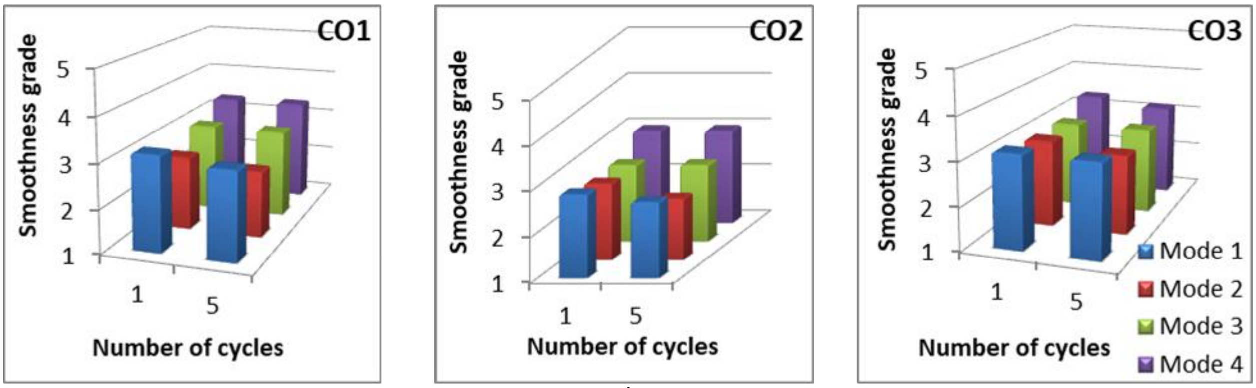
3 RESULTS & DISCUSSION

3.1 Smoothness appearance

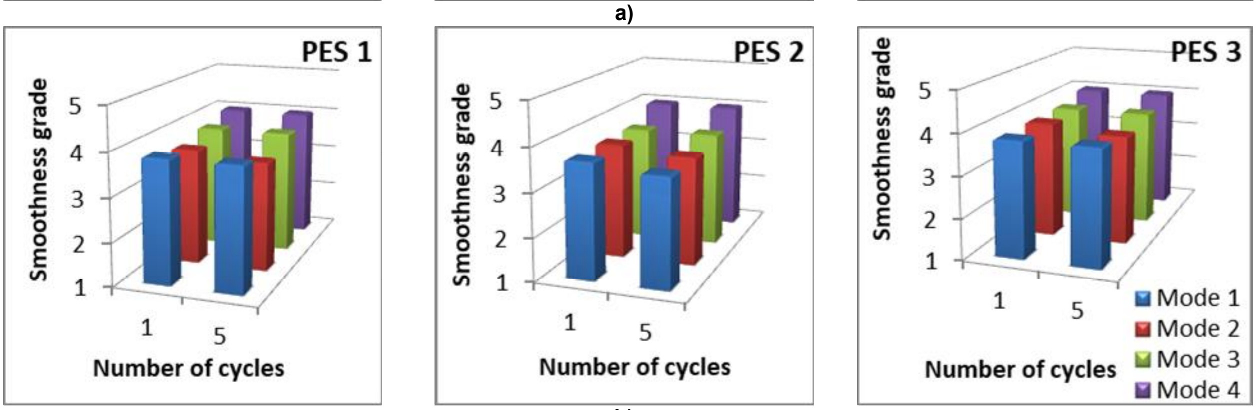
AATCC 124: 2009 is based on a numerical scale of 5 for negligible or no wrinkles to 1 for severe wrinkles. Results relative to cotton, polyester and wool fabrics are respectively shown in Figures 1a, 1b and 1c.

Tumble drying (mode 4) produced higher wrinkle evaluation grades than static drying (mode 1, 2, 3) after one washing drying cycle. For cotton and polyester fabrics, tumble drying caused the least wrinkling and the highest wrinkle evaluation grades at the end of the 5th cycle.

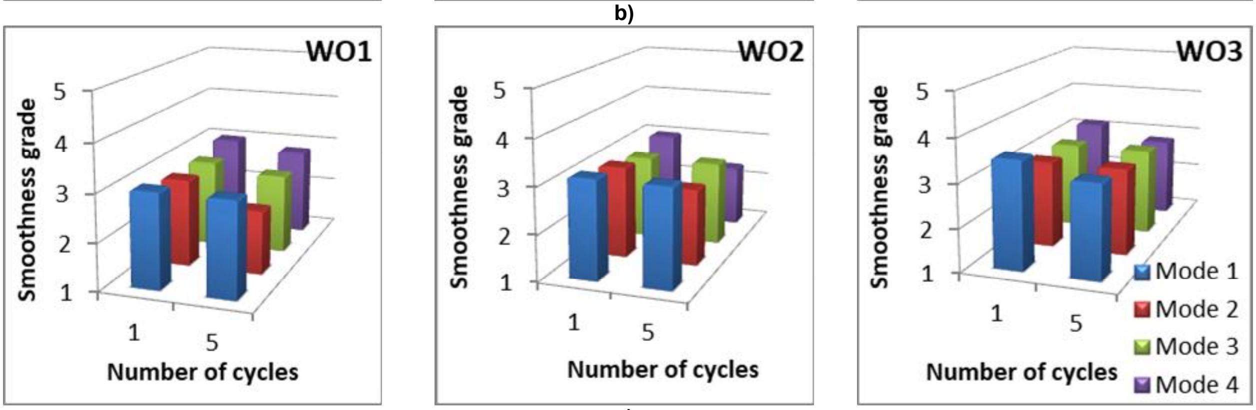
Cotton and wool fabrics dried in machine received ratings between 2 and 3. Polyester fabrics used generally for blouses, skirts and shirts had rating between 3 and 4 which is the range typically found as the minimum required in apparel performance specifications [15]. In fact, polyester fabrics have the smallest absorption ability because of the higher degree of crystalline zones in the polymer fibers. In addition, the glass transition temperature is about 85°C and it is not reached by the laundering. So, the fabric can resist to wrinkles.



a)



b)



c)

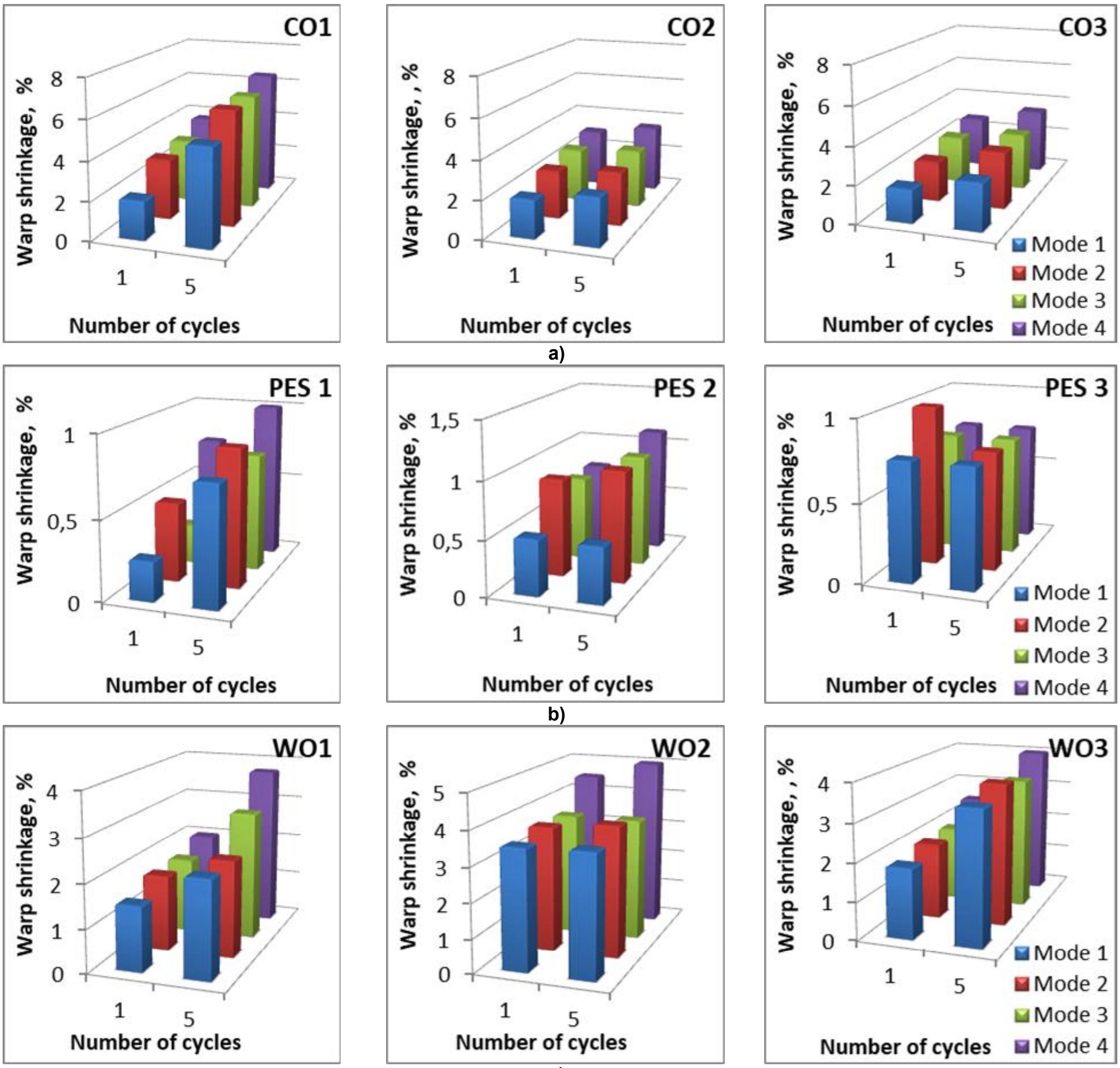
Figure 1 Mean fabric smoothness rating for drying treatments: a) cotton fabrics, b) polyester fabrics and c) wool fabrics

Under static drying conditions, drainage and evaporation of water from the cotton and wool fabrics cause increasing capillary attraction between fibers and yarns. This tends to hold the fabric in the wet conformation, and as the fibers de-swell and the moisture content falls, strong inter and intra fiber adhesion develop as hydrogen bonds reform in the cellulosic matrix. Any wrinkles folds or creases then become hydrogen-bonded into the dry fabric structure. These cannot easily be removed unless T_g is exceeded by an appropriate combination of moisture and heat [16].

In tumble drying, the constant agitation of the fabric structure prevents capillary attraction between yarns and fibers from forming inter-fibers adhesions in the structure. Consequently as the fibers de-swell, there is sufficient mobility in the structure for further relaxation to occur. At tumble drying temperatures, intra fibers hydrogen bonds will not reform until the fabric is almost bone dry. Consequently, as long as cotton and wool fabrics are removed from the drier before they are completely dry, and before the drier cools down, much of the undesirable wrinkling and creasing can be avoided.

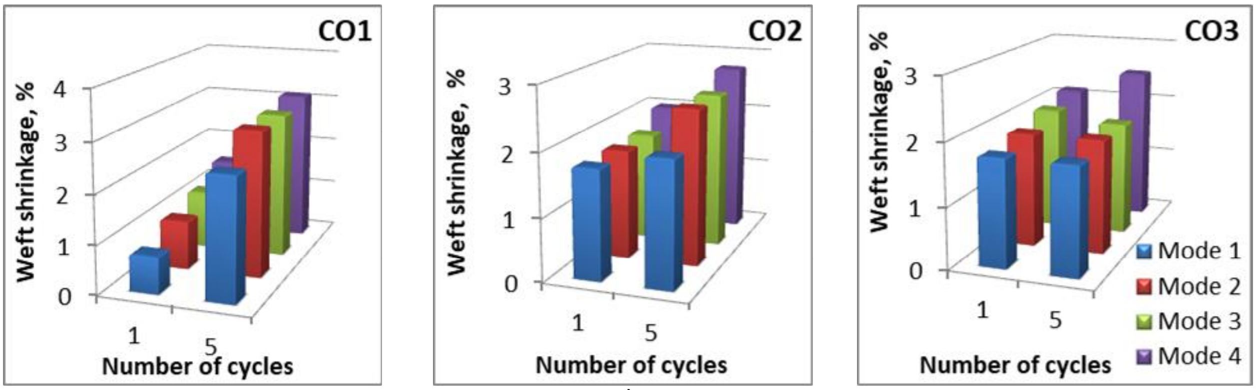
3.2 Shrinkage

Mean fabric shrinkage, in warp and in weft direction, for each fabric following machine or static drying are shown respectively in Figures 2 and 3.

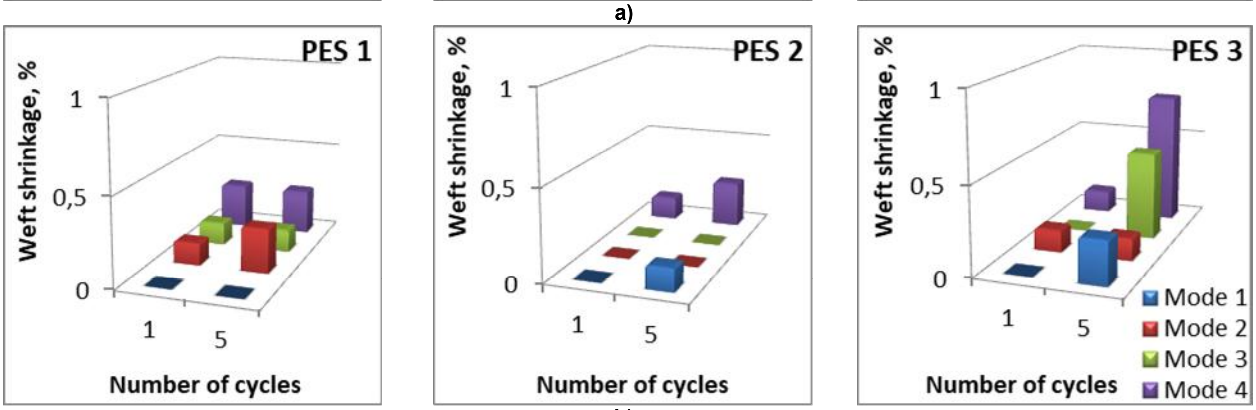


c)

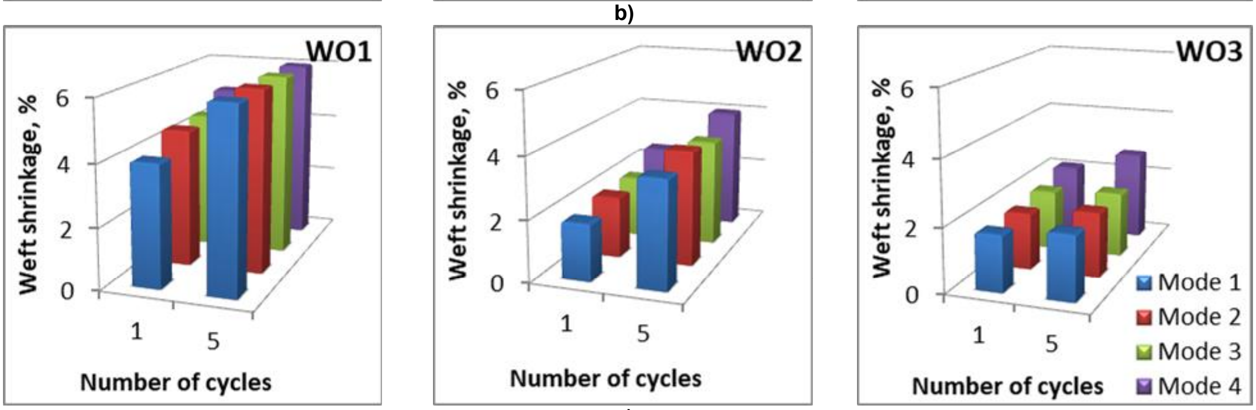
Figure 2 Mean fabric shrinkage in warp direction for drying treatments: a) cotton fabrics, b) polyester fabrics and c) wool fabrics



a)



b)



c)

Figure 3 Mean fabric shrinkage in weft direction for drying treatments: a) cotton fabrics, b) polyester fabrics and c) wool fabrics

Tumble drying caused higher mean levels of shrinkage compared to static drying, both in warp and in weft direction. The value of shrinkage is due to fabric structure and fiber composition.

Cotton and wool fabrics continue to shrink after the 5th cycle of washing. Agitation and temperature is the cause of shrinkage in tumble drying. Polyester fabrics shrink lower than cotton and wool fabrics after tumble drying. The cause may be the contraction of the structure by temperature during time.

Wool fabrics shrank more under tumble drying and with less level in the case of line drying and after drip line drying. This may be due to the fact that the yarn diameter increased after line drying, since studies on the role of yarn swelling on the mechanism of shrinkage in wool fabrics have suggested that voids are created within the yarn as it dries. Tumble drying breaks the hydrogen bonds that had been formed between fibers and yarns when in the swollen state and allows the yarn to collapse inward, reducing yam diameter and facilitating further shrinkage.

3.3 Fabric handle

Fabric handle is related to basic mechanical properties; compression, bending, tensile especially initial low stress regions of these properties [17]. The results of the measurements of different fabric properties before and after various drying regimes are given below in Tables 3 and 4. We analyzed the data set for any possible trends or cause-effect relationships.

Table 3 Mean fabric properties measured by Siro Fast system for drying treatments, 1st cycle

Fabric	Mode	T_2 [mm]	ST [mm]	B-1 [μNm]	B-2 [μNm]	E100-1 [%]	E100-2 [%]	G/10 [N/m]
CO1	1	0.957	0.658	9.29	12.31	5.20	2.96	10.88
	2	0.969	0.67	9.35	12.31	5.20	2.90	11.08
	3	0.956	0.657	8.95	12.18	5.33	2.90	9.84
	4	0.954	0.655	9.04	12.49	5.25	2.95	10.25
CO2	1	0.807	0.263	34.26	5.80	5.30	2.93	11.18
	2	0.806	0.262	48.62	8.75	5.33	3.00	12.30
	3	0.806	0.262	33.92	6.33	5.25	2.87	10.98
	4	0.809	0.265	34.57	5.99	5.25	2.95	10.25
CO3	1	0.941	0.275	38.03	39.81	4.83	3.27	13.67
	2	0.955	0.288	38.02	40.06	4.90	3.33	12.95
	3	0.955	0.256	39.81	39.81	5.00	3.33	13.67
	4	0.952	0.285	37.74	40.38	4.85	3.30	13.18
PES1	1	0.411	0.111	8.41	5.33	0.70	3.20	1.54
	2	0.402	0.101	7.89	5.08	0.85	3.20	1.54
	3	0.408	0.108	8.23	5.07	0.75	3.20	1.51
	4	0.405	0.105	7.92	5.10	0.90	3.25	1.45
PES2	1	0.286	0.032	5.50	13.03	2.13	0.70	4.27
	2	0.288	0.033	5.35	13.68	2.66	0.70	4.32
	3	0.287	0.032	5.03	13.66	2.25	0.75	4.32
	4	0.286	0.032	5.51	13.07	2.80	0.75	4.10
PES3	1	0.62	0.165	0.72	8.89	2.65	2.80	2.98
	2	0.618	0.162	0.76	8.08	2.70	2.80	3.08
	3	0.619	0.163	1.03	8.60	0.65	2.75	3.08
	4	0.621	0.166	0.46	8.10	0.65	2.80	2.89
WO1	1	0.641	0.275	4.37	4.26	2.85	6.00	2.05
	2	0.683	0.317	4.28	4.28	3.15	6.00	2.34
	3	0.645	0.279	4.24	4.36	2.88	6.00	2.14
	4	0.638	0.272	3.88	4.02	3.15	6.33	2.24
WO2	1	0.982	0.32	6.99	6.99	4.00	3.00	2.93
	2	0.99	0.328	7.74	7.01	4.22	3.10	3.09
	3	0.991	0.329	7.49	7.01	4.25	3.00	2.99
	4	0.988	0.326	6.86	6.38	4.50	3.25	3.04
WO3	1	0.904	0.291	10.80	9.89	3.50	4.55	3.08
	2	0.957	0.342	10.90	9.92	3.80	4.50	3.24
	3	0.955	0.339	10.90	8.96	3.50	4.50	3.20
	4	0.915	0.302	9.99	9.05	4.13	4.75	3.24

Compression may be defined as a decrease in intrinsic thickness with an appropriate increase in pressure. Surface thickness *ST* (equation 1) shows the roughness of fabric surface and structural stability of a surface layer. The fabric is considered to consist of an incompressible core and a compressible surface. It is reported that an increase in the surface thickness (less than 0.1 mm) can be perceived subjectively in fabric handle. For very thin and light-weight fabrics, a smaller increase in *ST* could produce a perceptible change in handle [18]. The thickness T_2 measured in cotton fabrics in the case of tumble drying is lower compared to the same fabrics dried with static methods and a maximum is reached after flat drying. These results coincide with the results of reference [7] which explains this with an increase of the weft and the warp yarn diameter of cotton in plain structures dried on the line compared to the same samples dried on machine. In another reference, the some author explained that drying in tumble broken hydrogen bonds of cotton in yarns and in fibers in a swollen state which allow to yarns to penetrate in the spaces formed in the dry state [6].

Table 4 Mean fabric properties measured by Siro Fast system for drying treatments, 5th cycle

Fabric	Mode	T_2 [mm]	ST [mm]	B-1 [μNm]	B-2 [μNm]	E100-1 [%]	E100-2 [%]	G/10 [N/m]
CO1	1	0.938	0.646	7.30	9.66	5.66	3.16	14.30
	2	0.938	0.646	8.00	9.60	5.60	3.20	13.67
	3	0.938	0.646	7.96	9.40	5.70	3.00	15.00
	4	0.938	0.647	8.06	9.77	5.65	3.20	13.67
CO2	1	0.811	0.268	29.39	4.80	5.00	2.81	12.30
	2	0.807	0.262	31.02	4.67	5.20	2.85	11.83
	3	0.81	0.265	30.70	4.80	5.11	2.79	11.18
	4	0.815	0.27	29.89	4.70	5.20	2.90	11.71
CO3	1	0.972	0.305	32.17	29.78	6.50	4.12	15.77
	2	0.962	0.295	32.95	30.65	6.49	4.22	15.38
	3	0.972	0.305	32.87	30.57	6.55	4.25	15.38
	4	0.972	0.305	30.73	30.51	6.56	4.35	14.47
PES1	1	0.406	0.116	5.94	4.82	1.20	3.00	1.51
	2	0.41	0.119	6.26	4.34	1.35	3.00	1.51
	3	0.408	0.116	6.40	5.10	1.30	3.33	1.50
	4	0.407	0.116	6.43	4.72	1.40	3.12	1.45
PES2	1	0.28	0.028	4.97	10.45	2.90	0.65	3.46
	2	0.282	0.031	4.78	10.13	3.10	0.65	3.51
	3	0.281	0.031	4.94	10.13	3.33	0.65	3.28
	4	0.281	0.03	5.07	10.40	3.40	0.70	3.08
PES3	1	0.615	0.132	7.38	6.64	2.85	2.80	2.59
	2	0.613	0.131	7.16	7.16	3.00	2.85	2.54
	3	0.612	0.129	7.40	7.40	3.00	2.85	2.52
	4	0.614	0.132	6.40	7.94	3.13	2.90	2.46
WO1	1	0.645	0.273	3.23	3.30	3.12	6.65	1.54
	2	0.699	0.327	3.13	3.25	3.55	6.66	1.70
	3	0.684	0.306	3.50	3.24	3.11	6.50	1.51
	4	0.725	0.345	2.80	2.80	3.33	6.85	1.51
WO2	1	0.991	0.326	6.46	5.81	4.00	3.33	2.46
	2	1.002	0.324	6.61	5.83	4.20	3.30	2.59
	3	1.003	0.325	6.46	5.97	4.00	3.35	2.31
	4	1.115	0.423	5.84	5.69	4.25	3.50	2.34
WO3	1	0.97	0.26	8.97	8.67	4.00	4.88	2.40
	2	0.978	0.268	9.03	8.73	4.33	4.90	2.84
	3	0.977	0.267	9.22	8.41	4.00	4.85	2.34
	4	1.004	0.292	7.40	7.59	4.50	5.00	2.40

Under different drying methods, the thickness of polyester and wool fabrics is not affected in the first cycle of laundering. The felting phenomena of wool fabrics appear after successive cycles of tumble drying and may explain the fact that fabrics becomes thicker after tumble drying.

Bending length (equation 2) is related to the ability of a fabric to drape and bending rigidity is related more to the quality of stiffness felt when the fabric is touched and handled.

Static drying (mode 1, 2, 3) resulted in higher stiffness compared to tumble drying. In ASTM D1388: 1981, it is stated that differences in bending rigidity of about 10 percent can just be detected subjectively [15]. Using this criterion, there should be no perceivable differences in stiffness between the line-dried, the flat dried, the drip line dried and the machine-dried samples in the first cycle. After five cycles of washing drying, all samples should exhibit pronounced decreases in stiffness. The drip line dried cotton, polyester and wool samples show slight noticeable stiffness after 5th cycles of laundering. The decrease is more severe in the case of tumble drying.

The ability of a fabric to stretch at low loads is critical to garment and other sewn product's making up procedures. Tumble drying gives higher extensibility in warp direction of wool and cotton fabrics. This is may be due to the increase in fiber and yarn crimp as a consequence of relaxation from weaving tension and more freedom for fibers and yarn movement. However, there are no differences in extensibility in weft direction. The method of drying appeared to have little or no effect on the results of polyester fabrics. These results are confirmed after five cycles of laundering.

Shear rigidity is a parameter providing a measure of the resistance to rotational movement of warp and weft threads within a fabric when subjected to low levels of shear deformation. A decrease in shear rigidity is noted after tumble drying. Shear rigidity is higher after static drying. Shear rigidity decreases by successive cycles of washing-tumble drying. In fact, there is a reduction of fiber-fiber contact in interlacement points of yarns and a decrease of inter yarns pressure in the structure which becomes completely relaxed under washing and especially after tumble dry.

4 WRINKLE RECOVERY

Wrinkle recovery is the property of a fabric which enables it to recover from folding deformations. The approach based on wrinkle recovery angles standardized in AATCC 66-20083 and ISO 2313:1972 specified the compression force and time to create a folded wrinkle and the suspension condition to observe the change in the folding angle.

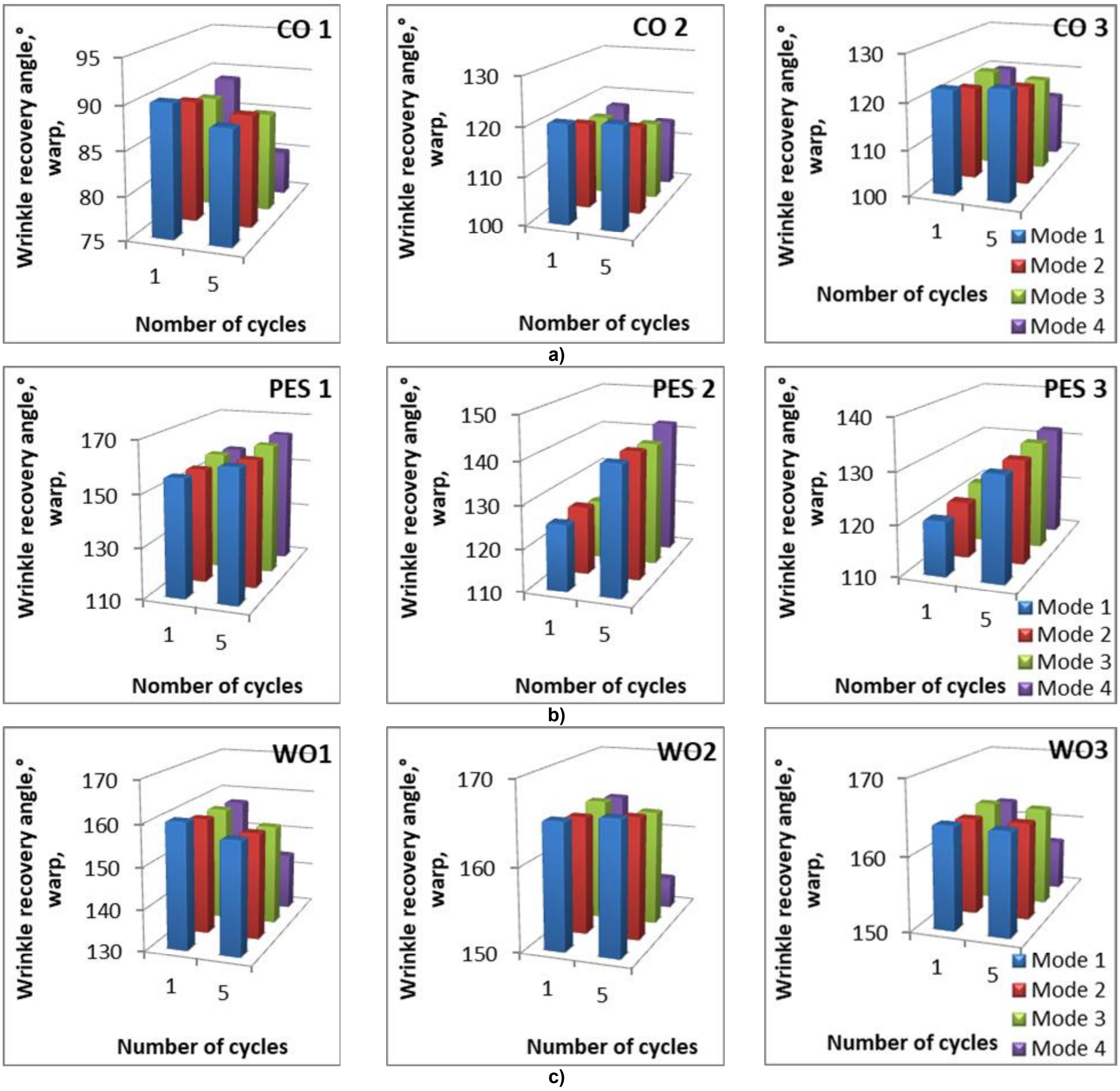
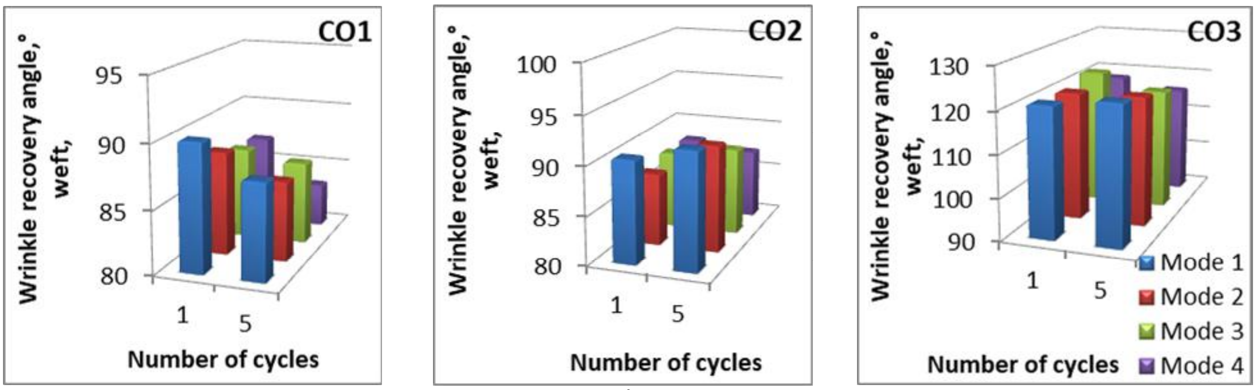
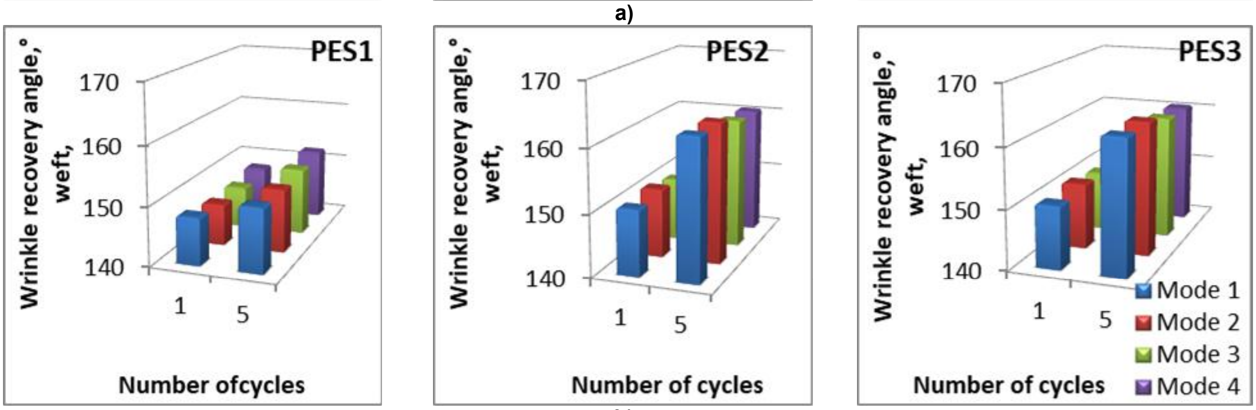


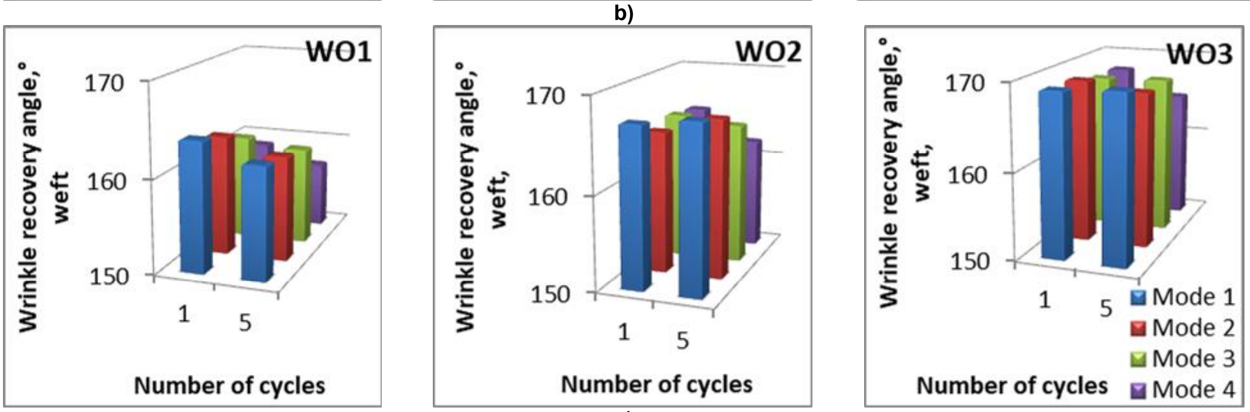
Figure 4 Mean fabric wrinkle recovery in warp direction for drying treatments: a) cotton fabrics, b) polyester fabrics and c) wool fabrics



a)



b)



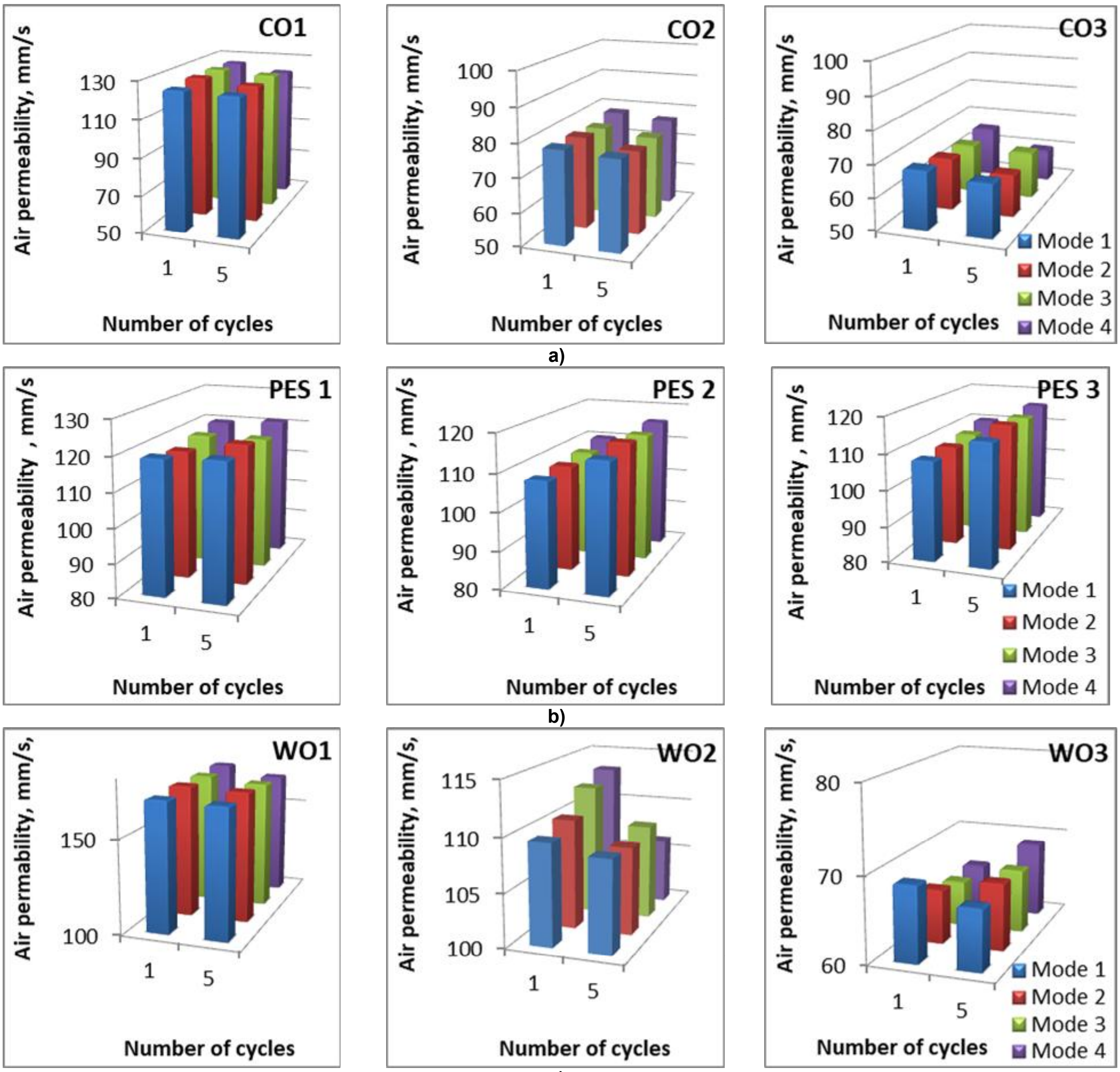
c)

Figure 5 Mean fabric wrinkle recovery in weft direction for drying treatments: a) cotton fabrics, b) polyester fabrics and c) wool fabrics

Figures 4 and 5 show that successive washing-drying cycles, whatever the drying method, decreases wrinkle recovery angle of cotton and wool fabrics, but increase in the case of polyester fabrics. Drying method had not a large effect on the wrinkle recovery angle in weft and in warp direction in the first cycle of laundering-drying. The variation is clearer after successive cycles during which tumble drying have a clear effect.

5 AIR PERMEABILITY

Air permeability facilitates human body ventilation and vapor removal. This property is crucial, especially for underwear and clothes worn in a hot environment [19]. Air permeability is defined according to ISO 9237: 1995 as the velocity of an air flow passing perpendicularly through a test specimen under specified conditions of test area, pressure drop and time.



c)

Figure 6 Mean fabric air permeability for drying treatments: a) cotton fabrics, b) polyester fabrics and c) wool fabrics

The results presented in Figure 6 show that air permeability strongly depends on the fabric structure and fiber contents. The air permeability of all fabrics, after washing and drying cycles, decreased compared to air permeability of untreated fabrics. It occurred because of the influence of shrinkage during washing and drying under the impact of moisture, heat and mechanical action. Interestingly, that air permeability of fabrics from cotton and wool yarns decreased most of all than fabrics weaved from synthetic yarns. In fact, laundering processes cause an increase in the thread density of the fabrics, and as a result a decrease in the fabric's porosity, this in turn diminishes the air permeability. So, drying regimes which cause the most fabric shrink may also cause the most loss in air permeability.

6 CONCLUSION

The study summarized the effect of drying methods on the smoothness appearance, wrinkle recovery, shrinkage, hand properties and air properties on woven fabrics. Tests were carried on nine different fabrics and four different drying methods: drip line drying, flat drying after water extraction, line drying after water extraction and tumble drying were tested. The fabric changes that occur during repeated laundering, especially during drying such as, shrinkage, are highly dependent of fiber type and fabric construction. In terms of the overall objectives of this investigation, we have shown that tumble drying causes greater levels of shrinkage than static drying. We also have shown that consumer will be satisfied by fabric appearance after tumble drying through successive cycles. In spite of the weak variations of the mechanical properties, the effect of drying method reveals significant especially in the case of cotton and wool fabrics. Succeeded cycles of drying intensified the effects. In future works, we will interest on other types of fabrics and also on garment behavior.

7 REFERENCES

1. Wilkinson P.R., Hoffman R.M.: The effects of wear and laundering on the wrinkling of fabrics, Textile Research Journal 29(8), 1959, pp. 652-660, https://doi.org/10.1177/004051755902900806
2. Mikučionienė D., Laureckienė G.: The influence of drying conditions on dimensional stability of cotton weft knitted fabrics, Materials Science (Medžiagotyra) 15(1), 2009, pp.64-68
3. Burkett F.H.: The starfish project: An integrated approach to shrinkage control in cotton knits, Part 1 - Introduction and definition of the reference state, Knitting International 40, 1986, pp. 40-42
4. Heap S.A.: Computer predictions for cotton shrinkage, Knitting International 23, 1984, pp 40-44
5. Brown K.S.M.: The effect of laundering on the dimensional stability and distortion of knitted cotton fabrics, PhD thesis, Bolton Institute, 2000
6. Higgins L., Anand S.C., Hall M., Holmes D.: Factors during tumble drying that influence dimensional stability and distortion of cotton knitted fabrics, International Journal of Clothing Science and Technology 15(2), 2003, pp.126-139, https://doi.org/10.1108/09556220310470132
7. Higgins L., Anand S.C., Holmes D.A., Hall M.E., Underly K.: Effects of various home laundering practices on the dimensional stability wrinkling, and other properties of plain woven cotton fabrics. Part II: Effect of rinse cycle softener and drying method and of tumble sheet softener and tumble drying time, Textile Research Journal 73(5), 2003, pp.407-420, https://doi.org/10.1177/004051750307300507
8. Fianu D.A.G., Sallah A.R.; Ayertey A.: The effect of sunlight and drying methods on the strength of Ghanaian Real Wax printed fabrics, International Journal of Consumer Studies 29(1), 2005, pp. 34-40, DOI: 10.1111/j.1470-6431.2005.00371.x
9. Rawlings G.D., Stanley H.E., Wilkinson P.R.: The home laundering of wash and wear garments of hydrophobic fibers, Textile Research Journal 26(12), 1956, pp. 974-980, https://doi.org/10.1177/004051755602601213
10. Morris M.A., Prato H.H., White N.L.: Line-dried vs. machine-dried fabrics: Comparison of appearance, hand and consumer, Home Economics Researchs Journal 13(1), 1984, pp. 27-35, https://doi.org/10.1177/1077727X8401300105
11. Cheriaa R., Jedda H., Ben Marzoug I., Sakli F.: Optimization of spinning cycle conditions via overlaid contour plot of weave cotton fabrics, International Conference of Applied Research on Textile CIRAT-7, November 10-12, 2016, Hammamet, Tunisia
12. Cheriaa R., Ben Marzoug I., Sakli F., Study of woven cotton fabrics during industrial ironing, International Conference of Applied Research on Textile CIRAT-8, November 9-10, 2018, Monastir, Tunisia
13. Cheriaa R., Ben Marzoug I., Sakli F: Effects of repeated ironing-laundering cycles on cotton, cotton/ polyester and polyester plain fabrics, International Journal of Applied Research on Textile 4(2), 2016, pp.31-44, http://atctex.org/ijartex/current-issue.html
14. Cheriaa R., Ben Marzoug I., Sakli F.: Effects of industrial ironing on mechanical and dimensional properties of cotton, wool and polyester fabrics, Indian Journal of Fibre & Textile Research 41, 2016, pp.167-172
15. American Society for Testing and Materials: 1981, Annual Book of ASTM Standards, Part 32, 249
16. Bishop D.P.: Physical and chemical effects of domestic laundering processes, Chemistry of the Textiles Industry, Carr C.M. (eds), Springer, Dordrecht, 1995; pp 125-172, https://doi.org/10.1007/978-94-011-0595-8_4
17. Matsudaira M.: Fabric handle and its basic mechanical properties, Journal of Textile Engineering 52(1), 2006, pp.1-8, https://doi.org/10.4188/jte.52.1
18. Ly N.G., Tester D.H., Buckenham P., Roczniok A.F., Adriaansen A.L., Scaysbrook F., De Jong S.: Simple instruments for quality control by finishers and tailors, Textile Research Journal 61(7), 1991, pp. 402- 406, https://doi.org/10.1177/004051759106100707
19. Frydrych I., Dziworska G., Matusiak M.: Influence of the kind of fabric finishing on selected aesthetic and utility properties, Fibres & Textiles in Eastern Europe 11(3), 2003, pp.31-37

THE EFFECT OF REINFORCING FABRIC ON ION EXCHANGE MEMBRANE PROPERTIES UNDER CYCLIC pH CHANGES

Kristyna Janegova and Zbysek Meloun

MemBrain s.r.o, Pod Vinici 87, 471 27 Straz pod Ralskem, Czech Republic
kristyna.janegova@membrain.cz

Abstract: *The article deals with comparison of the influence of ion exchange membranes (IMs) composition on their dimensional changes and electrochemical properties. Mainly the influence of chemical stability of polyester (PES) or poly(phenylene sulfide) (PPS) reinforcing fabric was investigated. These fabrics were made from fibers of the same thickness and had the same construction of warp and weft. IMs were exposed to cyclic pH changes which were realized by alternately soaking in HCl and NaOH solutions of concentration 1 mol.L^{-1} for 24 hours. Overall, IMs spent 9 days in each solution. Dimensions, weight, ion exchange capacity and area resistance of IMs were continuously evaluated. Reinforcing with PPS fabric led to length and height stabilization of IMs as compared with reinforcing by PES fabric. Moreover membranes reinforced with PPS fabric showed the highest ion exchange capacity and stable area resistance (7.4±0.5 Ω.cm^2 or 6.3±0.1 Ω.cm^2 for anion or cation exchange membrane, respectively) during the testing period. Contrary, IMs reinforced with PES fabric showed gradual decrease of area resistance corresponding to increased swelling. The sharpest decrease in area resistance was observed for IM(H)-PES Ralex, from 11.6 Ω.cm^2 to 3.5 Ω.cm^2 for anion exchange membrane and from 6.1 Ω.cm^2 to 3.5 Ω.cm^2 for cation exchange membrane. It was proved that by minimizing the dimensional changes of IMs longer stability of area resistance and ion exchange capacity was obtained.*

Keywords: *reinforcing fabric, degradation, pH, polyester, poly(phenylene sulfide)*

1 INTRODUCTION

Membrane processes are being used for drinking and industrial water treatment. The processes find their application more and more in chemical, automotive and food industry or energetics. Membranes used in processes in which the gradient of electric field is the moving force are classified as ion exchange membranes (IMs). They are mainly used in electrodialysis, electrodeionization, diffusion dialysis or cataphoresis [1-3].

IMs are preferentially made from polymer materials [4]. So called heterogeneous IM belong to the polymer composites as is demonstrated from the structure of its fracture on Figure 1. Basic component of heterogeneous IM is resin functionalized with ion exchange groups. Particles of the resin are dispersed in thermoplastic matrix, so the IM can be produced via extrusion in a form of sheet, hollow fiber or tubular membrane [2, 5, 6].

Flat sheet membranes use to be reinforced with polymer fabric which significantly improves their mechanical properties [7, 8]. Under working conditions IMs contain usually tens of weight percent of water which enables the swelling of resin particles and fills pores and voids present in membrane structure. Water acts as a plasticizer and medium for transport of ionic species. Based on the type of resin functional groups, two kinds of IMs are distinguished. Anion exchange membranes (AMs) transport preferentially anions and reject cations and cation exchange membranes (CMs) transport cations and reject anions [1].

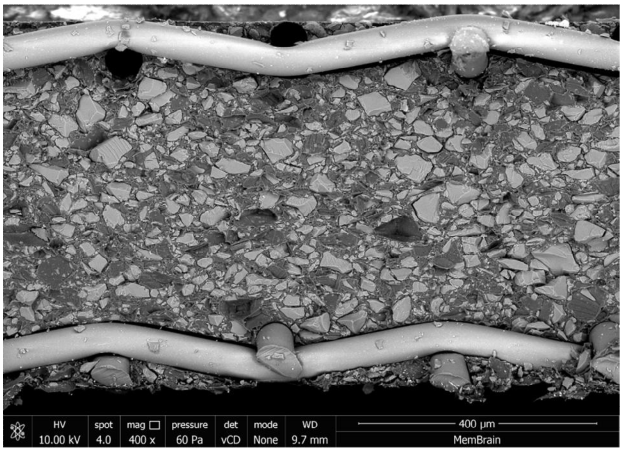


Figure 1 Fracture of ion exchange membrane obtained by scanning electron microscopy

Before use, IMs need to be swollen which is usually realized by soaking them in demineralized water for several hours. Membrane swelling is strongly affected by the properties of reinforcing fabric. In general, dimensional changes of IMs caused by swelling are not isotropic. Also membrane tensile properties are dependent on the direction of measurement, thus IMs represent orthotropic structure. Properties of IMs gradually change under the operational conditions of individual technologies. These changes are referred to the changes in membrane microstructure. Some producers recommend activation of membranes in various chemical solutions prior to their use. Some types of activation are also usually done before membrane characterization and quality control. The main objective of the activation is to make the resin particles available in a matrix. As a consequence of volumetric changes of the resin caused by hydration pressure and changes of ionic form of functional groups membrane matrix become more open and a network of conductive channels through IM is generated [9]. Usually acid or base solutions are used for IMs activation or clean in place [10].

This work deals with repeated applying of HCl and NaOH solutions to the IMs. The objective was to evaluate the effect of cyclic pH changes on the geometry and functional properties of IMs. The purpose of examining IMs reinforced with poly(phenylene sulfide) (PPS) fabric was its enhanced chemical stability against polyester (PES) fabric.

2 EXPERIMENTAL

2.1 Ion exchange membranes

Three IMs were characterized, commercially available IM(H)-PES Ralex (MEGA a.s., Czech Republic) and two development samples IM-PES and IM-PPS. IMs had the same type and filling of the resin. The development membranes differed from the commercial one in the thermoplastic matrix. Matrix of IM-PES and IM-PPS was based on different types of linear low density polyethylene (LLDPE) whereas IM(H)-PES Ralex was made from low density polyethylene (LDPE) matrix. Membranes differed also in their reinforcing fabric which was made from polyester (PES), specifically poly(ethylene terephthalate), or poly(phenylene sulfide) (PPS). Both fabrics were made from monofilament of a diameter 55 µm and had identical construction of warp and weft (32/35 threads per 1 cm). Size of link was approximately 260/230 µm in the direction of warp and weft. Free area of used fabrics was 67%. Ultimate force and ultimate strain in the warp direction were higher for PES fabric (220 N, 31%) than for PPS fabric (140 N, 25%). Figure 2 illustrates the construction of used PES fabric. Dry IMs had thickness in the range 350-450 µm.

2.2 Membrane activation

First, IMs were swelled 24 h under room temperature in demineralized water. Individual membranes were soaked in 0.5 L of appropriate solution, AMs in NaOH (1 mol.L^{-1}), CMs in HCl (1 mol.L^{-1}). After 24 h solutions were poured out and IMs were rinsed with demineralized water till the neutral pH. Then, AMs were soaked in HCl solution and CMs in NaOH solution for 24 h and after that rinsed again with demineralized water till neutral pH. This procedure represented one activation cycle. During this cycle the change of ionic form of AMs is represented as $Cl^{-} \rightarrow OH^{-} \rightarrow Cl^{-}$, for CMs as $Na^{+} \rightarrow H^{+} \rightarrow Na^{+}$. Membranes underwent totally nine activation cycles.

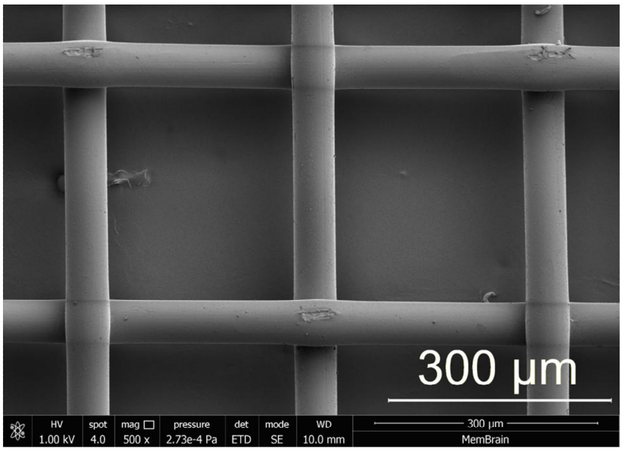


Figure 2 Scanning electron microscopy scan of PES fabric used for membranes reinforcement

2.3 Dimensional and weight changes

After each activation cycle, dimensional and weight changes (Δx, %) of IMs were determined according to (1).

$$\Delta x = 100\%(x_s - x_d)/x_d \tag{1}$$

The symbols in (1) represent the values of parameters (mass *m*, length *l*, width *w* or thickness *h*) in swelled (x_s) or dry (x_d) state.

2.4 Electrochemical properties

Ion exchange capacity (IEC, mmol.g$_{dry}^{-1}$) was determined after each activation cycle by titration procedure described in [4, 11] using Metrohm 682 Titroprocessor (Gemini BV). The uncertainty of IEC determination was below 1%.

After 3rd, 6th and 9th cycle area resistance (R_A, Ω.cm^2) (2) was measured. Membranes were equilibrated in NaCl solution (0.5 mol.L^{-1}) previous the measurement. Resistance was determined by potentiometric compensation method at 25°C. The scheme of electrochemical cell of self-made construction is mentioned in [4].

$$R_A = S(U_{IM+sol} - U_{sol})/I \tag{2}$$

The symbols in (2) represent effective membrane area (S, cm^2), potential of measuring cell filled with NaCl solution (0.5 mol.L^{-1}) and membrane (U_{IM+sol}, mV) or electrolyte itself (U_{sol}, mV), and applied direct current (I, mA).

3 RESULTS AND DISCUSSION

Dimensional changes of IMs connected to swelling or change of ionic form are fundamentally affected by the presence of reinforcing fabric. Generally, reinforced IMs swelled preferentially in the direction of their thickness contrary to the width and length.

3.1 Dimensional and weight changes

Figures 3 and 4 show the impact of cyclic pH changes on the length of AMs and CMs. It is clearly visible that CMs resistance against cyclic pH changes is higher than the resistance of AMs. The resistance of CMs is given by different mechanism of exposure in alkaline solution towards AMs. As CMs reject anions, OH^- cannot penetrate into their structure and attack PES fabric [9, 12]. The alkali solution acts predominantly on the CMs surface whereas the fabric is during the extrusion lamination pressed between two heated rolls underneath the membrane surface. As AMs enables the transport of anions, presence of OH^- can cause the alkali hydrolysis. In this reaction carbonyl oxygen is attacked by OH^-, the scission of an ester bond occurs and equivalent amount of hydroxyl and carboxyl end groups is produced [13]. Alkaline hydrolysis is catalyzed by quaternary ammonium chloride present in the anion exchange resin [14]. Generally, it is accepted, that PES fibers are attacked by alkaline solutions from their surface, thus their diameter decreases. Moreover cracks which significantly reduce the strength of fiber can be indicated when the fibers are stressed in alkaline solution [15]. Fabric made of PES loses its strength and is not able to limit the swelling in the direction of length and width. This is obvious from the significant enlargement of the length on Figure 3. After the 3rd activation cycle, AM-PES showed steep increase of its length whereas for AM(H)-PES Ralex the length increased significantly after the 5th cycle. Using the same resin type and filling and the same PES fabric, AM(H)-PES Ralex seemed to be loosely two times more resistant against the beginning of fabric degradation towards AM-PES.

The dimensional stability of IMs is very important during the operation in membrane units. Taking this in mind, PPS fabric is suitable alternative to PES fabric for operations in alkali environment. Even the construction of both fabrics was virtually the same, PPS fabric enables higher increase in length for AMs and CMs immediately after the swelling in demineralized water (0th cycle). However, change in length for IMs reinforced with PPS fabric was below 4%.

The changes in length and width of IMs depend on the number of threads in warp and weft and also on the fixation method. Both PES and PPS fabrics had the same construction but differed in their mechanical properties. Changes in width reflected trends observed for change in length. Moderate anisotropy was observed, which can be associated with different tensile stress of warp and weft threads during the weaving [16]. Fabric from PPS enabled higher increase in width than PES fabric, for AM and CM below 9%.

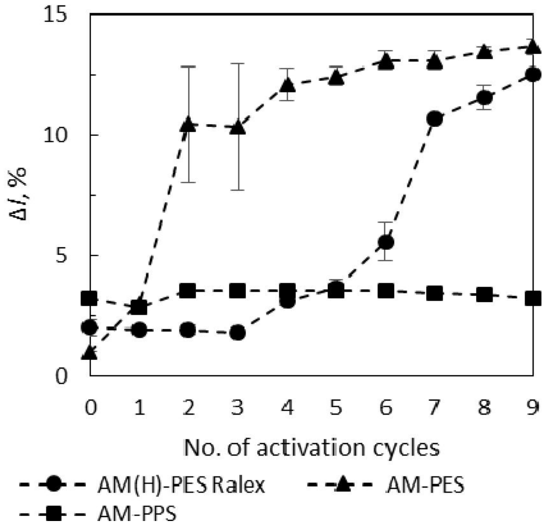


Figure 3 Dependence of length change of AMs according to the number of activation cycles

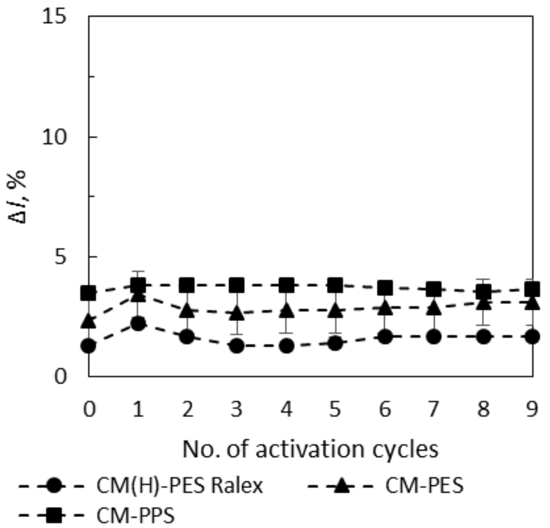


Figure 4 Dependence of length change of CMs according to the number of activation cycles

The increase in thickness of IMs after the swelling (0th cycle) was in the range 40-45% for AMs and 59-68% for CMs. The course of thickness changes according to the number of activation cycles for AM(H)-PES Ralex and AM-PES depicted in Figure 5 shows the mutual relationship of dimensional changes. Whereas the length (Figure 3) and width of these AMs increased with the number of cycles, thickness had decreasing trend. The least affected were IMs reinforced with PPS fabric. For CM(H)-PES Ralex and CM-PES (Figure 6) a decline in thickness change after 5th cycle was observed. This behavior did not correspond to the stable length (Figure 4) and width.

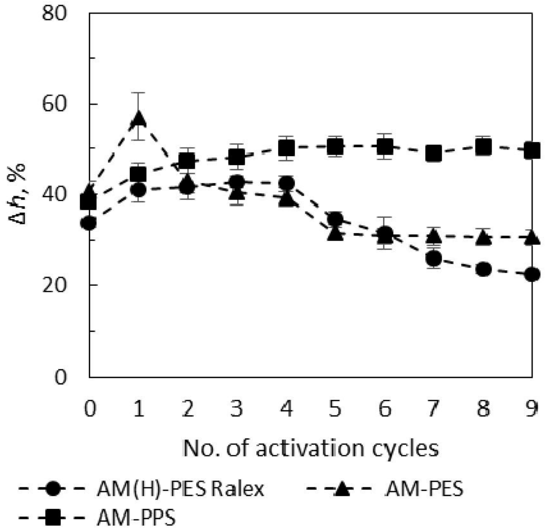


Figure 5 Dependence of height change of AMs according to the number of activation cycles

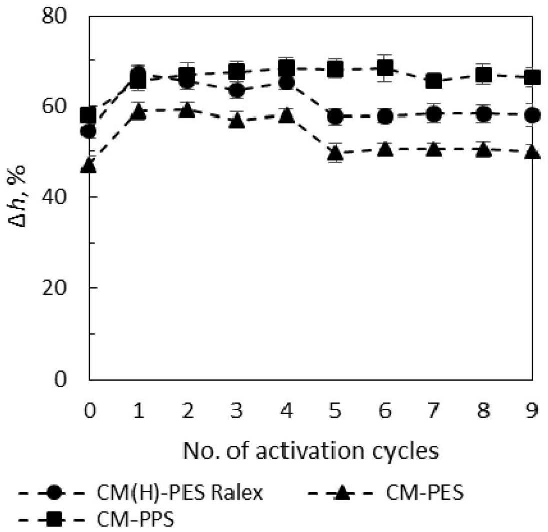


Figure 6 Dependence of height change of CMs according to the number of activation cycles

The increase in thickness was higher for CMs than for AMs which is the result of lower IEC of anion exchange resins. Therefore, by intensive swelling in the direction of thickness the matrix of CMs is more stressed than in AMs. The increase of swelling tends to rise membrane porosity. At high water content the resin particles could be washed out of the matrix to the surrounding solution. Lower content of resin thus could cause the decrease of swelling in the direction of thickness without significant influence on length and width. Weight changes of AMs and CMs are shown in Figures 7 and 8.

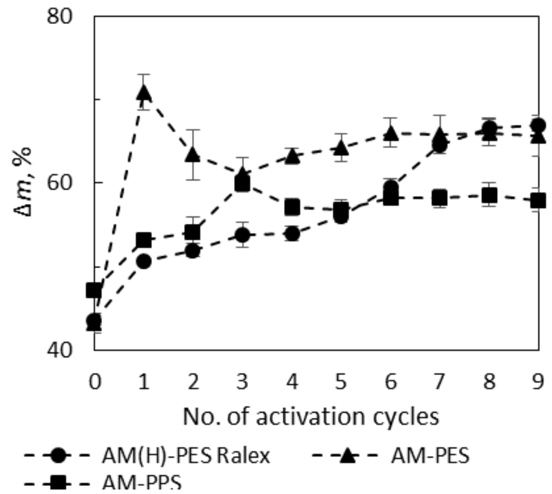


Figure 7 Dependence of weight change of AMs according to the number of activation cycles

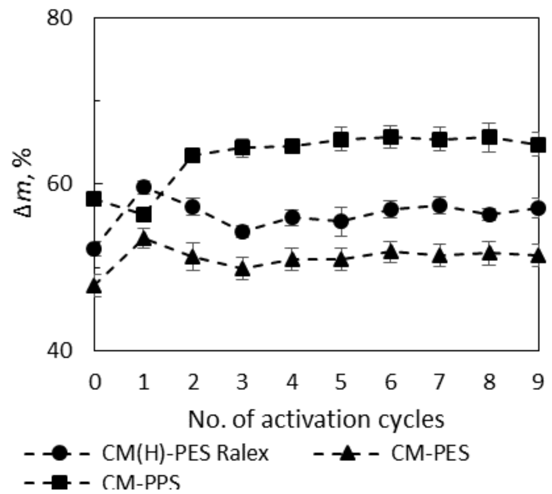


Figure 8 Dependence of weight change of CMs according to the number of activation cycles

The course of weight changes is essential for understanding the evolution of porosity in membrane structure under the effect of cyclic pH changes. After the swelling (0th cycle) the network of ion conductive channels is being formed which is further developing during membrane operation or also static exposition to the aqueous solutions. The more aggressive is the surrounding environment, the faster is the development in IM porosity, the coherence of thermoplastic matrix decreases and resin particles are more prone to be washed out [9]. Porous structure is filled with surrounding solution and the increase in weight of IM is usually observed [17] as in the case of AM(H)-PES Ralex and AM-PES. For this couple of AMs the presumption of alkali hydrolysis of PES fabric was the highest. With gradual degradation of PES threads, the resulting porosity was filled with HCl or NaOH solutions or demineralized water.

3.2 Electrochemical properties

Area resistance is a measure of membrane process power requirements. Ideal IM has as low area resistance as possible and thus intensive ionic transport enabling to increase the capacity of given technology. Prior to area resistance determination it is usual to use membrane pre-conditioning ranging 1-2 activation cycles described in the article. Results of membranes characterized without pre-conditioning (0^{th} cycle) show the importance of the activation on membrane properties. As mentioned previously, activation is important for development of ion conductive channels throughout the IM. As a consequence, resistance is decreasing as is shown for most of the IMs in Figures 9 and 10.

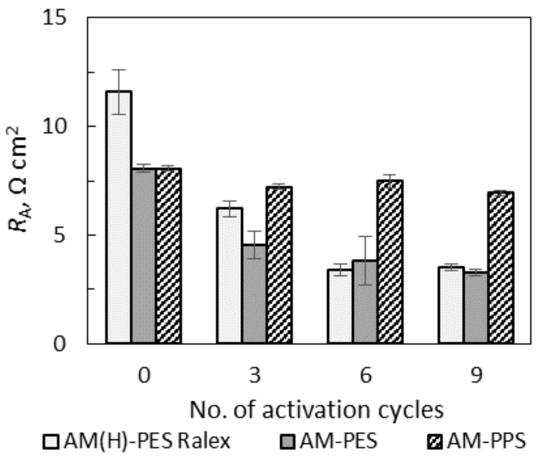


Figure 9 Dependence of area resistance of AMs according to the number of activation cycles

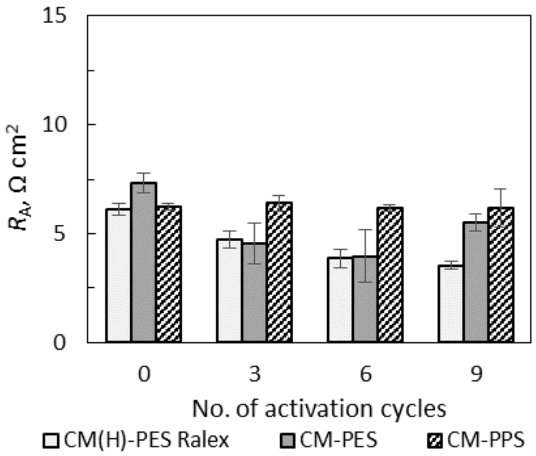


Figure 10 Dependence of area resistance of CMs according to the number of activation cycles

The method of area resistance determination is destructive; each measurement was thus done for a different piece of IM. The decrease of resistance is not caused only by accessibility of larger amount of resin particles. As a side effect of porosity increasing cracks and voids in thermoplastic matrix arise, which generally increase the permeability of IM for both anions and cations regardless the ionic charge of functional groups attached to the resin. As a consequence, IM loses its permselectivity, i.e. preferential selectivity of AM towards anions or CM towards cations.

The ability of ionic transport of IM can be quantified via ion exchange capacity (IEC). This parameter was evaluated after each activation cycle. The results of IEC need to be interpreted with respect to microstructure development. Only resin particles enabling interaction with solution or electrolyte can contribute to the final IEC value. If there are particles which are fully wrapped with polymer matrix they cannot contribute to the resulting IEC. With ongoing activation of IM structure larger amount of resin particles is accessible, thus IEC should increase. At the same time with increasing porosity finer particles could be washed out resulting in decrease of IEC. Final IEC reflects all mentioned effects. The values of IEC found during cyclic pH changes for all IMs were nearly constant. The highest value for AMs was found for AM-PPS and was constant during all measurements (1.9±0.0 mmol.g_{dry}^{-1}). Ion exchange capacity of AM(H)-PES Ralex and AM-PES matched 1.7±0.2 mmol.g_{dry}^{-1}. All CMs had IEC in the range 2.3±0.2 mmol.g_{dry}^{-1}, specifically 2.5±0.0 mmol.g_{dry}^{-1} for CM-PPS. Article [12] evaluated long-term influence of NaOH solution (5-15 wt.%) on heterogeneous IMs. The authors did not observe any changes of IEC during IM exposition but they reported the decrease in resistance. The cause was degradation of PES fabric and related dimensional changes of IMs leading to the increase in membrane porosity.

4 CONCLUSION

Three types of AMs and CMs were compared. Based on the obtained results it was shown that chemical composition of reinforcing fabric is very important for dimensional stability of membranes as well as for their electrochemical properties. Reinforcing with PPS fabric contrary to PES fabric which is used in commercially available IM(H)-PES Ralex membranes had positive impact for dimensional changes minimization. The more IM is resistant to dimensional changes connected to the swelling and ionic form changes, the slower the porosity develops. As a consequence lower amount of ion exchange resin particles is washed out of membrane matrix and fewer pores and voids developed thanks to PES fabric degradation in alkaline environment are filled with solution which surrounds IM. Fabric made of PPS had significantly positive impact on stabilization of IMs electrochemical properties.

***Acknowledgement**: This work was supported by the Ministry of Education, Youth and Sports of the Czech Republic within the framework of the project "Progressive Development of the Membrane Innovation Centre" program NPU I No. LO1418, using the infrastructure of the Membrane Innovation Centre (No. CZ 1.05/2.1.00/03.0084).*

5 REFERENCES

1. Ray P.: Performance studies of heterogeneous ion exchange membranes in the romval of bivalent metal ions in an electrodialysis stack, Journal of applied polymer science 113(2), 2009, pp. 1155-1164, DOI: 10.1002/app.29983
2. Stranska E., Hadrava J.: Tubular anion exchange membranes for cataphoretic boxes, CHEMAGAZÍN XXIX(2), 2019, pp. 18-20
3. Grabowski A., Zhang G., Strathmann H., Eigenberger G.: Production of high-purity water by continuous electrodeionization with bipolar membranes: Influence of concentrate and protection compartment, Separation and Purification Technology 60(1), 2008, pp. 86-95, https://doi.org/10.1016/j.seppur.2007.07.052
4. Stranska E., Nedela D., Valek R., Krivcik J.: Optimization of preparation of heterogeneous cation exchange membranes using different particle size distributions of ion exchange resins, Chemicke Listy 109(9), 2015, pp. 701-709
5. Martins N.C., Rodrigues L.B., do Nascimento F.T., da Silveira G.M., Corte J.F., Flach M.V., Rodrigues M.A.S., Celso F., Jahno V.D., de MartinsR.M.: Evaluation of the influence of method preparation in properties of heterogeneous ion exchange membranes, Proceedings of 8th International Conference on Waste Management and the Environment, 2016, pp. 391-400, DOI: 10.2495/WM160351
6. Gohil G.S., Shahi V.K., Rangarajan R.: Comparative studies on electrochemical characterization of homogeneous and heterogeneous type of ion-exchange membranes, Journal of Membrane Science 240(1-2), 2004, pp. 211-219, https://doi.org/10.1016/j.memsci.2004.04.022
7. Krivcik J., Nedela D., Valek R.: Ion-exchange membrane reinforcing, Desalination and Water Treatment 56(12), 2014, pp. 1-6, https://doi.org/10.1080/19443994.2014.981411
8. Stranska E., Nedela D., Krivcik J., Weinertova K., Vaclavikova N.: Impact of reinforcing fabric thread count on cation exchange membrane properties, International Journal of Clothing Science and Technology 30(4), 2018, pp. 517-524, https://doi.org/10.1108/IJCST-10-2017-0161
9. Bulejko P., Stranska E., Weinertova K.: Electrochemical and mechanical stability of ion-exchange membranes in alkaline solution Chemical Papers 71(7), 2017, pp. 1303-1309, https://doi.org/10.1007/s11696-016-0122-3
10. Brozova L., Krivcik J., Nedela D., Kysela V., Zitka J.: The influence of activation of heterogeneous ion-exchange membranes on their electrochemical properties, Desalination and Water Treatment 56(12), 2015, pp. 3228-3232, https://doi.org/10.1080/19443994.2014.980975
11. Weinertova K., Stranska E., Nedela D., Krivcik J.: Optimization of preparation of heterogeneous anion exchange membrane based on polypropylene, Chemicke Listy 112(7), 2018, pp. 440-445
12. Bulejko P., Stranska E., Weinertova K.: Properties and structure of heterogeneous ion-exchange membranes after exposure to chemical agents, Journal of Solid State Electrochemistry 21(1), 2017, pp. 111-124, https://doi.org/10.1007/s10008-016-3341-1
13. Pirzadeh E., Zadhous A., Haghighat M.: Hydrolytic and thermal degradation of PET fibers and PET granule: The effect of crystallization, temperature, and humidity, Journal of Applied Polymer Science, 106(3), 2007, pp. 1544-1549, https://doi.org/10.1002/app.26788
14. Das J., Halgeri A.B., Sahu V., Parikh P.A.: Alkaline hydrolysis of poly(ethylene terephthalate) in presence of a phase transfer catalyst, Indian Journal of Chemical Technology 14(2), 2007, pp. 173-177, http://nopr.niscair.res.in/handle/123456789/1079
15. East G.C., Rahman M.: Effect of applied stress on the alkaline hydrolysis of geotextile poly(ethylene terephthalate). Part 1: room temperature, Polymer 40(9), 1999 pp. 22841-2288, https://doi.org/10.1016/S0032-3861(98)00451-0
16. Stranska E., Zarybnicka L., Weinertova K., Nedela D., Krivcik J.: Anisotropy of mechanical properties of heterogeneous ion exchange membrane, Chemicke Listy 110(7), 2016, pp. 498-503
17. Ghalloussi R., Garcia-Vasquez W., Chaabane L., Dammak L., Larchet C., Deabate S.V., Nevakshenova E., Nikonenko V., Grande D.: Ageing of ion-exchange membranes in electrodialysis: A structural and physicochemical investigation, Journal of Membrane Science 436, 2013, pp. 68-78, https://doi.org/10.1016/j.memsci.2013.02.011

PROGNOSIS APPLICATIONS NONNARCOTIC HEMP BASED ON THE CRITERIAL CHARACTERISTICS

Natalia Lyalina[1], Olga Yudicheva[1], Olga Votchenikova[1] and Yury Berezovskiy[2]

[1]*Kiev National University of Construction and Architecture, Air Fleet Avenue 31, Kiev, 03037, Ukraine*
[2]*Kherson National Technical University, Berislavskoye Highway 24, Kherson-8, 73008, Ukraine*
lialina1975natali@gmail.com; olga.iudicheva@gmail.com; kompan-olga@ukr.net; berezov.sky.ua@gmail.com

Abstract: *The article is devoted to solving the problem of developing the scientific basis for the primary processing of non-narcotic hemp stems in order to produce high-quality fiber that can be used in various industries. The current state of hemp production in Ukraine and other countries of the world was analyzed and also promising uses of hemp raw materials was considered. Criteria characteristics of straw stalks of non-narcotic monoecious hemp must be considered when developing innovative technologies for preparing trusts and its mechanical processing in order to produce fibers suitable for use in various industries, which will contribute to an increase in the production of hemp products, improve its quality, and increase the competitiveness of non-narcotic hemp products as well as the Ukraine's entry into the world market.*

Keywords: *hemp, processing, criteria charcteristics, content of bast, trust, fiber.*

1 INTRODUCTION

The increase in demand for the environmentally friendly products made of natural raw materials despite a big variety of goods from synthetic and artificial fibers is recently observed in the developed countries of the world. It should be noted that thanks to specific natural properties of natural fibers, including hempy, they cannot be replaced with other types of fibers at production of a certain range of products. Besides, fiber of hemp can replace even linen fiber in the most various scopes of application [1-9]. Therefore today hemp draws to itself great attention both researchers and producers. First, it is a commercial crop which is capable to accumulate huge biological weight in comparison with other cultures. Secondly, it can be used for production of the unlimited range of products in various industries. And the third, it is capable to clean the polluted territories and promoting preservation of the environment.

All parts of a plant of hemp, namely: the fiber emitted from stalks, leaves and seeds; are widely used in the textile, food, chemical, pharmaceutical, cosmetic industry and other branches of the national economy. The list of the products made of hemp now approaches 50 thousand names [10-13].

Thanks to high productivity of hemp in comparison with wood of coniferous and deciduous breeds of trees, to high content of cellulose (nearly 80%) and low content of lignin in fiber and also high qualitative of the paper made on the basis of hempy cellulose (to high rates of whiteness, absolute resistance to breakdown and the absolute resistance to tear), the hemp is competitive raw materials for production of different types of paper: valuable, technical filtering, tissue, printing, etc. The paper of fiber of hemp is made in China, India, USA, the countries of South America, Spain, Great Britain and other countries [12, 13].

Valuable properties of the oil received from hemp seeds, namely high saturation its fatty acids (oleic acid - 10-16%, linolenic acid - 50-60%, gamma and linolenic acid - 2-5%), allow to apply it not only in the food industry, but also in cosmetology (as a component of products for care of a body and spirits), paint and varnish, building industry, etc. Production of oil from hemp seeds now actively develops in Canada, France and the countries of South America [14].

The modern technologies applied in China and Romania allow to produce from hemp fibers the fine fabrics which are characterized by high rates of air permeability, hygroscopicity, wear resistance and durability.

It is known that hemp fibers are widely used for production of the reinforced composite polymeric materials applied in the car, an avia - and shipbuilding. Besides, the ability of hemp to accumulate the big biological weight (more than 15 t/hectare) allows to use it as raw materials for receiving biogas, ethanol and liquid biofuel.

Recently, in our country fiber of hemp was a main type of raw materials only for production of twisted products - ropes and ropes of different types and appointment, a twine, driving belts, etc. However, the high prime cost of the twisted products made of natural raw materials forced businessmen to replace natural fibers with chemical.

Reduction of demand for long fiber of hemp became the reason of reduction of the acreage reserved for this culture. It led to decrease in efficiency of enterprises which are engaged in cultivation of hemp and enterprises for hemp processing as they were the main consumers of a hempy raw materials.

Comparing the level of development of enterprises which are engaged in cultivation of hemp and enterprises for hemp processing in Ukraine and in the other countries of the world, it should be noted that this culture, having huge potential, in our country is not used in full. Such position of the industry is caused by two important reasons. First, only recently it was succeeded to overcome the contradictory attitude of power structures towards this culture connected with insufficient knowledge of people of existence of modern industrial grades of not narcotic monoecious hemp (with the minimum contents the cannabinoid substances of connections or their total absence) which are widely used in production in many countries of the world already now. So, the hemp grades created at Institute of bast cultures of NAAN of Ukraine (Glukhov of the Sumy region) grow up in such states as Australia, Austria, Great Britain, Canada, Netherlands, Germany, Czech Republic, Finland, etc. [9.15]. Secondly, reduction of acreage of hemp in Ukraine in comparison with global trends is caused by lack of demand on long and short hempy fiber in our country, which is domestic sales market of hempy products, impossibility of selling of these products in foreign markets, due to their poor quality and also narrow scope of a hempy fiber.

Exit of the industry on hemp processing from crisis can be reached by development of the latest technologies of processing of straw and trusts of hemp that will allow to receive fiber with new technological properties which will conform to requirements of technologies for their further use in textile, pharmaceutical, pulp-and-paper and other industries. Therefore improvement of the existing technologies of receiving trusts and development of new technology of machining of stalks trusts of hemp which will promote expansion of scope of the fiber received from it, is a relevant task of the industry.

2 LITERATURE REVIEW

Created by the Ukrainian selectors Senchenko G.I., Migal M.D., Vyrovets V.G., Layko I.M., etc. not narcotic grades of hemp are known around the world. Thanks to the biological feature of a plant removed by the Ukrainian scientists which consists in lack of psychotropic compound of tetrahydrocannabinol in total with high performance technical grades of hemp allowed to keep a of enterprises which are engaged in cultivation of hemp in such countries as France, Russia, Canada, China and to revive the industry in one and all economically developed countries of the world.

Works of the leading scientists of Ukraine [2, 5, 15] who confirm that changes of not narcotic grades of hemp were resulted by changes in the morphological structure of a fibrous part of stalks of hemp which exclude a possibility of use of traditional technologies of its processing are devoted to studying of features of the anatomic and morphological structure of stalks and the chemical composition of fiber of not narcotic monoecious hemp. Earlier conducted pilot studies of technological properties of stalks of hemp showed that physicomechanical properties significantly differ in a dioecious hemp which was still widely applied in production from properties of modern grades of not narcotic monoecious hemp.

Achievements of domestic and foreign scientists in the field of preprocessing and profound processing of stalks of not narcotic hemp which are opened in scientific works [4, 9, 12, 14] give the chance to claim that these developments are pioneer and are at an initial stage of pilot studies. Their system development demands the further scientific practices directed to a solution of the problem of effective use of a hempy raw materials in various industries.

Researches and the analysis of physicomechanical properties of various forms of hemp for the purpose of definition and assessment of characteristics on which the modes and parameters of technological processes of receiving high-quality hempy products are based is a main objective of work. In article the current state and the prospects of development of enterprises which are engaged in cultivation of hemp in Ukraine, a possibility of the maximum multipurpose use of this crop is also analysed, to contribute to the development of production of consumer goods and expansion of scope of not narcotic monoecious hemp in various industries.

3 RESEARCH METHODOLOGY

In Ukraine industrial crops of technical hemp till September, 2012 were protected. The industry of enterprises which are engaged in cultivation of hemp therefore suffered huge losses, and cultivation of extremely profitable crop at that time was non-profitable that led to sharp reduction of crops of this valuable commercial crop. Recognition at the level of government institutions of uniqueness of not narcotic grades of hemp allowed to make changes to the Ukrainian legislation and to remove protection of crops of plants with the content of tetrahydrocannabinol of less than 0.08% then acreage of the specified culture in the country increased by 3 times.

Comparing the level of development of enterprises which are engaged in cultivation of hemp and enterprises for hemp processing in Ukraine to other states of the world, it should be noted that this culture, having huge potential, in our country is not used in full. If in other countries of the world production of a hempy fiber increased from 57.5 thousand tons in 1996 to 115 thousand tons in 2005, then in our country, on the contrary, during this period rapid reduction of its production and reduction of acreage from 3200 to 1940 hectares was observed [16-18].

This negative trend, unfortunately, remained and until recently: in 2009 the acreage of hemp was only 300 hectares, in 2010 - 800 hectares, in 2011 - 430 hectares, in 2012 - 650 hectares, in 2013 - 860 hectares, in 2014 - 980 hectares, and since 2015 increase in acreage under technical hemp almost by 3 times (Figure 1) is observed.

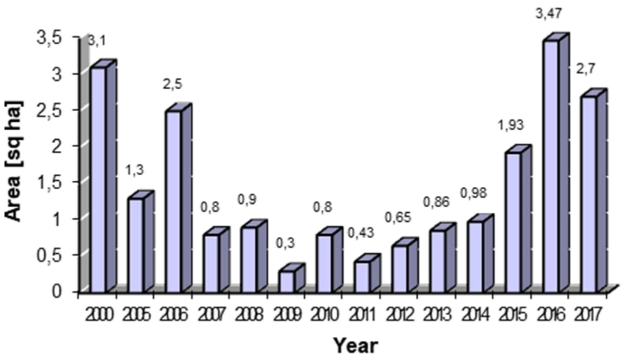


Figure 1 Dynamics of acreage of technical hemp in Ukraine [19]

Increase in demand for hempy raw materials in the world is connected with expansion of the sphere of its use, namely: for replacement of synthetic materials on the basis of natural fiber, production of cellulose, construction materials, products of the food industry and many other things [20]. Thanks to detailed studying of properties of modern not narcotic grades of hemp, development of the latest technologies of its processing allowing to use all components of a stalk of hemp the innovative products with new qualitative characteristics which find broad application in various branches of industrial production [21-23] are created. Fiber content in modern grades of not narcotic hemp is 30-35%. Technical textiles of hemp are used as sea and river ropes, twine, ropes, grids, tarpaulin and canvas and also textile products: fabrics, working clothes, footwear, haberdashery products. In the world not narcotic hemp is used for production of nonwoven and composite materials, geotextiles, cellulose, paper of different types and appointment. Today there is a possibility of use of the whole stalk of not narcotic hemp on the power purposes, in particular, for production of liquid biofuel, ethanol and biogas [24]. A fibre of hemp makes 65-70% of all weight bast stalks and consists mainly of cellulose (45-58%), lignin (21-29%) and pentozan (23-26%). From fibres are made construction and heat-insulating plates, paper, fuel, etc. Hemp is the most suitable raw materials for production of a construction blocks from hemp fibres, than flax. Good strength indicators of a construction blocks from hemp fibres with use fibres of hemp are explained a portlandtsement by the fact that on the enterprises for hemp processing before release of bast fibers of a stalk of hemp are exposed to long hydrothermal processing (within 20-30 days are soaked, then dry). It allows to reduce significantly contents in them the easily hydrolyzed of substances which slow down curing of the portlandtsement. A construction blocks from hemp fibres, light concrete, a kind of wood concrete with application hempy fires as organic filler, is made of mix fibres, binding substance (as a rule, cement), mineral filler (sand) and waters. For a mineralization fibres and accelerations of hardening of mix add chloride calcium, sulfate alumina together with lime-pushonkoy to it or other additives. The volume mass of a construction blocks from hemp fibres is from 400 to 700 kg/m^3. Material has low warm and sound conductivity, is convenient for processing, does not give in to rotting, and is the adverse environment for rodents and insects. It is used for construction of internal partitions in rooms and also for warm and sound insulation. The main producers are France, Australia, Ireland, Germany and Ukraine [25].

It is known that process of preprocessing of bast fiber raw materials consists of a number of consecutive operations which nature and quantity depend on the anatomic structure of stalks and also on many economic and organizational factors. It should be noted that broad use of technologies of nonconventional use of a hemp production, thanks to scientific developments in processing industry, will contribute to innovative development of a hemp breeding of Ukraine [26]. At the same time nearly the only solution of problems which face the enterprises for processing the bast fiber materials is profound processing of low-grade short fiber in various industries, fuller use of production wastes, etc. Complex processing of hemp raw materials is an indispensable condition of overall performance of the enterprise. Besides, now in Ukraine selectors created new highly productive grades of not narcotic monoecious hemp, however processing them on traditional technology does not allow receiving quality fiber. Therefore the solution of an issue of primary and profound processing of modern not narcotic grades needs to be carried out, since correction of the modes and parameters of technological processes of receiving fiber. For the purpose of justification and development of technology of preprocessing of modern grades of not narcotic hemp a number of pilot and theoretical studies of physicomechanical properties of stalks and fiber by not narcotic monoecious hemp and cannabis on the basis of the Kherson National Technical University is conducted. For determination of the main technical characteristics on two types of hemp two sexual types (fimble and female hemp) grades of dioecious hemp as the Ermakovsky local and all sexual types of a high-performance grade of monoecious hemp USO-31 were chosen. By results of these researches it is established that stalks of straw of not narcotic monoecious hemp of various sexual types are characterized by uniformity on such morphological and technological to indicators as length and diameter of stalks, the maintenance of a bass and its explosive loading. Therefore preprocessing of not narcotic monoecious hemp does not demand application of the specific technological modes for plants of each sexual type that is characteristic of preprocessing of stalks of a fimble and a female of hemp dioecious.

Complex researches of physicomechanical properties trusts not narcotic monoecious hemp and cannabis showed that between them there are considerable differences in quality and quantitative indices. Despite increase in explosive loading, decline in quality of fiber of not narcotic monoecious hemp in comparison with cannabis is observed, namely: increase in linear density and reduction of flexibility. The difference in properties demonstrates that technologies which were applied on the dioecious hemp processing plants earlier cannot be used for modern grades of not narcotic monoecious hemp. Therefore there was a need of the detailed analysis and assessment of physicomechanical and technological properties of various forms of hemp. For quantitative assessment of distinctions on physicomechanical characteristics of monoecious not narcotic hemp from similar characteristics of dioecious hemp it is necessary to use methods of mathematical statistics: comparison of two averages selective for selections with randomly the distributed populations - big independent selections [26]. Such assessment is necessary for definition of physicomechanical characteristics most of which differ between two forms of hemp. A dioecious hemp and monoecious hemp further it is accepted to call these characteristics "criteria". Taking into account these characteristics it is necessary to adjust the modes and parameters of technological processes of receiving trusts and its machining.

Let's consider application of the theory of mathematical statistics for assessment of differences of two forms of hemp - a dioecious hemp (fimble and a female hemp) and all types of monoecious hemp (a monoecious female hemp, the monoecious feminized fimble, feminized fimble and monoecious masculinised female hemp) on the following indicators: diameter of stalks of straw and the maintenance of a bass in stalks, an exit of long fiber about trusts, explosive loading and linear density of fiber.

From the theory of mathematical statistics it is known that when independent selections have large volume (not less than 30 everyone), averages selective are distributed approximately normally and selective dispersions are rather reliable estimates of general dispersions. In this interpretation general dispersions can be considered known. Under our assumptions the approximate criterion of comparison of two averages selective takes place. In order that at the chosen significance value α to check a null hypothesis H_0: $M(X) = M(Y)$ about equality of population means of two populations with unknown general dispersions at the competing hypothesis H_1: $M(X) \neq M(Y)$ it is necessary to calculate value of criterion on the presented formula, it is estimated, W_c:

$$W_c = \frac{\bar{x} - \bar{y}}{\sqrt{\frac{D_в(X)}{n} + \frac{D_в(Y)}{m}}} \tag{1}$$

where $\bar{x}$ is an average selective values of criteria characteristics of dioecious hemp; $\bar{y}$ is average selective values of criteria characteristics of monoecious hemp; $D_в(X)$ is selective dispersion for dioecious hemp; $D_в(Y)$ is selective dispersion for monoecious hemp; n is number of measurements of each characteristic dioecious hemp and m is number of measurements of each characteristic of monoecious hemp.

Then according to the table of values of function of Laplace Φ find a critical point of $W_{кр}$ from equality:

$$\Phi(\mathrm{W_{кр}}) = \frac{1-\alpha}{2} \tag{2}$$

If $|W_c| < W_{кр}$, then indicators of physicomechanical characteristics of different sexual types of two forms of hemp differ slightly.

If $|W_c| > W_{кр}$, then indicators of physicomechanical characteristics of different sexual types of two forms of hemp differ considerably and these characteristics have to be used for correction of the modes and parameters of technological processes of receiving trusts and its machining. Significance value $\alpha = 0.05$.

Calculate values of function of Laplace in a critical point by a formula (2):

$$\Phi(W_{кр}) = \frac{1-\alpha}{2} = \frac{1-0{,}05}{2} = \frac{0{,}95}{2} = 0{,}475$$

After that, from the table of values of function of Laplace find that $W_{кр} \approx 1.96$.

For all above-mentioned physicomechanical characteristics of two forms of hemp absolute values of criterion W_c which are presented in Tables 1-3 were calculated and analysed.

Absolute values of criterion W_c on an indicator diameter of stalks of grades of Ermakovsky local and USO-31 are presented in Table 1.

Table 1 Absolute values of criterion W_c according to selective data of diameter of stalks of the studied hemp grades

Grade and sexual types of hemp	Ermakovsky local fimble	Ermakovsky local female	USO-31[1]	USO-31[2]	USO-31[3]	USO-31[4]
Ermakovsky local fimble	0.000					
Ermakovsky local female	82.976	0.000		symmetric.		
USO-31[1]	100.073	23.953	0.000			
USO-31[2]	65.568	8.246	9.828	0.000		
USO-31[3]	76.175	11.524	8.692	1.808	0.000	
USO-31[4]	80.671	17.889	2.115	7.097	5.767	0.000

Note: 1 - monoecious female hemp; 2 - monoecious feminized fimble; 3 - feminized fimble; 4 - monoecious maskulinizirovanny female hemp.

Analyzing values of criterion W_c presented in the table according to selective data of an indicator diameter of stalks, it is possible to draw a conclusion that all values of criterion W_c on an indicator diameter of stalks considerably exceed values of criterion $W_{кр}$, i.e $|W_c| > W_{кр}$. It gives the grounds to claim that on an indicator diameter of stalks the studied grades of hemp differ considerably. An exception is feminized fimble and monoecious feminized fimble USO-31 grades which on an indicator diameter of stalks practically do not differ. These are sexual types of monoecious not narcotic hemp therefore, really, on an indicator diameter of stalks they also should not differ considerably. For monoecious hemp of different sexual types of technology of processing should not differ. Absolute values of criterion W_c on an indicator the maintenance of a bass in stalks of hemp of grades of Ermakovsky local and USO-31 are presented in Table 2. From Table 2 it is visible that all values of criterion W_c considerably exceed values of criterion $W_{кр}$, i.e $|W_c| > W_{кр}$. Thus, on an indicator the maintenance of a bass in stalks the studied grades of hemp differ considerably.

Thus, the criteria characteristics given above - diameter of stalks of straw of hemp and the maintenance of a bass in them - further it is necessary to use for adjustment of parameters and the modes of machining of stalks trusts of not narcotic monoecious hemp in comparison with the modes and parameters of this process for dioecious hemp.

Absolute values of criterion W_c on an indicator an exit of long fiber from trusts of hemp of grades of Ermakovsky local and USO-31 are presented in Table 3.

Analyzing of Table 3, it is possible to draw a conclusion that all values of criterion W_c much more exceed values of criterion $W_{кр}$, i.e $|W_c| > W_{кр}$. Thus, on an indicator an exit of long fiber from trusts the studied grades of hemp differ considerably.

Table 2 Absolute values of criterion W_c according to selective data of an indicator the maintenance of a bass in stalks of the studied hemp grades

Grade and sexual types of hemp	Ermakovsky local fimble	Ermakovsky local female	USO-31[1]	USO-31[2]	USO-31[3]	USO-31[4]
Ermakovsky local fimble	0.000					
Ermakovsky local female	10.340	0.000		symmetrically		
USO-31[1]	25.500	67.882	0.000			
USO-31[2]	19.558	62.191	14.767	0.000		
USO-31[3]	12.738	26.679	8.370	2.025	0.000	
USO-31[4]	3.478	9.588	10.184	6.663	4.950	0.000

Table 3 Absolute values of criterion W_c on selective given vent an indicator of long fiber from trusts of the studied hemp grades

Grade and sexual types of hemp	Ermakovsky local fimble	Ermakovsky local female	USO-31[1]	USO-31[2]	USO-31[3]	USO-31[4]
Ermakovsky local fimble	0.000					
Ermakovsky local female	41.800	0.000		symmetric		
USO-31[1]	43.412	104.355	0.000			
USO-31[2]	34.059	87.057	7.913	0.000		
USO-31[3]	32.271	86.461	10.787	2.530	0.000	
USO-31[4]	31.921	111.734	22.804	11.068	8.165	0.000

Table 4 Absolute values of criterion W_c according to selective data of explosive loading of fiber studied hemp grades

Grade and sexual types of hemp	Ermakovsky local fimble	Ermakovsky local female	USO-31[1]	USO-31[2]	USO-31[3]	USO-31[4]
Ermakovsky local fimble	0.000					
Ermakovsky local female	24.343	0.000		symmetric		
USO-31[1]	58.316	21.922	0.000			
USO-31[2]	49.115	12.456	21.974	0.000		
USO-31[3]	62.879	24.318	3.508	31.623	0.000	
USO-31[4]	38.694	11.617	8.528	2.657	10.733	0.000

Table 5 Absolute values of criterion W_c according to selective data of linear density of fiber studied hemp grades

Grade and sexual types of hemp	Ermakovsky local fimble	Ermakovsky local female	USO-31[1]	USO-31[2]	USO-31[3]	USO-31[4]
Ermakovsky local fimble	0.000					
Ermakovsky local female	41.158	0.000		symmetric		
USO-31[1]	190.671	113.399	0.000			
USO-31[2]	239.473	121.342	14.261	0.000		
USO-31[3]	200.798	110.068	14.078	1.754	0.000	
USO-31[4]	156.183	96.000	7.593	3.178	4.093	0.000

Absolute values of criterion W_c on an indicator explosive loading of fiber and monoecious hemp of the studied grades are presented by a two-blast furnace in Table 4. From Table 4 it is visible that all values of criterion W_c considerably exceed values of criterion $W_{кр}$, i.e $|W_c| > W_{кр}$. Thus, on an indicator explosive loading of fiber the studied grades of hemp differ considerably.

Absolute values of criterion W_c on an indicator the linear density of fiber of the studied grades of hemp are presented in Table 5. Analyzing of Table 5, it is possible to draw a conclusion that practically all values of criterion W_c much more exceed values of criterion $W_{кр}$, i.e $|W_c| > W_{кр}$. Therefore on an indicator the linear density of fiber the studied grades of hemp differ considerably.

Exception is feminized fimble and monoecious feminized fimble USO-31 grades which on an indicator the linear density of fiber differ slightly.

Thus, according to the theory of mathematical statistics physicomechanical characteristics of two forms of hemp which differ considerably were defined. Treat them: diameter of stalks of straw, the maintenance of a bass in stalks, an exit of long fiber from trusts, explosive loading and linear density of fiber. Considering the revealed criteria characteristics of stalks of straw of not narcotic monoecious hemp it is necessary to develop innovative technologies of preparation trusts and its machining for the purpose of receiving the fiber suitable for use in different industries that will promote increase in the production of a hemp produktion, improvement of its quality, improving competitiveness of goods from not narcotic hemp and entry of Ukraine into the world market.

4 RESULTS

Modern market conditions demand new approaches to development of technologies which have to consider the forecast concerning demand for a concrete type of a hemp produktion. The directions of use of hemp change that, in turn, causes requirement of change of technologies of cultivation, cleaning and processing. Besides, modern technologies have to be energy saving and most mechanized.

Effective primary processing of stalks of hemp is impossible without development of innovative technologies and providing the hemp processing enterprises with new, more highly productive effective processing equipment which use will promote improvement of quality, expansion of the range and reduction of prime cost of fiber. In modern conditions new scientific approach to development of technologies is necessary for preprocessing of stalks of not narcotic monoecious hemp.

The presented calculations on the basis of methods of mathematical statistics give the chance to define criteria characteristics of stalks of straw of not narcotic grades of hemp – diameter of stalks and the maintenance of a bass in stalks according to which it is necessary to carry out adjustment of parameters and the modes of technological processes of receiving trusts and machining of hempy raw materials. Criteria characteristics of fibers - explosive loading and linear density - it is offered to use for determination of functional purpose of fibers after machining trusts.

5 REFERENCES

1. Goloborodko P.A.: Hemp conquer the world, Propozitciia 5, 1999, pp. 26-27
2. Virovetc V.G., Laiko I.M., Kirichenko G.I.: Modern hemp collection as not primary source of selection material, Selection, production technology and primary processing of flax and hemp Vol. 4, 2007, pp. 35-42
3. International Year of Natural Fibres 2009 Background Note on Natural Fibres, http://www.fao.org/es/ESC/common/ ecg/322/en
4. Small E., Marcus D.: Hemp: a new crop with new uses for North America, Trends in new crops and new uses, Janick J., Whipkey A. (Eds.), ASHS Press, Alexandria, VA, 2002 , pp. 284-325
5. Migal M.D.: Biology of bast fiber hemp, monograph, Sumi, 2011, 390 p.
6. Dudukova S.V.: Some trends of flax growing and hemp growing in the world. Problems and possibilities in breeding, genetics, technologist of cultivation, harvesting, processing and standardization of bast crops, Glukhov, 2004, 168 p.
7. Goloborodko P.A., Sitneyk V.P., Barannik V.G.: Flax and hemp growing: problems and possibilities. Selection, technology of production and primary processing of flax and hemp, Glukhov, 2000, pp. 3-15
8. Mokher I.V., Barannik V.G.: Actual problems of revival of hemp production in Ukraine. Biology, cultivation, harvesting and primary processing of flax and hemp, Glukhov, 2004, pp. 177-192
9. Chursina L.A., Bogdanova O.F., Lyalina N.P., Rezvikh N.I.: Commodity science and standardization of non-narcotic hemp products, monograph, Kherson, 2012, 308 p.
10. Bolbatenko V.A., Virovetc V.G.: Condition of hemp production in Ukraine. Collection of scientific works of Tavrichesky State Agrotechnological University Vol. 44, Melitopol’, 2006, pp. 69-73
11. Wasko J., Kozlovwski R., Markovski J.: The state and the perspective of flax and hemp utilization it Poland and in the World. Euroflax Vol. 1, Poznan, 2004, pp. 6-10
12. Kane M.: The State of Hemp in America Today: State Legislative Action Builds, http://www.votehemp.com/PDF/VHR/VH_Report_FINAL.pdf
13. Vyrovetc V.G., Sitneyk V.P., Orlov N.M.: Hemp breeding and seed production in Ukraine. Breeding, production technology for primary processing of flax and hemp, Gluhov, 2000, pp. 25-33
14. Rezvikh N.I., Lialina N.P.: Analysis of the potential of the production of non-narcotic hemp. Problems of light and textile industry, Kherson, 2009, pp. 67-69
15. Lialina N.P.: Development of scientific bases of primary processing stalk of non-narcotic hemp for obtaining fibers of various functional purpose, Kherson, 2015, 310 p.
16. Primakov O.A., Marinchenko I.O., Kozorizenko M.P.: Economic efficiency of the hemp industry in modern production conditions. Visnik KNUTD Vol.1, Kiev, 2014, pp. 84-91
17. Shinkaruk M.V., Kuzmina T.O.: Growing and processing of non-narcotic hemp in Ukraine, Pratci TDATU 18(1), Melitopol’, 2018, pp. 90-96
18. Boiko G., Tihosova G., Kutasov A.: Technical hemp: possibilities for market development in Ukraine, Goods and markets Vol. 1, Kiev, 2018, pp. 110-120
19. Grabovska L., Pnevska I.: Possibilities for the cultivation of industrial hemp and the use of hemp raw materials in the EU. Problems and possibilities of development of flax and hemp industry, Sumi, 2009, pp. 17-22
20. Van de Velde K., Van Langenhove L., Kiekens P.: Research on the use of flax as reinforcement for thermoplastic pultruded composites, The 1st Nordic Conference om Flax and Hemp Processing, Tampere University of Technology,. Belgium, 1998, pp. 227-234, http://hdl.handle.net/1854/LU-282322
21. Zhang J.: Natural Fibres in China, Proceedings of the Symposium on Natural Fibres Vol.5, 2007, pp. 53-61
22. Munder F.: Advanced technology for processing of natural fiber plants for industrial application, Woodfiber-Plastics Composites: International Scientific-Technical Conference, Madison, 2003, p. 29
23. Primakov O.A., Giliazetdinov R.N., Koropchenko S.P.: Hemp stem as a raw material for energy use. Topical issues in the development of the flax and hemp industry, Sumi, 2007, pp. 70-73
24. Clevtcov K.N.: Development of scientific bases of resource-saving technologies for complex processing of favorite cultures, Kherson, 2013, 279 p.
25. Shvorob G.M.: Improving the management of the development of hemp processing enterprises, Odesa, 2010, 231 p.
26. Sevastyanov A.H.: Methods and means of research of mechanical and technological processes of textile industry, Moscow: Light Industry, 1980, 392 p.

THERMAL COMFORT PROPERTIES OF KNIT-PLATED FABRIC MADE OF BALLISTIC NYLON WITH WOOL

Rana Faruq Mahbub

College of Human Sciences & Design, Department of Fashion & Textile, King Abdul-Aziz University, Abdullah Suleiman Street, Jeddah, Saudi Arabia
rfmahbub@kau.edu.sa

Abstract: *Recently knitted fabrics structure was developed for protective garments. The new fabric made of ballistic nylon plated with wool called knit-plated was designed and evaluated for thermal and water-vapour resistance. Also, the moisture management properties were investigated to measure the enhancement of wool to the fabric. The surface properties of the fabric, including coefficient of friction and surface roughness, were measured. The results indicates that the ballistic nylon-wool achieved good thermal comfort as well as the wool provide an average accumulative one way water transport. Furthermore, the results reveal that the fabric has smooth surface in the next-to-skin side due to plated wool.*

Keywords: *ballistic nylon, thermal comfort, knit plated, moisture management, surface roughness.*

1 INTRODUCTION

Knitted fabric structures have been used in deferent applications that include protective apparel such as firefighter clothes and soft body armour [1]. Most ballistic body armours used today consist of multiple layers of fabric and are made of expensive high-performance fibres such as Kevlar, Zylon, Twaron or Spectra [1, 2]. Several knitted structures, including single jersey, plush, interlock and 1×1 rib, have been investigated to understand their stab and cut resistant performance. Flambard [2] developed a plush and single jersey knitted fabric using an 18 gauge circular knitting machine. The fabrics were produced using spun yarns of Zylon and Kevlar®29 and weight 2640 g/m^2. Alpyildiz [1] proposed a new style of knitted structure fabric called “double-face” and “double-face-Inlay” for stab and cut resistance by using a flat knit machine. The yarns used were similar to those used by Flambard [2].

However, the thermal comfort properties of the knitted ballistic fabric were not examined in most of this literature. Traditional protective garments used are heavy, bulky, inflexible, and uncomfortable to wear, especially in hot-humid climates [3]. On the other hand, Mahbub [4] has developed a weft-knit plated Kevlar-wool for seamless soft body armour panel for female police officers. The panel consist of five layers, the first layer was made of Kevlar-wool plated and the rest were made of 100% Kevlar plated, the weight were 555 g/m^2 and 520 g/m^2 respectively. In addition, the body armour panel and its fabrics were tested and evaluated for thermos-physiological comfort. The results revel that both fabrics provided a moderate comfort as a multi-layer panel and single fabric [5].

In this study, the Knit-Plated structure made of ballistic nylon-wool fabric was manufactured based on the Mahbub [4] "weft-knit plated" Kevlar-wool fabric, and wool has been incorporated in the fabric to enhance the thermal comfort performance. In addition, ballistic nylon was used to reduce the fabric cost in compares with Kevlar price. The physical properties of the designed knitted fabric was tested and evaluated for thermal and water-vapour resistance. The Sweating Guarded Hot-Plate (SGHP) was used to simulate the heat and processes that occur between the skin and the fabric. Also, the moisture management performance was determined by using the Moisture-Management Tester (MMT), which was used to measure liquid moisture transport behaviour of the fabric including the liquid absorbency, liquid spreading and transport of water through the fabric. In addition, the surface friction was investigated to determine the roughness of the fabric.

1.1 Research objectives

The research aim to evaluate the thermal comfort properties of the developed ballistic nylon wool fabric to determine the enhancement of wool plated to the fabric structure. The objectives are:

1- to measure the thermal and water resistance in order to regulate fabric comfort.

2- to evaluate fabric moisture management properties in order to provide good moisture transfer properties.

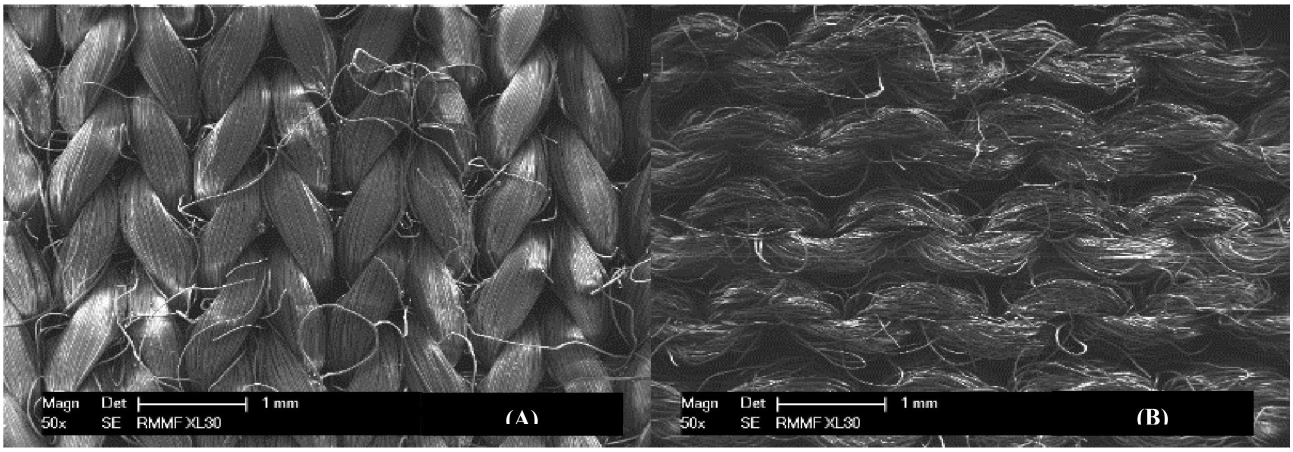


Figure 1 Front face made of ballistic nylon (A) and back face made of wool (B)

2 MATERIAL DESIGN

2.1 Yarn

The yarns used in this study were 93 tex continuous filament of ballistic nylon and 41 tex wool, spun two-fold yarn.

2.2 Ballistic nylon-wool (BNW) fabric production

The BNW fabric was produced using a flat knitting machine Shima Seiki SES-S.WG® and its CAD program. The knit-plated fabric made of ballistic nylon and wool yarns was produced at 18 gauges with 30 knitted fabric quality (tightness). The fabric structure was designed as a single jersey weft-knitted and is illustrates in Figure 1(A, B). The ballistic nylon has been knitted on the front face Figure 1(A) and Figure 1(B) shows the wool yarn plated on the back of the fabric.

3 METHODS AND METHODOLGY

The BNW fabric's physical properties, includes fabric thickness, mass per unit area and dimensional change, were tested. The following standards were used: AS 2001.2.15-1989 for fabric thickness, AS 2001.2.13-1987 for mass per unit area and AS 2001.5.4-1987 for dimensional change. The thermal and water-vapour resistance were measured according to ISO 11092:1993, while moisture management according to AATCC TM 195-2009. In addition, the Automatic Surface Tester (KES-FB4-AUTO-A) was used to measure the surface friction and roughness. The fabric specimens were conditioned for 24 hours under standard conditions of 65±3% relative humidity (RH) and temperature of 20±2°C, according to the Australian Standard AS 2001.1-1995.

3.1 Dimensional change test (D_C)

Three specimens from BNW fabric were marked (200×200 mm) and measured, avoiding the fabric edge by 25 mm. Three pairs of marks parallel to the course and wale directions were drawn. The distance between each pair was measured and recorded. The washing procedure used was (3A) gentle heating and rinsing in 20±3°C for a horizontal machine with household detergent (Surf brand). The samples were dried by flattening the fabric on a table until completely dried. Measurement after washing was recorded. The percentage change was calculated using equation (1):

$$D_C = (D_a - D_o)/D_o \times 100 \tag{1}$$

where: D_c = percentage change in dimension, D_a = dimension after washing and D_o = initial dimension.

3.2 The sweating guarded hot-plate (SGHP)

The designed fabric was tested for thermal and water-vapour resistance before and after washing to measure the difference that could occur. The test specimens were cut as squares of 300×300 mm. Three specimens were tested and the arithmetic mean of three individual reading for each sample was recorded and the standard deviation (*SD*) was calculated. The thermal resistance test measures the energy required to maintain a constant temperature of 35°C on the surface of the measuring plate [6]. Both thermal measurement unit temperature and the thermal guard temperature were set to 35.0°C. The air temperature was 20.0°C and the relative humidity was 65%. The air speed was 1 m/sec. The thermal resistance for the fabric was calculated by measuring the heat temperature between the plate surface and the surrounding ambient air every 15 minute [7].

The water-vapour test measured the power required to keep a constant vapour pressure between the top and the bottom surface of the fabric [8]. The test recorded the average power required to keep the measuring unit at its selected temperature based on 15 minute integration. The value of the arithmetic mean of three reading results from each fabric was calculated. The test atmosphere was 35.0°C and 40% relative humidity for the water-vapour test measurement unit. The thermal guard temperature was set to 35.0°C and the air speed was 1 m/sec. The water-vapour resistance results were calculated by the vapour pressure difference between the saturated plate surface and the ambient air according to the Standard [7].

3.3 Moisture-management tester (MMT)

The MMT instrument was used to test the liquid solution transfer and distribution behaviour. The test started by placing an 80×80 mm test specimen between two horizontal electrical sensor rings. A saline solution (9 g sodium chloride per liter) was dripped freely onto the top surface at the centre of the fabric. As the solution moved, the moisture behaviour of the test specimen was measured and recorded. The MMT parameters measured were:

- Wetting time - the time in which the top and bottom surfaces of the fabric just started to get wet respectively after the test commenced. The results can be explained as following: **1)** ≥120 no wetting; **2)** 20-119 slow; **3)** 5-19 medium; **4)** 3-5 fast; **5)** <3 very fast.
- Absorption rate - the average moisture absorption ability of the fabric's top and bottom surfaces during the rise of water content, respectively. The results can be explained as following: **1)** 0-10 very slow; **2)** 10-30 slow; **3)** 30-50 medium; **4)** 50-100 fast; **5)** >100 very fast.
- Maximum wetted radius - defined as the maximum wetted ring radius at the top and bottom surfaces, respectively. The results can be explained as following: **1)** 0-7 no wetting; **2)** 7-12 small; **3)** 12-17 medium; **4)** 17-20 fast; **5)** >22 very fast.
- Spreading speed - the accumulative spreading speed from the centre of the fabric sample to the maximum wetted radius. The results can be explained as following: **1)** 0-1 very slow; **2)** 1-2 slow; **3)** 2-3 medium; **4)** 3-4 fast; **5)** >4 very fast.
- The accumulative one-way transport capability (OWTC) - which measure the water content between the two surfaces. The higher results indicate that the quicker and easier for water to transfer to the atmosphere from the skin. The results can be explained as following: **1)** <-50 very poor; **2)** -50-100 poor; **3)** 100-200 good; **4)** 200-400 very good; **5)** >400 excellent.
- The overall moisture management capability (OMMC) - indicates the capability of the fabric to manage the transport of the water. In other words, the higher result means better moisture management. The results can be explained as following: **1)** 0-0.2 very poor; **2)** 0.2-0.4 poor; **3)** 0.4-0.6 good; **4)** 0.6-0.8 very good; **5)** >0.8 excellent.

3.4 Automatic surface tester

The coefficient of friction (MIU) and the surface roughness (SMD) was measured. The test was on the wool face of the BNW, which represent the next-to-skin side, of the fabric. Three fabric samples were cut to 200×200 mm and then placed under the test sensor, which measures the friction at three different positions on each specimen from the next-to-skin side. The wales and courses directions were measured and the arithmetic mean was recorded. The range for MIU is from 0 to 1, where the value close to 1 indicates increasing friction and decreasing smoothness. The range for SMD is range among 0 to 20, the value of 20 can be considered as the maximum surface roughness (irregularity) [9].

4 RESULTS AND DISCUSSION

The BNW fabric physical properties results are shown in Table 1.

Table 1 Fabric physical properties

Knit-plated Fabric (BNW)		
Thickness [mm]	Mass per unit area [g/m²]	Dimensional change [%]
1.2	530	wales -1 courses -2.5

It can be seen that the BNW fabric has reasonable thickness however the fabric mass is heavy with 530 g/m^2. Furthermore, the BNW dimension has changed after washing due to the nature of wool fibre. The wales direction shrunk about (-1%), while the courses lost more than with (-2.5%) of it dimension due to the plated wool in the back as shown in Figure 1.

4.1 Thermal and water-vapour resistance

The thermal resistance results before and after washing are shown in Figure 2.

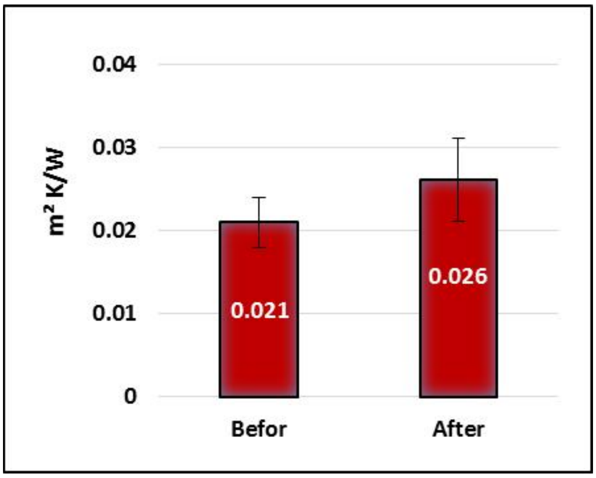


Figure 2 Thermal resistance results

The results reveal minor increase in thermal insulation after fabric been washed, which could be due to the fuzz of wool fiber that appear after washing. In addition, the BNW fabric is heavy and has achieved almost the high rate of thermal resistance value of 0.026±0.01 m².K/W. Data indicates that the developed fabric can transfer heat away, hence can be considered as comfortable in moderate activity. According to the Standard, the thermal resistance for heavy-weight fabrics should be between 0.02 and 0.025 m².K/W.

Water-vapour results are shown in Figure 3. The results indicate slight increase about 0.17 m².Pa/W. Therefore, the fabric can be considered as a comfortable and breathable fabric.

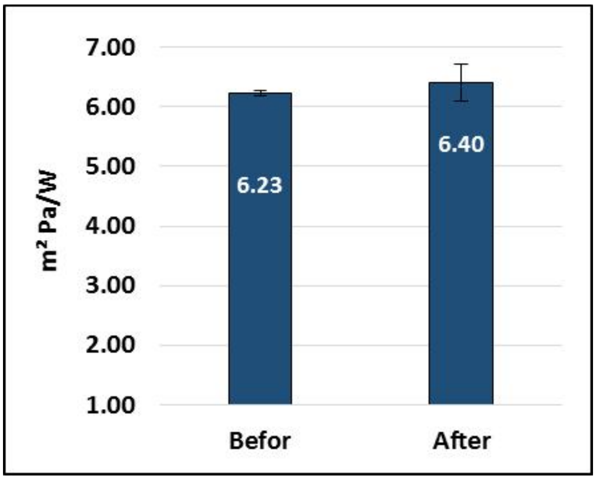


Figure 3 Water-vapour resistance

According to Horrocks [8], if a fabric achieves a value less than 20 m².Pa/W, it can be considered as breathable and comfortable at a moderate activity rate. The BNW fabric after wash was 6.40 m².Pa/W, which is less than the standard.

4.2 Moisture-management

For the MMT tests, the ballistic nylon face was on the bottom surface (UB) of the machine, which is the outer-to-skin side of the fabric. The plated wool was located on the next-to-skin side, which represent the top surface (UT) of the machine. The moisture measurement properties for the BNW are summarized in Table 2.

Table 2 Fabric MMT results

	UT	UB
Wetting time [s]	15.2	30
Absorption rate [%/s]	37.3	25.5
Wet-out radius [mm]	15	19
Spreading speed [mm/s]	1.3	2.5
OWTC [%]	145.8	
OMMC	0.4	

The results show that the wetting time between the two surfaces is varied. The low wetting time and high absorption rate of the wool surface suggest that the wool surface can absorb water faster than the ballistic nylon surface. Hence the wool face is next-to-skin for better moisture management. In addition, Figure 4 shows the water content versus times and confirms that the wet-out radius for UT was lower than UB, which means UT has a moderate ability to transfer the absorbed water to the outer surface.

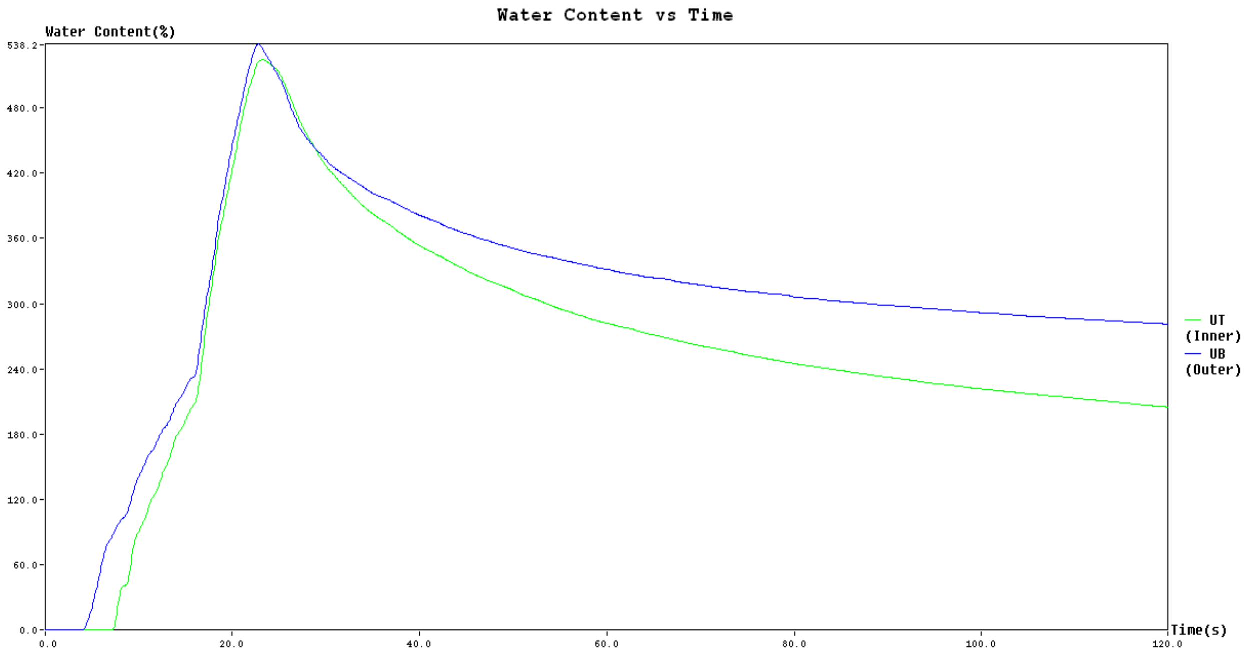


Figure 4 Water content versus times

Figure 5 shows the wet-out radius difference between the two surfaces.

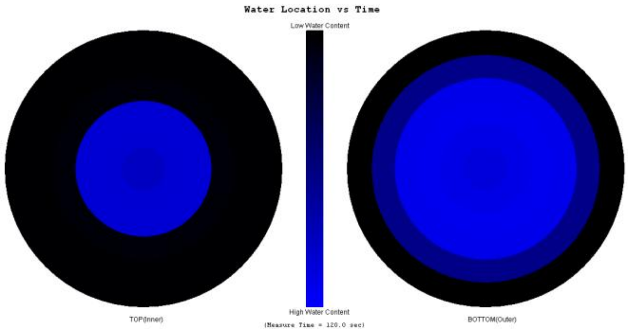


Figure 5 Fabric moisture transport

The result reveals that the BNW fabric has a relatively large spreading rate (2.5 mm/s) and large wet-out radius (19 mm) on the UB, indicating that liquid can spread quickly, transfer easily and dry quickly on the outer surface of the fabric. The fabric OWTC was 145.8% and the OMMC was 0.4 hence, the grade was good. Figure 6 illustrates the finger print of the BNW fabric, which is the moisture management property for all the parameters. This is indicating that the BNW knit-plated fabric has an average water penetration between both surfaces.

4.3 Surface friction (MIU) and roughness (SMD)

The fabric coefficient of friction and the surface roughness are shown in Table 3 for both wales and courses directions.

Table 3 Surface properties

coefficient of friction (MIU)		surface roughness (SMD)	
wales	**course**	**wales**	**course**
0.33±0.099	0.19±0.001	17.25±0.94	4.37±0.57

The table reveals the significant differences between the wales and course directions with 0.33 and 0.19 MIU, respectively. This due to the wool plated in the next-to-skin side as the course direction would be smoother than the wale direction, which can be confirmed in Figure 1(B) for the back face structure. According to machine manual [9] the range for MIU is from 0 to 1, where a value close to 1 indicates increasing friction and decreasing smoothness. In addition, the BNW has a low coefficient of friction in both direction with (<0.05) and can be considered as a smooth fabric when it be worn in the next-to-skin.

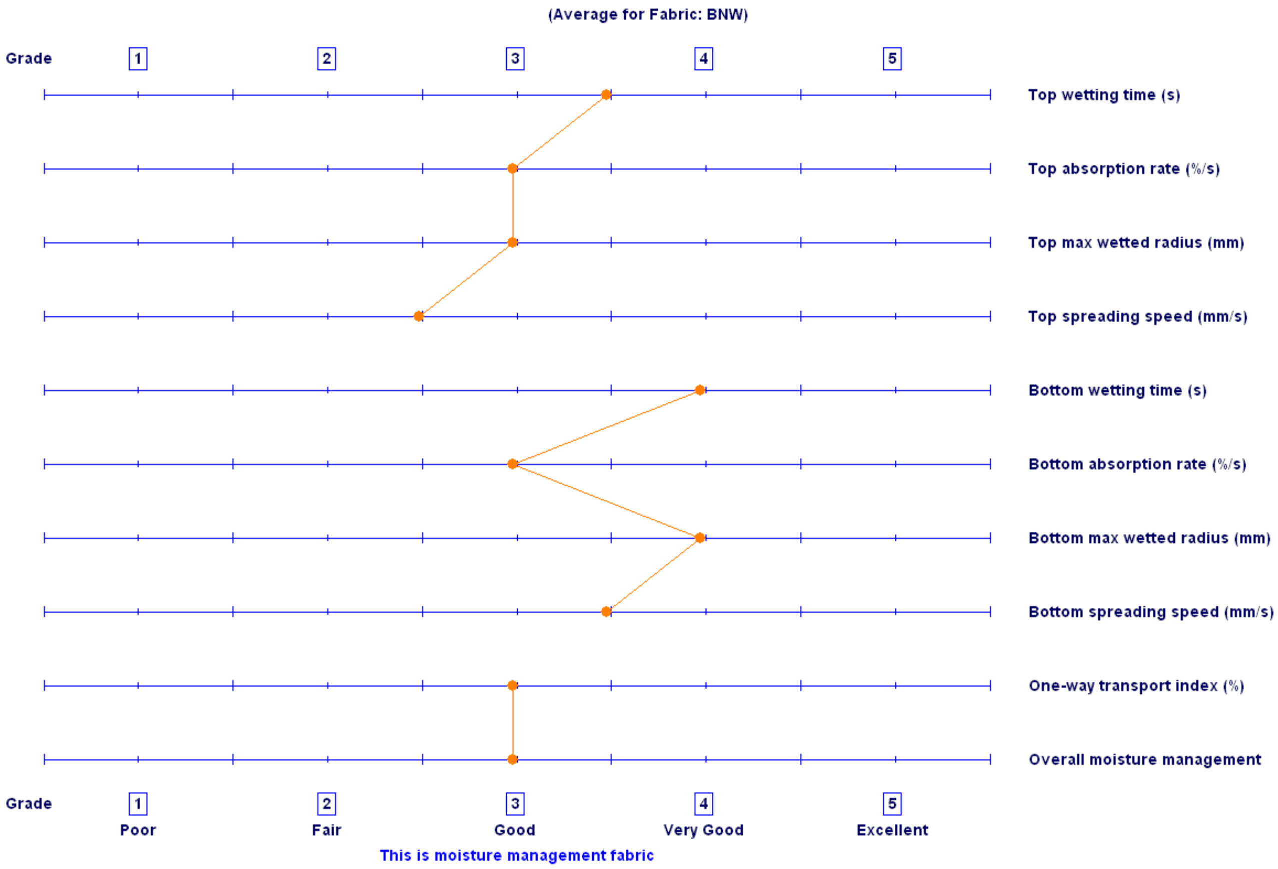
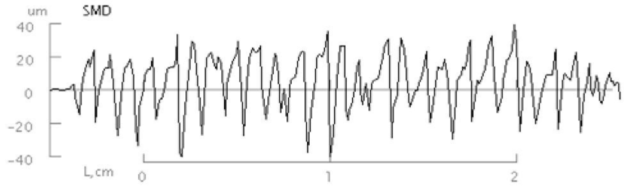
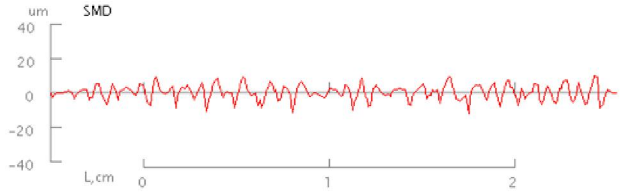


Figure 6 Fabric finger print of MMT properties

The fabric surface roughness is shown in Figure 7. It can be seen that the wale direction roughness is higher than the course with 17.25 SMD. On the other hand, the roughness is remarkable in the course direction with 4.37 SMD, indicating the less regularity that the wale.



Wale



Course

Figure 7 Fabric surface roughness (irregularity)

According to the machine manual [9] for SMD the range is among 0 to 20, the value of 20 can be considered as the maximum surface roughness (irregularity). In spite of the low SMD in the course direction, the wale illustrates the high surface roughness close to the 20 SMD. This is due to the plated structure of the back face of the BNW fabric which cases the irregularity. From the results it can be reveal that the BNW fabric has low coefficient of friction and high roughness in the next-to-skin side.

5 CONCLUSION

A new weft knit-plated fabric made from ballistic nylon and wool using a flat knitted machine was developed. The thermal and water-vapour resistance were evaluated for comfort. Also, the moisture management performance and the surface properties were measured. The results reveal that the new fabric has good thermal and water-vapour resistance and can be considered as comfortable in moderate activity rate. Furthermore, plating wool into the fabric produced good moisture absorbency and transport properties. The fabric shows high irregularity in surface roughness (SMD) and low value of coefficient of friction (MIU), the fabric can be worn next-to-skin.

6 REFERENCES

1. Alpyildiz T., Rochery M., Kurbak A., Flambard X.: Stab and cut resistance of knitted structures: a comparative study, Textile Research Journal 81(2), 2011, pp. 205-214, https://doi.org/10.1177/0040517510383617
2. Flambard X., Polo J.: Stab resistance of multi-layers knitted structures: comparison between para-aramid and PBO fibers, Journal of Advanced Materials 36(1), 2004, pp. 30-35
3. Tavanai H., Wang L., Golozar M., Ebrahimzade M.: An investigation on the piercing resistance of abrasive particle coated fabrics, The 1^{st} International and the 7^{th} National Iranian Textile Engineering Conference, Rasht, Iran: ACECR-Amirkabir University of Technology Branch; 2009
4. Mahbub R.F., Wang L., Arnold L.: Design of knitted three-dimensional seamless female body armour vests, International Journal of Fashion Design, Technology and Education 7(3), 2014, pp. 198-207, https://doi.org/10.1080/17543266.2014.956152
5. Mahbub R., Nayak R., Wang L., Arnold L.: Comfort properties of 3D-knitted seamless female body armour vests, The Journal of the Textile Institute 108(11), 2017, pp. 1997-2005, https://doi.org/10.1080/00405000.2017.1306904
6. Gibson P., Auerbach M., Giblo J., Teal W., Endrusick T.: Interlaboratory evaluation of a new sweating guarded hot-plate test method (ISO 11092), Journal of Building Physics 18(2), 1994, pp. 182-200, https://doi.org/10.1177/109719639401800207
7. ISO 11092:1993(E). Textile - physiological effects - measurement of thermal and water-vapour resistance under steady - state conditions (sweating guarded-hotplate), International Organization for Standardization 1993, ISO 11092:1993(E)
8. Horrocks A.R., Anand S.C. (Eds): Handbook of Technical Textiles, 1^{st} Edition, Woodhead Publishing, 2000, Hardcover ISBN: 9781855733855, eBook ISBN: 9781855738966
9. KATO TECH CO. LTD., Automatic surface tester, Kyoto, 2010, Catalog No: KESFB4-AUTO-A

SEAM SLIPPAGE AND PUCKERING OF SEWN COTTON FABRICS

Ghada Ali Abou Nassif

Fashion Design Department, Design and Art Faculty, University of Jeddah, Jeddah, Saudi Arabia
drghada2017@gmail.com

Abstract: *Seam puckering and slippage are the main parameters which determine the seam and sewn fabrics quality. This study sheds light upon the effects of weave structure, sewing needle size and weft yarn density on seam slippage and puckering. A full factorial design with 3^3 experiments was executed to investigate this study. Non-linear regression models were derived to correlate seam quality with stitch density and needle size for all weave structures. From the experimental results, it was revealed that all parameters under study were found to have a significant impact on seam slippage and puckering.*

Keywords: *Seam slippage, puckering, seam performance, sewn fabrics, stitch density, seam type.*

1 INTRODUCTION

The quality of sewn textile products is largely determined by their sewing qualities. Some of the moist important characteristics which are used to determine and evaluate the quality of sewn garment are seam slippage, puckering, seam strength and efficiency. When the sewn fabrics at their both sides of seams undergo dynamic or static stresses, the slippage of their constituent yarns away from these seams refers mainly to seam slippage. This slipping of the seams generally deteriorates the sewn fabric appearance and reduces its usage life. When sewn fabrics undergo applied forces, which result in slipping weft yarns over warp ones or the vice versa, causes what called seam slippage. This mechanical characteristic of the seam generally relies on type and content of the constituent fibers, type and structure of the constituent yarns, seam size, seam type and allowance, stitch density and constituent yarn densities, sewing threads linear density and tension, and the woven fabric constructional parameters [1-9].

Many research studies related the seam slippage to fabric and sewing parameters. Kalaoglu, et al. [10] related seam slippage to the fabric weaves and weft yarn density. Meric and Durmaz [11] investigated the influence of sewing thread structure and lubrication ratio on seam slippage. In their study, sewing threads were made up of multifilament, staple and core-spun polyester with different lubrication ratios range between 2 and 4% and with different twist factors. They have found that seam opening was more related to fabric structure than sewing thread structure. Sewing thread structure and the value of twist multipliers were found to have no influence on seam slippage. However, core-spun sewing thread exhibited more resistance to seam slippage than other sewing thread types. Bharani, et al. [12] studied the influence of cotton woven fabric structures treated with silicon softener on seam slippage. The results obtained from this study revealed that the finishing of cotton woven fabrics with silicon softener reduced the seam slippage significantly. Also it was found that cotton fabric with plain structure has a higher seam slippage than twill and satin woven structures. In another research study [13], the higher seam slippage associated with plain woven fabrics is attributable to the highest intersections and friction between warp and weft yarn in the weave repeat. It was also stated that not only fabric structure, sewing thread structure and sewing machine condition but also dyestuffs significantly affect the seam slippage [14]. Sewing thread tension, displacement of sewing fabrics' yarns, machine feeding and sewn fabric shrinkage which occur after or during sewing or laundering processes results in gathering seams of sewn garment which causes what so called seam puckering. This undesirable phenomenon leads to unwanted appearance of the seam line and consequently reduces the aesthetic value of sewn products. Therefore it is acquired much attention from researchers in the last two decades [15]. Nguyen, et al. [16] evaluated seam puckering objectively using fuzzy logic. The data of seam pucker in this study were obtained from 3D designed scanning. The measurement process determined the amplitude, wavelength and wave generating points. The correlation coefficient between these shape parameters of the seam puckering and objective grade was found to be 0.94. In another study [17] it was found that less extensible sewing threads do not affect the seam puckering. While sewing thread and fabric shrinkage have a huge influence on seam puckering.

Finally, the seam performance mainly depends upon the mechanical properties of the sewing threads and sewn fabrics. Fabric and their constituent yarn mechanical properties have been investigated in numerous studies [18-28]. While seam slippage and puckering still need more investigation. Therefore, this paper focuses on studying the slippage of the seams and their puckering during sewing process. The effects of sewing thread linear density, stitch densities and weave structure of woven fabrics were intended to be investigated on seam slippage and seam puckering.

2 EXPERIMENTAL PART

2.1 Materials

Throughout this study, twenty seven sewn cotton fabric samples were produced. These sewn fabrics under study made from 100% Egyptian cotton yarn fabrics with warp and weft yarns of count 30/1 Ne. The warp yarn densities were kept constant at 60 end/inch while the weft density was varied as 50, 60 and 70 ppi respectively. The fabrics samples were woven with different weave structures, i.e. plain-1/1, twil-2/2 l, and satin-4. After leaving the weaving machine, all fabric samples were desized, scoured and bleached. The general view of weave repeat for all structures was shown in Figure 1.

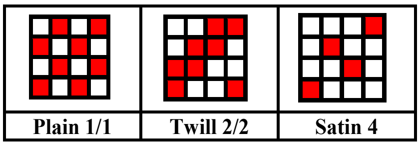


Figure 1 Weave repeats used in this study

The cotton fabric samples were cut in the warp direction with a dimension of 10 cm length and 10 cm width; thereafter the width of all samples was raveled to be 5 cm. Each tow raveled samples were put on each other and sewn in the weft direction. The sewing process was accomplished using a Joki DDL-5550 Lockstitch sewing machine with stitch density 7 stitches per cm; while sewing needle size was varied. All fabrics were sewn using stitch of type 301 Lockstitch (shown in Figure 2) and superimposed seam of type SSa as shown in Figure 3. A sewing thread made of 100% polyester core spun yarn with linear density 22 tex was also used to sew the specimen samples. The levels of fabric and sewing parameters were listed in Table 1.

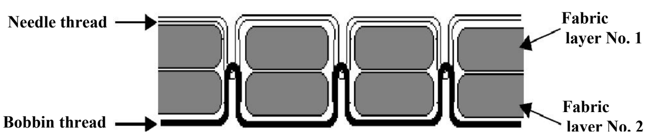


Figure 2 Lockstitch of type 301

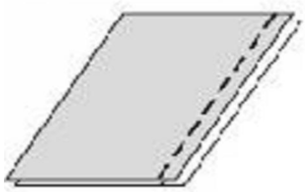


Figure 3 General view of superimposed seam of type SSa

Table 1 Sewing parameters used in this study

Weave structure	Weft density [ppi]	Sewing needle count (needle size)
Plain 1/1	50	80
Twill 2/1	60	90
Satin 4	70	100

2.2 Laboratory testing

Before testing, all fabric samples were conditioned in 20±2°C temperature and relative humidity 65±2% for one day. For each test method, ten readings were carried out for each sample and then their average was calculated.

In this study, seam puckering of different sewn garments was evaluated and measured objectively using the seam thickness strain which is considered an indicative to seam puckering. This test was done according to standard ISO 9073-2: 1997-02. The seam thickness strain measures the percentage increase in the sewn fabric thickness over the thickness of woven fabrics without sewing under a constant compression of load 2 kPa. The seam puckering can be calculated using thickness strain as follows:

$$\textit{Thickness strain [\%]} = \frac{S-2F}{2F} \times 100 \qquad (1)$$

where: *S* - seam thickness and *F* - fabric without seam thickness.

Throughout this study, seam slippage resistance in weft direction, in which warp yarns slipping over weft ones, was carried out using Instron of model 4411 testing tester in accordance with International standard ISO 13936-1-2004.

2.3 Statistical analysis

In order to disclose the influence of independent parameters, i.e. weave structure, weft density and sewing needle size on seam slippage and puckering, a 3^3 full factorial design was implemented. This factorial design was statistically analyzed using Analysis of variance (ANOVA) to detect the significant effect of each factor on seam quality parameters. The significance level was determined as 0.05 ≤ α (significance level) ≤ 0.01. In order to detect the regression relationship between each of seam slippage and seam puckering and the independent variables, i.e. weft density and sewing needle size, a non-linear regression model was derived. The regression models in this study were derived for each type of weave structure; and these models have the following form:

$$Z= a_0 + a_1\ x + a_2\ y + a_3\ xy + a_4\ x^2 + a_5\ y^2 \qquad (2)$$

where: Z - seam quality parameter, i.e. seam slippage or seam puckering; x - weft density [ppi]; y - sewing needle size [Nm]; a_0 – constant; a_1, a_2 - regression coefficients.

3 RESULTS AND DISCUSSION

Throughout this study, the effects of independent parameters i.e. weave structure, sewing needle size and weft density on seam quality which lies in seam slippage and puckering will be discussed. The effect of weft density and sewing needle size on seam quality parameters for each weave structure will be plotted and investigated.

Generally, the sewing needle diameter is called needle count or needle size. To express the sewing needle size, there are two well-known systems in the apparel industry. These are metric and singer systems. Metric system, which abbreviated as Nm was used to express sewing needle size or count in this study. In this system, as the metric count increases, the sewing needle size also increases and also the needle diameter increases. One Nm is equal to one hundredth of millimeter that is the needles of count 80, 90 and 100 Nm corresponds to the diameter of 0.8, 0.9 and 1 mm respectively.

3.1 Effects on seam slippage

Seam slippage is a pulling away or separation of fabric yarns at the seam, resulting in gaps or holes to develop without yarn breakage. The values of seam slippage resistance against both weft density and sewing needle size for different weave structure were depicted in Figures 4-6. The results of the statistical analysis were listed in Tables 2-4. It can be proved that weft density and sewing needle size have a huge influence at 0.01 significance level on seam slippage.

From Figures 4-6 it can be noticed that as the sewing needle size increases, the seam slippage resistance decreases. By contrast, as the weft density increases, the seam slippage resistance has the same manner. The resistance to seam slippage of plain, twill and satin weaves increased by 22, 25 and 13% respectively with the increase in weft density from 50 to 70 ppi. Increasing the contact points between sewn fabric yarns and sewing thread occurs with increasing the stitch density, which in turn giving a strong gripping of fabric yarns which preventing them from slippage.

For plain, twill and satin weaves, a reduction in seam slippage resistance was exhibited by 12, 11 and 17% with the increase in sewing needle size from 80 to 100 Nm. Regardless the influence of the weft density, increasing sewing needle size from 80 to 100 Nm leads to a reduction of seam slippage resistance by approximately 12, 11 and 17% for plain - twill and satin sewn fabrics.

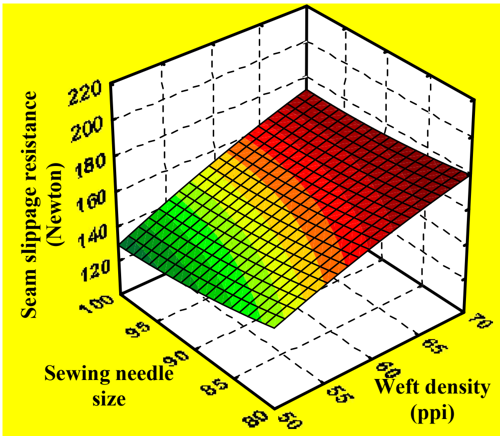


Figure 4 Response surface of the influence of weft density and sewing needle size on seam slippage resistance of sewn ***plain fabrics***

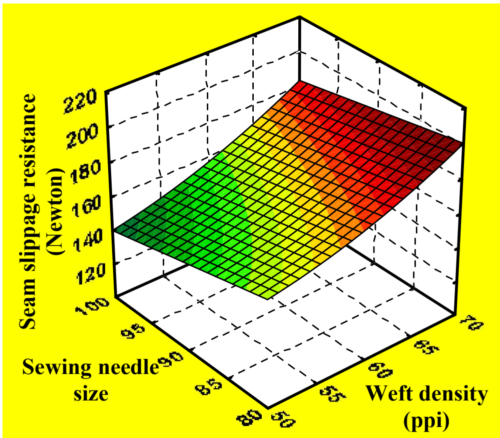


Figure 5 Response surface of the influence of weft density and sewing needle size on seam slippage resistance of sewn ***twill fabrics***

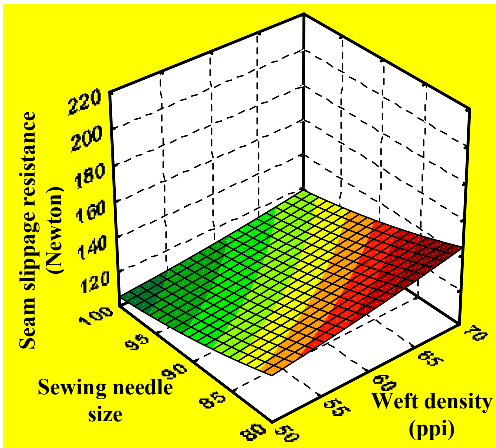


Figure 6 Response surface of the influence of weft density and sewing needle size on seam slippage resistance of sewn ***satin fabrics***

Table 2 ANOVA results for the effects on seam slippage of ***plain fabric***

Source of variation	Sum - Squares	Degree of freedom	Mean squares	F value	P value	F_{crit} value
Weft density	1688.889	2	844.444	76.000	0.001	6.944
Sewing needle size	705.556	2	352.778	31.750	0.004	6.944
Error	44.444	4	11.111			
Total	2438.889	8				

Table 3 ANOVA results for the effects on seam slippage of ***twill fabric***

Source of variation	Sum - Squares	Degree of freedom	Mean squares	F value	P value	F_{crit} value
Weft density	1777.556	2	888.778	192.747	0.000	6.944
Sewing needle size	450.889	2	225.444	48.892	0.002	6.944
Error	18.444	4	4.611			
Total	2246.889	8				

Table 4 ANOVA results for the effects on seam slippage of ***satin fabric***

Source of variation	Sum - Squares	Degree of freedom	Mean squares	F value	P value	F_{crit} value
Weft density	402	2	201	46.385	0.002	6.944
Sewing needle size	914.667	2	457.333	105.538	0.000	6.944
Error	17.333	4	4.333			
Total	1334	8				

The negative impact of sewing needle size on seam slippage resistance may be due to increase the opening in the sewn fabric when penetrating the needle in the fabric which results in the reduction of seam slippage resistance.

The regression relationships which correlate the resistance to seam slippage with both weft density and sewing needle size have the following non-linear forms:

$$\textit{Seam slippage (Newton)-plain weave} = \\ = 384.2 - 5.1x - 1.8y + 0.05x^2 + 0.013xy \tag{3}$$

$$\textit{Seam slippage (Newton)-twill weave} = \\ = 341.7 + 2.7x - 6.6y - 0.03x^2 + 0.03xy + \\ + 0.03y^2 \tag{4}$$

$$\textit{Seam slippage (Newton)-satin weave} = \\ = 368.4 + 0.51x - 5.2y + 0.01x^2 - 0.01xy + \\ + 0.03y^2 \tag{5}$$

3.2 Effects on seam puckering

One of the most frequent sewability problems confronting the garment industry is the seam puckering. This phenomenon can adversely affect the garment appearance at the seam line. Seam puckering affects significantly by sewing thread tension, structural jamming, finishing type, seam and sewing parameters.

The values of seam puckering at the levels of weft yarn density and sewing needle size for different weave structures were plotted in Figures 7-9. The results of the statistical analysis listed in Tables 5-7 showed that weft density and dewing needle size have a significant impact on seam puckering. It was also proved that there is a significant difference among the three weave structures in relation to seam puckering.

Table 5 ANOVA results for the effects on seam puckering of ***plain fabric***

Source of variation	Sum - Squares	Degree of freedom	Mean squares	F value	P value	F_{crit} value
Weft density	300.222	2	150.111	57.489	0.001	6.944
Sewing needle size	160.222	2	80.111	30.681	0.004	6.944
Error	10.444	4	2.611			
Total	470.889	8				

Table 6 ANOVA results for the effects on seam puckering of ***twill fabric***

Source of variation	Sum - Squares	Degree of freedom	Mean squares	F value	P value	F_{crit} value
Weft density	317.556	2	158.778	21.817	0.007	6.944
Sewing needle size	166.889	2	83.444	11.466	0.022	6.944
Error	29.111	4	7.278			
Total	513.556	8				

Table 7 ANOVA results for the effects on seam puckering of ***satin fabric***

Source of variation	Sum - Squares	Degree of freedom	Mean squares	F value	P value	F_{crit} value
Weft density	192.889	2	96.444	66.769	0.001	6.944
Sewing needle size	112.889	2	56.444	39.077	0.002	6.944
Error	5.778	4	1.444			
Total	311.556	8				

From these figures it can be noticed that as the sewing needle size increases, the seam puckering also increases; while seam puckering decreases with increasing the weft yarn density. Increasing the weft yarn density from 50 to 70 ppi cm leads a reduction in the seam puckering by 38, 35 and 35% for plain 1/1, twill 2/2 and satin 4 respectively. Decreasing the seam pucker with weft yarn density may be attributed to increasing woven fabrics weight, which in turn decreases the seam puckering.

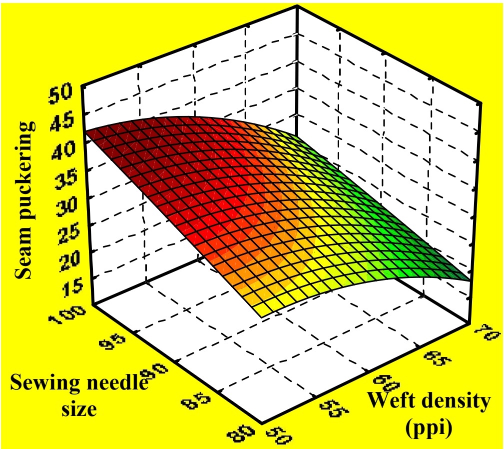


Figure 7 Response surface of the influence of weft density and sewing needle size on seam puckering of sewn ***plain fabrics***

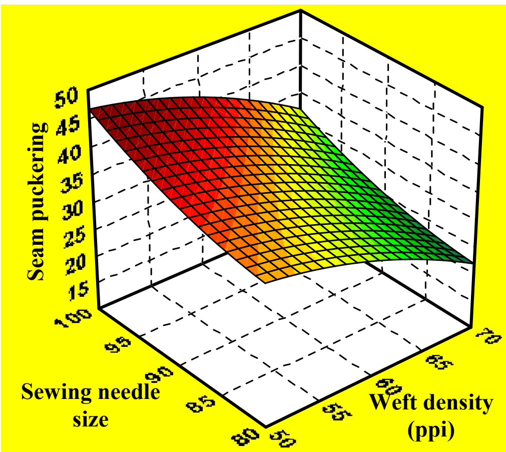


Figure 8 Response surface of the influence of weft density and sewing needle size on seam puckering of sewn ***twill fabrics***

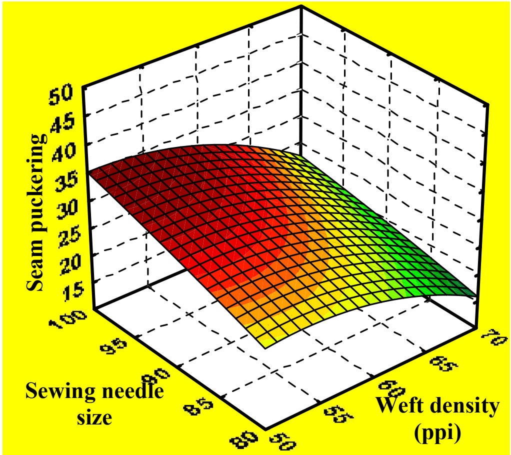


Figure 9 Response surface of the influence of weft density and sewing needle size on seam puckering of sewn ***satin fabrics***

The effect of sewing needle size was found to have an inverse trend to the effect of stitch density. The higher the needle size the higher is the seam puckering values for all weave structures. Increasing the sewing needle size from 80 to 100 Nm results in increasing the seam puckering by 41% for plain weave, 34% for twill weave and 40% for satin weave. It was also deduced that twill woven fabric associated with higher seam puckering values, while satin weaves accompanied by lower seam puckering values.

The relationships which correlate the seam puckering with both weft density and sewing needle size have the following non-linear forms:

$$\textit{Seam puckering-plain weave} = -168.4 + 4.2x + 1.6y - 0.03x^2 - 0.01xy - 0.002y^2 \quad (6)$$

$$\textit{Seam puckering-twill weave} = 87.9 + 2.1x - 2.6y - 0.02x^2 - 0.03xy + 0.023y^2 \quad (7)$$

$$\textit{Seam puckering-satin weave} = -179.8 + 4.4x + 1.6y - 0.03x^2 - 0.01xy - 0.003y^2 \quad (8)$$

4 CONCLUSION

Seam slippage and seam puckering are the main factors influencing the appearance of garment. These seam quality parameters are affected by many sewing process and seam variables. In this study the effect of weft yarn density, weave structure and sewing needle sized on seam slippage and puckering were investigated. A full factorial design of 3^3 experiments was performed and analyzed using ANOVA. In order to derive regression relationships between seam quality, sewn woven fabric and sewing parameters, a regression analysis was also used. The findings of this study can be sum up as follows:

- Weave structure, weft yarn density and sewing needle size were found to have a huge influence on seam slippage resistance and seam puckering.
- As the weft density increases, the seam slippage resistance increases. On the contrary, the higher the sewing needle size, the lower is the resistance to seam slippage.
- Increasing the weft density enhances the seam appearance by lowering the values of seam puckering.
- Increasing sewing needle size results in yarn jamming, which in turn increases the values of seam puckering.
- Sewn fabrics from plain weave structure associated with higher seam slippage resistance compared to other weave structures. While twill structures exhibited higher seam puckering.

5 REFERENCES

1. Yildirim K.: Predicting seam opening behavior of woven seat fabrics, Textile Research Journal 80(5), 2010, pp. 472-480, DOI: 10.1177/0040517509355348
2. Gribaa S., Ben Amar S., Dogui A.: Influence of sewing parameters upon the tensile behavior of textile assembly, International Journal of Clothing Science and Technology 18(4), 2006, pp. 235-246, https://doi.org/10.1108/09556220610668581
3. Germanova-Krasteva D., Petrov H.: Investigation on the seam's quality by sewing of light fabrics, International Journal of Clothing Science and Technology 20(1), 2008, pp. 57-64, https://doi.org/10.1108/09556220810843539
4. Guararda A.: Investigation of the seam performance of PET/nylon-elastane woven fabrics, Textile Research Journal 78(1), 2008, pp. 21-27, DOI: 10.1177/0040517507082636
5. Bačkauskaite D., Daukantiene V.: Investigation of wear behaviour of sewn assemblies of viscose linings with different treatment, Materials Science (Medžiagotyra) 17(2), 2011, pp. 155-159, https://doi.org/10.5755/j01.ms.17.2.485
6. Miquel R.A.L., Lucas J.M., Carvalho M.D., Manich A.M.: Fabric design considering the optimisation of seam slippage, International Journal of Clothing Science and Technology 17(3/4), 2005, pp. 225-231, https://doi.org/10.1108/09556220510590920
7. Paviinic D.Z., Gersak J.: Predicting seam appearance quality, Textile Research Journal 76(3), 2006, pp. 235-242, DOI: 10.1177/0040517506061533
8. Daukantiene V., Lapinskiene M.: Influence of the deformation mode on seam slippage in woven fabrics, Fibers and Polymers 13(8), 2012, pp. 1086-1093, https://doi.org/10.1007/s12221-012-1086-8
9. Pasayev N., Korkmaz M., Baspinar D.: Investigation of the techniques decreasing the seam slippage in chenille fabrics (Part I), Textile Research Journal 82(9), 2012, pp. 855-863, https://doi.org/10.1177/0040517511413320
10. Kalaoglu F, Meric B.: Investigation of the performance of linings, International Journal of Clothing Science and Technology 17(3/4), 2005, pp. 171-178, https://doi.org/10.1108/09556220510590867
11. Meric B., Durmaz A.: Effect of thread structure and lubrication ratio on seam properties, Indian Journal of Fiber & Textile Research 30(3), 2005, pp. 273-277, http://nopr.niscair.res.in/handle/123456789/24687
12. Bharani M., Shiyamaladevi P.S.S., MahendraGowda R.V.: Characterization of seam strength and seam slippage on cotton fabric with woven structures and finish, Research Journal of Engineering Sciences 1(2), 2012, pp. 41-50
13. Brnada S., Rogina-Car B., Kovacevic S.: Influence of woven fabric construction on seam thread slippage, Journal of Fiber Bioengineering and Informatics 9(4), 2016, pp. 213-222, doi:10.3993/jfbim00238
14. Nurunnabi, Shibly M.A:H., Tammana T.A., Rahman M.: Seam performance evaluation of plain fabric using different dyes in garments dyeing, International Journal of Textile Science 6(5), 2017, pp. 119-127, DOI: 10.5923/j.textile.20170605.01
15. Pan R., Gao W., Li W., Xu B.: Image analysis for seam-puckering evaluation, Textile Research Journal 87(20), 2017, pp. 2513–2523, https://doi.org/10.1177/0040517516673330
16. Nguyen T.L., Nguyen T.D., Ngo C.T., Tran D.K.: Journal of Science and Technology 73B, 2009
17. Samuel Wesley D., Rengasamy R.S.: An investigation on the role of sewing tension and thread's extension and shrinkage on the puckering of lock stitches seams, Journal of the Textile Association 77(1), 2016, pp. 5-11
18. Ibrahim N.A., Amr A., Eid B.M., Almetwally A.A., Mourad M.M.: Functional finishes of stretch cotton fabrics, Carbohydrate Polymers 98(2), 2013, pp. 1603-1609, https://doi.org/10.1016/j.carbpol.2013.07.047
19. Almetwally A.A., Idrees H.M.F., Hebeish A.A.: Predicting the tensile properties of cotton/spandex core-spun yarns using artificial neural network and linear regression models, Journal of Textile Institute 105(11), 2014, pp. 221-1229, https://doi.org/10.1080/00405000.2014.882043
20. Almetwally A.A., Mourad M.M.: Effects of spandex drawing ratio and weave structure on the physical properties of cotton/spandex woven fabrics, Journal of Textile Institute 105(3), 2014, pp. 235-245, https://doi.org/10.1080/00405000.2013.835092
21. Almetwally A.A., Mourad M.M., Eldsoky Mohammed A.E.: A Study of yarn breaks on warping machines, Life Science Journal 10(1), 2013, pp. 108-114, doi:10.7537/marslsj100113.16
22. Hassan Y.M.E., El-Salmawy A., Almetwally A.A.: Performance of woven fabrics containing spandex, Textile Asia 41(5), 2010, pp. 39-42

23. Almetwally A.A.: Multi-objective optimization of woven fabric parameters using Taguchi-Grey relational analysis, Journal of Natural Fibers, 2019, https://doi.org/10.1080/15440478.2019.1579156
24. Ibrahim N.A., Eid B.M., Khalil H.M., Almetwally A.A.: A new approach for durable multifunctional coating of PET fabric, Applied Surface Science 448, 2018, pp. 95-103, https://doi.org/10.1016/j.apsusc.2018.04.022
25. Omeroglu S., Karaca E., Becerir B.: Comparison of bending, drapability and crease recovery behaviors of woven fabrics produced from polyester fibers having different cross-sectional shapes, Textile Research Journal 80(12), 2010, pp. 1180-1190, DOI: 10.1177/0040517509355351
26. Almetwally A.A., Mourad M.M., Hebeish A.A.: Some handle properties of cotton fabrics woven from ring spun yarn and compact yarns spun from different pneumatic compacting systems, Journal of Textile Association 76(4), 2015, pp. 222-228
27. Ramadan M.A, El Sayed G.A., Almetwally A.A.: Treatment of cotton fabrics using microwave and subsequent dyeing, Textile Asia 43(3), 2012, pp. 22-25
28. Tezel S., Kavusturan Y.: Experimental investigation of effects of spandex brand and tightness factor on dimensional and physical properties of cotton/spandex single jersey fabrics. Textile Research Journal 78(11), 2008, pp. 966-976, DOI: 10.1177/0040517507087685

EVALUATION OF END USE PROPERTIES OF KNITTED SCARVES IN THE EGYPTIAN MARKET

Mona Mohamed Shawky Ragab and Heba Mohamed Darwish

National Research Centre, Textile Division, Clothing and Knitting Industrial Research Department, Cairo, Egypt
Mona_shawky9@hotmail.com, h_darwish2005@yahoo.com

Abstract: *In this study some mechanical and comfort properties of eleven cotton, viscose, cotton/Lycra, and viscose/Lycra single jersey knitted fabrics used as scarves in the Egyptian market were measured. Bursting strength, abrasion resistance, air permeability, thermal resistance, water vapour permeability and water permeability were measured. The relation between most of these properties and fabric constructional parameters was found. Regression equations were found to predict each of abrasion resistance, air permeability, and thermal resistance in terms of loop length and stitch density. While water vapour permeability was predicted in terms of fabric thickness and wales per centimeter. Loop length and stitch density are the key factors affecting the mechanical and comfort properties of single jersey knitted fabrics. The effect of percentage Lycra on the properties under study was investigated. An acceptable relation was found between Lycra percent and each of air permeability (R^2=0.65) and water vapour permeability (R^2=0.8). Increasing Lycra percent decreased both air permeability and water vapour permeability. Also a relation between Lycra percent and each of abrasion resistance and thermal resistance was found with (R^2=0.5) for both. Increasing Lycra percent increased both abrasion and thermal resistances. No relation was found between Lycra percent and bursting strength.*

Keywords: *Single jersey knitted fabric, mechanical properties, comfort properties, stitch density, loop length.*

1 INTRODUCTION

Viscose rayon has its silk-like feel and aesthetic property. It can retain its brilliant colors. It has similar properties to that of cotton and other cellulosic fibers. It has moisture absorbance more than cotton [1]. Fabric wicking, air permeability, water vapour permeability, evaporation rate and drying time were measured before and after laundering for six different knitted structures made from 37 tex viscose staple fibers. Fabric structure significantly affects air permeability and fabric wicking. Air permeability and water vapour evaporation rate correlated negatively to fabric thickness. Also they decreased after laundering process. The fabric wicking in both wales and course directions was high in the first five minutes after this the wicking rate decreased. Fabric structure affects the wickability strongly. Also the wickability increased after laundering [2]. Thicker single jersey synthetic fabric with Lycra has higher thermal insulation [3]. Cotton fabrics with longer stitch lengths absorb less energy than those of shorter stitch lengths. So fabric with lower stitch length feels cooler to the initial touch [4]. Lower yarn counts in tex have less thermal resistance and conductivity for rib 1x1 cotton fabrics. The statistical results show that thermal properties did not affected by the fabric tightness. The finer yarns have higher water vapour permeability. Also the water vapour permeability increases when the tightness factor increases [5]. The effect of yarn linear density and stitch length on thermal comfort properties, water vapour permeability and air permeability for 100% bamboo single jersey fabrics were studied. Thicker fabrics have less air permeability resulted from thicker yarn and higher loop length. The air permeability and the water vapour permeability increased with higher yarn counts and higher loop lengths. Also the thermal resistance decreased with the decrease in fabric thickness [6]. In a comparison between viscose and Excel yarns with two yarn counts 15, 20 tex and three stitch densities it was found that the thicker the fabric the lower its air permeability. Excel single jersey fabrics have higher air permeability than viscose fabric. Fabric thickness is a major parameter in determining the evaporation of water vapour [7]. The loop length has a significant effect on air permeability [7, 8]. The air permeability increased when the loop length increased. The same effect between water vapour evaporation and the loop length was found [8]. Two linear equations with high coefficients of determination were concluded to correlate each of air and water vapour permeability with loop length. Also a linear equation between thermal resistance and fabric thickness was concluded with high coefficient of determination [9]. A negative correlation was found between air permeability and fabric thickness [9, 10]. The effect of elastane on single jersey cotton fabrics on air permeability and bursting strength was studied. It was found that cotton elastane blended fabrics (elastane in every course) has very low air permeability compared with 100% cotton fabric knitted from yarn with count 30 Ne. Also the bursting strength for cotton elastane fabric was higher than that of cotton fabric [11].

A study of the effect of fleecy yarn's raw material using denim knitted fabrics with different raw materials (cotton, viscose, modal, tencel, and bamboo) and different counts on bursting strength were studied. Changing the count of the fleecy yarn was more effective on the bursting strength for the studied samples than changing the raw material of the fleecy yarn. Changing fleecy yarn raw material did not affect bursting strength parameter significantly [12].

2 MATERIALS AND METHODS

2.1 Preparation of samples

Eleven finished knitted fabrics suitable for scarves with two different raw materials cotton and viscose were collected from different Egyptian factories with different fabric constructions (three viscose, four cotton, three viscose Lycra and one cotton Lycra) with yarn count 20 tex. The Lycra was found in each course in the four fabrics that contains Lycra. Table 1 shows the fabric specifications of these fabrics.

Table 1 Fabric specifications

Sample No	Sample Code	Material	Lycra [%]	Yarn count [tex]	Structure
1	C1	100% cotton	0	30	single jersey
2	C2	100% cotton	0	30	single jersey
3	C3	100% cotton	0	30	single jersey
4	C4	100% cotton	0	30	single jersey
5	Cl1	cotton/Lycra	7	30	single jersey
6	V1	100% viscose	0	30	single jersey
7	V2	100% viscose	0	30	single jersey
8	V3	100% viscose	0	30	single jersey
9	Vl1	viscose/Lycra	3	30	single jersey
10	Vl2	viscose/Lycra	5	30	single jersey
11	Vl3	viscose/Lycra	3	30	single jersey

2.2 Test methods

Different properties were measured under standard working conditions for the fabrics under study by the following standards.

2.3 Fabric construction parameters

Fabric weight per unit area: Standard procedures for measuring GSM for fabric samples as per (ASTM-D3776) followed by using digital measuring balance [13].

A fabric thickness was measured according to standard (ASTM-D1777) [14].

Stitch density obtained by counting the number of courses and the number of wales in one inch according to standard (ASTM-D3887) [15].

Stitch length of each fabric sample was measured according to (ASTM-D3887) [15].

2.4 Mechanical and comfort properties of fabrics

Bursting strength dimension [kPa] was measured according to (ASTM-D3786) [16].

Abrasion Resistance (cycles) was measured according to (ASTM-D4966) [17].

Air permeability of the fabrics was measured according to (ASTM-D 737) [18].

Thermal resistances of the fabrics were measured on Permetest according to the standard ISO 11092. The thermal resistance was measured in m^2.mK/W [19].

Water vapour permeability of the fabrics was measured on Permetest at National Institute for Standard according to the standard ISO 11092 [19].

Water permeability of the samples was measured according to (JIS L 1092-1986) [20].

3 RESULTS AND DISCUSSION

Table 2 shows the results of the construction parameters of the fabrics under study. Table 3 shows the results of the properties measured of the fabrics under study.

Table 2 Fabric construction parameters

Sample No	Sample code	Weight [gm/m^2]	Wales per cm	Courses per cm	Loop length [mm]	Thickness [mm]
1	C1	117	13	17	2.74	0.390
2	C2	158.5	16	21	2.46	0.410
3	C3	139	16	15	2.73	0.367
4	C4	141.5	14	19	2.59	0.390
5	Cl1	197	14	20	3.34	0.703
6	V1	185	15	22	2.55	0.497
7	V2	148	15	19	2.50	0.397
8	V3	140	15	18	2.60	0.383
9	Vl1	202.5	16	23	2.72	0.470
10	Vl2	235.5	16	27	2.98	0.633
11	Vl3	203.5	17	19	2.95	0.470

Table 3 Fabric physical and mechanical properties

Sample code	Bursting strength [kPa]	Abrasion resistance [cycles]	Air permeability [$cm^3/s/cm^2$]	Thermal resistance [m^2.mK/W]	Relative water vapour permeability [%]	Water permeability [L/s]
C1	680	98.33	112.67	13.64	69.1	0.56
C2	680	73.33	45.37	10.26	67.83	0.57
C3	426.67	67.67	194	17.24	64.57	0.39
C4	580	90	188.3	15.44	69.93	0.36
Cl1	520	346.67	24.3	19.62	58.8	0.53
V1	560	26.67	183	14.12	66.13	0.55
V2	520	50.67	153	10.12	67.73	0.40
V3	473.33	63.33	171	12.36	69.47	0.41
Vl1	553.33	306.67	32.2	17.68	64.3	0.48
Vl2	546.67	356.67	23.17	20.62	60.8	0.53
Vl3	486.67	195	39.6	18.52	62.13	0.39

3.1 Effect of fiber material on different properties

Paired comparison test was applied between cotton and viscose fabrics to calculate the significant difference for all measured properties.

3.2 Bursting strength

Applying paired comparison test between the bursting strength of the four 100% cotton fabrics and the three viscose ones no significant difference was found between them (p value=0.36). This means that changing raw material did not affect bursting strength (agree with [12]). Also no significant difference was found between the three 100% viscose fabrics and the three viscose Lycra fabrics for bursting strength (p value=0.75), (contradicts with [11]). This contradiction may be because [11] used only two samples for comparison (one 100% cotton single jersey fabric and the other was cotton elastane single jersey fabric).

3.3 Abrasion resistance

Although no significant difference was found between fabric weights for the four 100% cotton fabrics and the three viscose ones when applying paired comparison test between them (p value=0.3). A significant difference was found between the abrasion resistance of the four 100% cotton fabrics and the three viscose ones when applying the same test (p value=0.04). Cotton fabrics have higher abrasion resistance than viscose fabrics. Also a significant difference was found between the three 100% viscose fabrics and the three viscose Lycra fabrics for abrasion resistance (p value=0.008).

The following regression equation was concluded to estimate abrasion resistance for the eleven fabrics under study.

$$A.R = -1140.8 + 363.3 * loop\ length + 0.98 * w * c; \quad R^2 = 0.87 \tag{1}$$

where *A.R* - abrasion resistance, *w* - number of wales per centimeter and *c* - number of courses per centimeter.

From equation (1), it is obvious that both stitch density and loop length have positive effect on abrasion resistance. The more compact fabric with higher stitch density has more abrasion resistance. Compact fabric means more amount of yarn in the unit area which needs more force (more number of cycles) to reach fabric distortion or abrasion. Figure 1 shows the relation between stitch density and abrasion resistance.

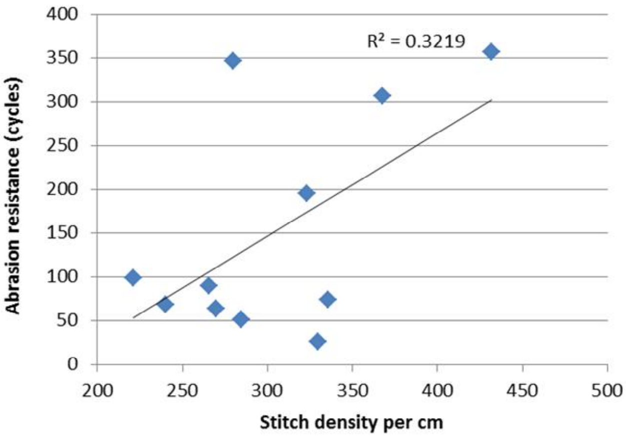


Figure 1 Relation between abrasion resistance and stitch density

It was found that loop length has no relation or correlation with neither courses per centimeter nor stitch density correlation coefficient = 0.1, while it has a good relation with fabric thickness correlation coefficient = 0.7. Fabric thickness increased when stitch length increased (as in Table 3 & Figure 1, reference [8]). This explains why in equation (1) by increasing the loop length the abrasion resistance increased. The increase of fabric thickness with loop length may be to finishing process.

3.4 Air permeability

Applying paired comparison test between the air permeability of the four 100% cotton fabrics and the three viscose ones no significant difference was found between them (p value=0.65). While a significant difference was found between the three 100% viscose fabrics and the three viscose

Lycra fabrics (p value=0.0003). From Table 3, it could be said that viscose Lycra fabrics has significantly lower air permeability than viscose fabrics, because Lycra gives more tight knitted structure, (agree with [11]).

The following regression equation was concluded to estimate the air permeability for the eleven fabrics under study.

$$A.P = 706.2 - 0.65 * w * c - 147 * loop\ length; \quad R^2 = 0.63 \tag{2}$$

where *A.P* - air permeability, *w* - number of wales per centimeter and *c* - number of courses per centimeter.

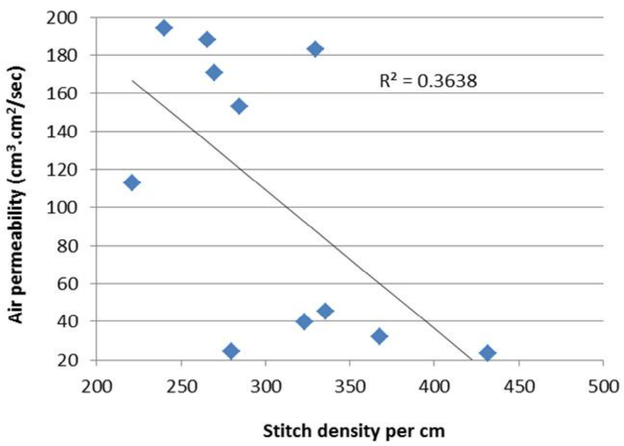


Figure 2 Relation between air permeability and stitch density

From equation (2), it is obvious that both stitch density and loop length have negative effect on air permeability. The higher stitch density leads to more compact structure which means more amount of yarn in the unit area that obstructs the air flow passage which leads to lower air permeability. Figure 2 emphasizes this effect. At the same time the higher loop length leads to higher fabric thickness as discussed before. This means more amount of yarn in the unit area which obstructs the air passage causing less air permeability.

3.5 Thermal resistance

Applying paired comparison test between the thermal resistance of the four 100% cotton fabrics and the three viscose ones no significant difference was found between them (p value=0.38). While a significant difference was found between the three 100% viscose fabrics and the three viscose Lycra fabrics for thermal resistance (p value=0.01). In other words it could be said that viscose Lycra fabrics has significantly higher thermal resistance than viscose fabrics.

The following regression equation was concluded to estimate the thermal resistance for the eleven fabrics under study.

$$T.R = -20 + 11 * loop\ length + 0.02 * w * c; \quad R^2 = 0.76 \tag{3}$$

where *T.R* - thermal resistance, *w* - number of wales per centimeter and *c* - number of courses per centimeter.

From equation (3), it can be concluded that loop length and stitch density are the factors affecting thermal resistance for the fabrics under study. The higher loop length leads to higher fabric thickness as discussed before. This means more amount of yarn in the unit area which leads to higher thermal resistance. Also the higher the stitch density (more compact) structure the lower the thermal resistance.

3.6 Water vapour permeability

Applying paired comparison test between the water vapour permeability of the four 100% cotton fabrics and the three viscose ones no significant difference was found between them (p value=0.96). While a significant difference was found between the three 100% viscose fabrics and the three viscose Lycra fabrics for water vapour permeability (p value=0.02). This means that viscose Lycra samples have significantly higher water vapour permeability than viscose fabrics, because Lycra gives more tight knitted structure.

The following regression equation was concluded to estimate the water vapour permeability for the eleven fabrics under study.

$$W.V.P = 96.4 - 28.7 * thickness - 1.15 * w; \quad R^2 = 0.85 \tag{4}$$

where *W.V P* - water vapour permeability, *w* - number of wales per centimeter.

From equation (4), it is clear that fabric thickness has positive effect on water vapour permeability which means thicker fabrics have lower water vapour permeability (agrees with [7]). Figure 3 emphasizes this effect. Also the more the number of stitches per centimeter the lower the water vapour permeability.

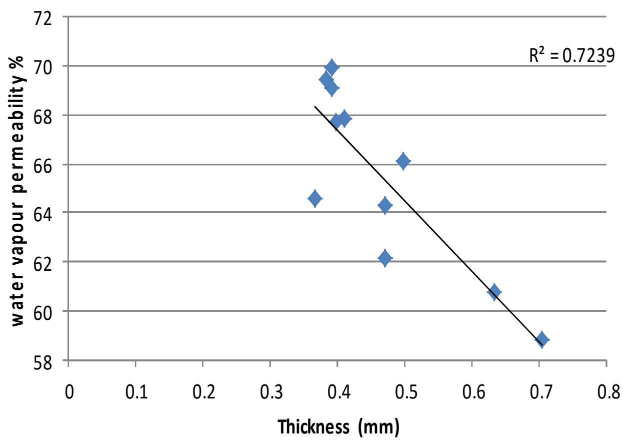


Figure 3 Relation between water vapour permeability and thickness

3.7 *Water permeability*

Applying paired comparison test between the water permeability of the four 100% cotton fabrics and the three viscose ones no significant difference was found between them (p value=0.8). Also no significant difference was found between the three 100% viscose fabrics and the three viscose Lycra fabrics for water permeability (p value=0.8).

3.8 *Effect of Lycra percent on properties under study*

For studying effect of Lycra percent the three viscose Lycra fabrics were used with the cotton Lycra fabric.

The effect of Lycra percent on bursting strength is shown in Figure 4

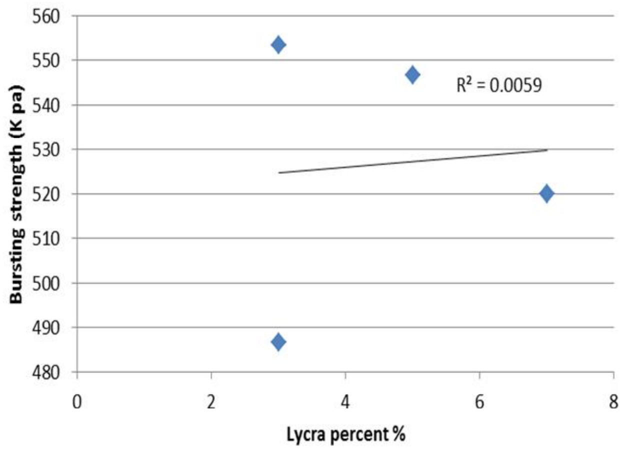


Figure 4 Relation between bursting strength and Lycra percent

From Figure 4, it is obvious that Lycra percent does not affect bursting strength significantly (R^2=0.006).

The effect of Lycra percent on abrasion resistance is shown in Figure 5.

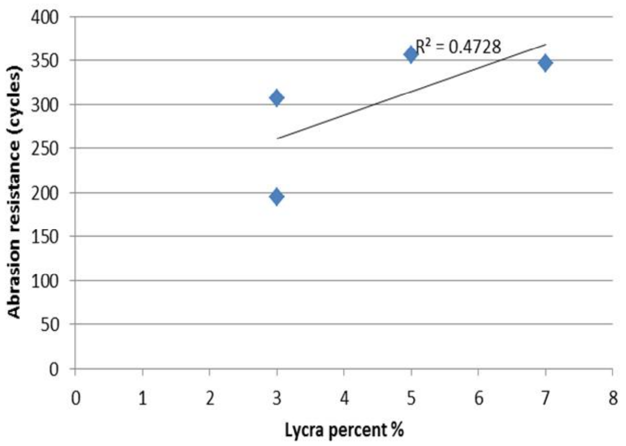


Figure 5 Relation between abrasion resistance and Lycra percent

From Figure 5 it can be said that Lycra percent affect abrasion resistance to some extent R^2=0.5. Abrasion resistance increased with the increase in Lycra percent.

The effect of Lycra percent on air permeability is shown in Figure 6.

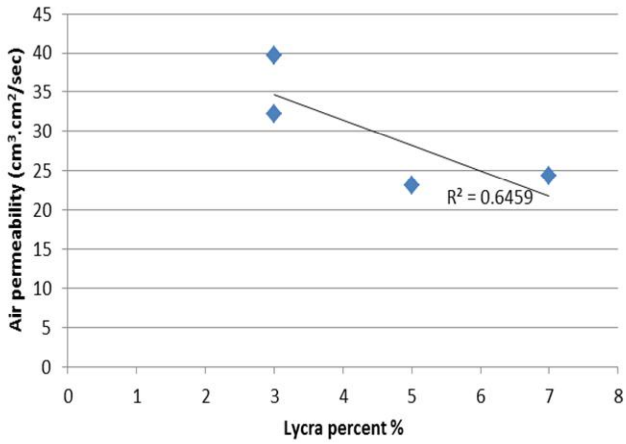


Figure 6 Relation between air permeability and Lycra percent

From Figure 6, it can be said that Lycra percent affects air permeability (R^2=0.65). Air permeability decreased with the increase in Lycra percent.

The effect of Lycra percent on thermal resistance is shown in Figure 7.

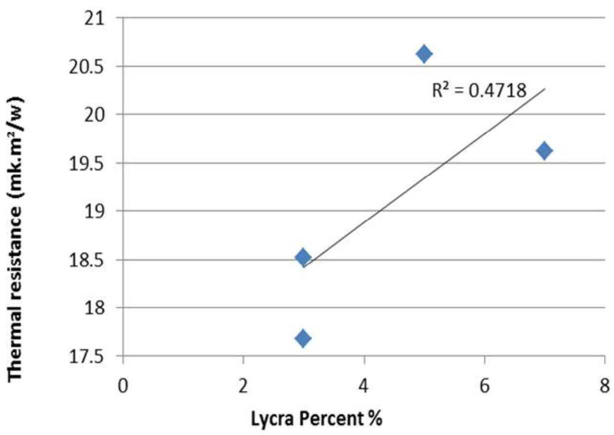


Figure 7 Relation between thermal resistance and Lycra percent

From Figure 7, it can be said that Lycra percent has effect on thermal resistance to some extent with R^2=0.5. Thermal resistance increased with the increase in Lycra percent.

The effect of Lycra percent on water vapour permeability is shown in Figure 8.

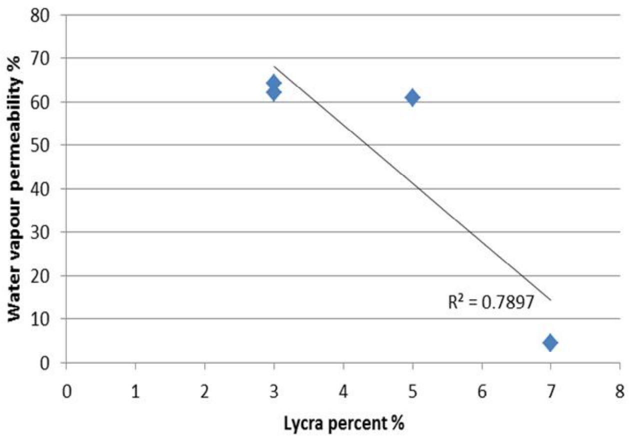


Figure 8 Relation between water vapour permeability and Lycra percent

From Figure 8 it can be said that Lycra percent has good effect on relative water vapour permeability (R^2=0.8). Water vapour permeability decreased with the increase in Lycra percent.

4 SUMMARY

Loop length is a key factor affecting single jersey knitted fabric properties. It affects abrasion resistance, air permeability and thermal resistance.

Stitch density in another key factor for single jersey knitted fabrics which affects abrasion resistance and air permeability.

The higher stitch density gives lower air permeability due to more compact structure which obstructs passage of air passage. Also higher stitch density increases abrasion resistances because of the higher amount of yarn exists in compact structure.

Fabric thickness as well as wales per centimeter affect relative water vapour permeability negatively.

The Lycra percent affects both water vapour permeability and air permeability negatively, while it affects both thermal resistance and abrasion resistance positively. Increasing Lycra percent in fabric decreased both relative water vapour permeability and air permeability. Increasing percent Lycra in the fabric increased both thermal resistance and abrasion resistance. The effect of Lycra percent on air and water vapour permeability is stronger than its effect on both thermal and abrasion resistances. Lycra percent has no effect on bursting strength in this study.

The effect of fiber row material appears only in abrasion resistance property, where cotton fabrics have more abrasion resistance than viscose fabrics, while for the other measured properties the effect of changing fiber row material does not affect these properties significantly.

5 REFERENCES

1. Shaikh T., Chaudhari S., Varma A.: Viscose Rayon: A legendary development in the manmade textile, International Journal of Engineering Research and Applications 2(5), 2012, pp. 675-680
2. Kyatuheire S., Wei L., Mwasiagi J.I.: Investigation of moisture transportation properties of knitted fabrics made from viscose vortex spun yarns, Journal of Engineered Fibers and Fabrics 9(3), 2014, pp. 151-157, https://doi.org/10.1177/155892501400900318
3. El-Dessouki H.A.: The thermal comfort properties of certain Egyptian stretched knitted fabrics, International Design Journal 5(1), 2015, pp. 69-72
4. Pac M.J., Bueno M.A., Renner M., Kasmi S.E.: Warm-cool feeling relative to tribological properties of fabrics, Textile Research Journal 71(9), 2001, pp. 806-812, https://doi.org/10.1177/004051750107100910
5. Ozdil N, Marmarali A., Kretzschmar S.D.: Effect of yarn properties on thermal comfort of knitted fabrics, International Journal of Thermal Sciences 46(12), 2007, pp. 1318-1322, https://doi.org/10.1016/j.ijthermalsci.2006.12.002
6. Prakash C., Ramakrishnan G., Koushik C. V., The effect of loop length and yarn linear density on the thermal properties of bamboo knitted fabric, Autex Research Journal 11(4), 2011, pp. 102-105, http://www.autexrj.org/No4-2011/0017_11.pdf
7. Bhattacharya S.S., Ajmeri J.R.: Factors affecting air permeability of viscose & excel single jersey fabric, International Journal of Engineering Research and Development 5(7), 2013, pp. 48-54
8. Coruh E.: Optimization of comfort properties of single jersey knitted fabrics, Fibres & Textiles in Eastern Europe 23(4), 2015, pp. 66-72, DOI: 10.5604/12303666.1152728
9. Gupta D., Kothari V.K., Jhanji Y.: Heat and moisture transport in single jersey plated fabrics, Indian Journal of Fibre & Textile Research 39(2), 2014, pp. 115-121, http://hdl.handle.net/123456789/28907
10. Shawky M., Darwish H.M.: Comfort properties of some cellulosic fabrics, International Journal of ChemTech Research 9(12), 2016, pp 266-276
11. Azim A.Y.M.A., Sowrov K., Ahmed M, Hasan H.M.R.U., Faruque M.A.A.: Effect of elastane on single jersey knit fabric properties-physical & dimensional properties, International Journal of Textile Science 3(1), 2014, pp. 12-16, doi:10.5923/j.textile.20140301.03
12. Degirmenci Z., Çelik N.: Relation between extension and bursting strength properties of the denim viewed knitted fabrics produced by cellulosic fibers, Fibres & Textiles in Eastern Europe 24(1), 2016, pp. 101-106, DOI: 10.5604/12303666.1170265
13. ASTM D3776:1996. Standard test method for mass per unit area (weight) of fabrics
14. ASTM D1777:2011. Standard test method for thickness of textile materials
15. ASTM D3887:1996. Standard test method for specification for tolerances for knitted fabrics

16. ASTM D3786:2013. Standard test method for bursting strength of textile fabrics, diaphragm bursting strength tester method
17. ASTM D4966:2010. Standard test method for abrasion resistance (cycles) of textile fabrics
18. ASTM D737:1996. Standard test method for air permeability of textile fabrics
19. ISO 11092:2014. Standard test method for textiles determination of physiological properties - measurement of thermal and water vapor resistance under steady-state conditions
20. JIS L 1092:1986. Standard test method for water permeability of textile fabrics

THE EFFECT OF TRADITIONAL KNOWLEDGE ON THE COMMUNITY'S PREFERENCE IN USING *TRITIK* AND *JUMPUTAN* CRAFT IN INDONESIA

Sarwono[1], Rahmanu Widayat[2] and Nadia Sigi Prameswari[3]

[1]*Study Program of Textile Craft, Faculty of Visual Art and Design, Sebelas Maret University, Jl. Ir. Sutami 36A, 57216 Surakarta, INDONESIA*
[2]*Study Program of Interior Design, Faculty of Visual Art and Design, Sebelas Maret University, Jl. Ir. Sutami 36A, 57216 Surakarta, INDONESIA*
[3]*Fine Arts Department, Faculty of Language and Art, Semarang State University, Jl. Sekaran Raya, Gunung Pati, Sekaran, 50229 Semarang, INDONESIA*
sarwono59@staff.uns.ac.id; rahmanuwidayat@staff.uns.ac.id; nadiasigi@mail.unnes.ac.id

Abstract: *Traditional knowledge is a knowledge structure about the environmental condition by utilizing traditional resources. One of traditional knowledge of Javanese people which has high historical value is tritik and jumputan craft art. Therefore, it needs evidence on how big is the effect of society traditional knowledge towards the society interest in using the product as the result of tritik and jumputan craft art. This research is as an effort to investigate the effect of traditional knowledge towards the level of society preference in using the product of tritik and jumputan motif craft art. This study used incidental sampling method in taking the respondents samples in the amount of 100 respondents. Based on the result of significance test multiple linear regression coefficient for variable the community knowledge* $t_{count} > t_{table}$, *is 7.491 > 1.66071 and significance value < 0.05, is 0.000. The result of determination coefficient* (R^2) *obtained in the amount of 0.364. The community knowledge has positive and significant effect towards the level of preference in wearing the product with tritik and jumputan motif.*

Keywords: *traditional knowledge, tritik and jumputan, craft, Indonesia.*

1 INTRODUCTION

Surakarta City is rich in handicraft which is a form of traditional knowledge [1]. Traditional knowledge is a composition of knowledge about environmental conditions by utilizing traditional resources [2]. Efforts are needed in order to continue its existence [3]. Global interest in protecting traditional knowledge and cultural wealth is increasingly evident in the Pacific region over the past few decades [4]. These efforts can be carried out through regeneration in the younger generation in order to be able to preserve the nation's cultural heritage [5]. Traditional knowledge transmission is delivered through socialization to schools to provide an overview of cultural protection for future generations [6]. Cultural protection can be transmitted well through traditional knowledge and legal protection of regional culture [7]. The need to maintain the existence of culture as a form of character strengthening and aesthetic protection of the supporting community life [8]. The cultural value system is the highest level of customs that becomes a guideline, gives enlightenment and becomes an orientation to the life of a society because it is considered valuable and important in community's lives [9].

The hereditary culture has been widely developed in Javanese society, more specifically the Surakarta region [10]. One of the traditional knowledge of the Javanese community that has high historical value is the art of *tritik* craft and *jumputan*. *Tritik* and *jumputan* is one form of textile craft from Java [11]. The method of decorating the white cloth using *tritik* techniques is to sew baste then pulled then dyed and the motif is formed after the yarn is released [12, 13]. *Tritik* is a technique to decorate cloth. *Tritik* fabric is made by stretching the fabric then being pulled tightly together into a lump of cloth which is then dipped into the dye [14]. The method of decorating a white cloth using a *tritik* technique is to sew baste and then be dyed and the motif is formed after the yarn is released [15]. It is named as dye sewing because the making is done by means of being sewn or folded in such a way and then dipped in a dye solution to form a motif [16]. *Tritik* experienced rapid development where initially the *tritik* fabric consisted of only one color, namely dark blue, black, or red like red noni which later developed into more complex patterns with contrasting color contours [17, 18]. Seeing the potential that can be developed and the demand from the world market, the development of *tritik* techniques is carried out to provide a different perspective on the process of work [19].

It is different with the case of *jumputan* techniques that are quite familiar in the world of textiles and clothing coloring. *Jumputan* comes from the word *"jumput"* which has a meaning in the form of making cloth that is pulled or being *jumput* which is a Javanese term [20]. *Jumputan* is a textile or handicraft product whose manufacturing process is easy and the equipment is simple so that it can be reached and many apply it as a product of a home industry [21]. *Jumputan* fabric usually has a motif that fills all ingredients. The usual *jumputan* cloth, one pair consists of material for the top, bottom, and shawl [22]. For this type, artisans generally make *jumputan* with one color theme. *Jumputan* is widely known by the term used as *Jumputan* batik cloth. *Jumputan* is the biggest commodity as a Javanese livelihood [23].

The existence of *tritik* and *jumputan* certainly needs to be realized through a form of cultural appreciation that arises from the formation of traditional knowledge in society [24]. Indicators of the ability to appreciate culture can be divided into three things, namely understanding, interpreting and valuing. Appreciation can occur if a person experiences, both directly and indirectly, in the artwork or culture [25, 26]. Cultural appreciation is a manifestation of community's preference in their cultural values [27], in this context the cultural values are in the form of *tritik* and *jumputan* motifs. In addition to respecting the use of the products, the community also needs to understand the meaning behind the motifs of *tritik* and *jumputan* [28]. *Tritik* and *jumputan* fabrics are fabrics that are unique both in terms of motifs and how they are made. Various types of *jumputan* cloths are quite popular with the people so that their products are widespread [29].

Understanding and meaning of cultural values is a reconstruction of principles in traditional knowledge [30]. The reality that occurs in the community is the large number of *tritik* and *jumputan* products that are starting to become national products, so that cultural works have been widely imposed by Indonesian society in general [31]. But in this case, there is no understanding and appreciation of the community towards the cultural products they use. The community has not fully understood the style and symbols that are worn so that the message of culture has not yet fully derived. The transmission of morality values and the message of a noble culture have not been well understood by the wider community [32]. The curiosity of community towards the products of *tritik* culture and *jumputan* needs to be encouraged so that they can take the message contained in every motif and color. Therefore, it is necessary to prove how much the community traditional knowledge affects their preference in using *tritik* and *jumputan* craft products.

Several previous studies that are relevant to this study have not specifically investigated traditional knowledge in *tritik* craft and *jumputan*. This study is more specific in investigating how much influence given by the community traditional knowledge on their preference in using *tritik* motifs and *jumputan* products.

2 METHODS

Participants in this study were the people of Surakarta City. The city of Surakarta was chosen because Javanese traditions and culture in this city still exist and continue so that the city of Surakarta has branding as the Representative City of Java. The incidental sampling method was used in this study [33] as the respondent's sampling method. Referring to Hair [34], the sample size is recommended at 100-200 respondents so that the precision value is high. 100 questionnaires were distributed in April 2019 with a span of one month by sharing it where the participants were filling it in directly at that time. There are 5 items for the measurement of variable knowledge of community and 6 items for the variable level of preference of *tritik* handicrafts and *jumputan*. The variables are measured by 5 Likert scales (1 = strongly disagree to 5 = strongly agree). The analytical method uses statistical descriptive analysis and analysis data.

3 RESULTS

Descriptive analysis is intended to find out the characteristics and responses of respondents to items in the questionnaire. According to Sugiono [33], descriptive analysis is a statistical analysis used to analyze data by describing collected data.

Table 1 The demographic profile from sample

Demographic variable	Categories	%
Gender	Male	19
	Female	81
Age	21 – 30	39
	31 – 40	19
	41 – 50	25
	51 – 60	17
Occupation	Employees	28
	Civil servant	25
	Entrepreneur	47
The highest education	SHS	39
	D1/Diploma 1	1
	D3/Diploma 3	18
	S1/Undergraduate	40
	Nurse assistant	1
	Pharmacist	1

From the 100 respondents surveyed, 81% were women. Up to 39% of respondents were aged between 21-30 years. While as many as 47%

of the respondents' jobs were self-employed and 40% of the respondents were undergraduate education.

Table 2 Indicators of community knowledge

Community knowledge	Item No.	n	N	%
Knowledge about traditional knowledge	1	379	500	75.8
Steps of making *tritik* and *jumputan* motif	2, 3	636	1000	63.6
The application of *tritik* and *jumputan* motif	4, 5	763	1000	76.3

The data above shows that the application of *tritik* and *jumputan* motifs has the highest percentage that is 76.3% because the phenomenon in the community shows great enthusiasm for the use of cultural products as a form of application of *tritik* and *jumputan* motifs. Then the community knowledge towards traditional knowledge is also in a good category with a percentage level of 75.8%. The last is the method of making *tritik* and *jumputan* motifs that are in a good category with a percentage level of 63.6% where there are still few people who know about the process of making *tritik* motifs and *jumputan*.

Table 3 Indicators of preference level

The level of preference	Item No.	n	N	%
The feeling of preference in *tritik* and *jumputan* motif	1, 2	775	1000	77.5
Goods ownership with *tritik* and *jumputan* motif	3, 4	695	1000	69.5
The usage of goods with *tritik* and *jumputan* motif	5, 6	651	1000	65.1

The data above shows that the community's preference on *tritik* and *jumputan* motifs has the highest percentage that is 77.5% because the general community is very interested in *tritik* and *jumputan* motifs which are considered attractive and aesthetic. Then community ownership of objects with *tritik* and jumputan motifs is also in a good category with a percentage level of 69,5%. The last is the use of objects with *tritik* and *jumputan* motifs that are in the good category with a percentage level of 65,1% where there are still a few people who use *tritik* and *jumputan* motifs.

3.1 Validity test

Validity test is a measure that shows the level of validity of an instrument. An instrument is said to be valid if the instrument can measure what should be measured. The validity test used is the Factor Analysis Method (KMO). To be able to do a factor analysis, it must be fulfilled the requirement that the value of Kaiser Meyer Olkin Measure of Sampling Adequacy (KMO MSA) must be more than or equal to 0.500 and significance below 0.05. While to know whether each item is valid, it can be seen from the MSA value in anti-image correlation that the value of MSA must at least 0.5 which indicates that the item is valid and can be further analyzed [34].

Table 4 Results of factor analysis

KMO and Bartlett's test		
Kaiser-Meyer-Olkin measure of sampling adequacy		0.769
Bartlett's test of sphericity	Approx. Chi-square	583.824
	Df	55
	Sig.	0.000

Based on Table 4 of the output of 'KMO and Bartlett's test', it can be seen that in the first test, the value of the KMO-MSA (Kaiser Meyer Olkin measure of adequacy) is 0.769 and is at the significance level of 0.000. With this data it means that it can be analyzed further, because it has met the criteria stating that the KMO MSA value must be greater or equal to 0.500.

Whereas in the output of 'anti-image matrices', the correlation value for validity test can be seen in the numbers with the sign 'a' which indicates the number of MSA (measure of sampling adequacy).

From the data in Table 5, it can be concluded that all items in the community knowledge questionnaire have an MSA value in anti-image correlation above 0.5 which indicates that the item is valid and can be analyzed further. Then from Table 6, it can be concluded that all items in the preference level questionnaire have an MSA value on anti-image correlation above 0.5 which indicates that the item is valid and can be analyzed further.

Table 5 Results of community knowledge data validity test

No	Community knowledge	Anti-image covariance	Anti-image correlation's
1.	I know that *tritik* and *jumputan* are one of traditional knowledge	0.650	0.914[a]
2.	I know how to make *tritik* motif	0.278	0.667[a]
3.	I know how to make *jumputan* motif	0.372	0.617[a]
4.	I know that *tritik* motif can be used to decorate *blangkon* and *kemben*	0.370	0.719[a]
5.	I know that *jumputan* motif can be used to decorate clothes and interior equipments like bed cover, pillow cover and table cloth	0.522	0.709[a]

Table 6 Results of validity test on the preference level data

No	The level of preference	Anti-image covariance	Anti-image correlation's
1.	I'm interested if there is cloth with *tritik* and *jumputan* motif	0.279	0.765[a]
2.	I'm interested if there is interior equipments such as bed cover, pillow cover, table cloth with *tritik* and *jumputan* motif	0.242	0.727[a]
3.	I have a t-shirt or shirt with *tritik* and *jumputan* motif	0.618	0.900[a]
4.	I have interior equipments such as bed cover, pillow cover and table cloth with *tritik* and *jumputan* motif	0.544	0.909[a]
5.	I frequently use clothes with *tritik* and *jumputan* motif because it can make me more confident	0.307	0.814[a]
6.	I feel more handsome or more beautiful if I wear clothes with *tritik* and *jumputan* motif	0.346	0.828[a]

3.2 Reliability test

Reliability test is a tool to measure a questionnaire which is an indicator of a variable. Reliability testing is done by looking at Cronbach alpha. A variable is said to be reliable if it gives a Cronbach alpha value that is > 0.70 [35]. Items that enter testing are valid items only. To determine whether the instrument is reliable, the 0.6 limit can be used. According to Sekaran [36], reliability that is less than 0.6 is not good, while 0.7 is acceptable and above 0.8 is good. The results show Cronbach alpha for each variable as follows:

Table 7 Results of reliability test

Variables	Cronbach's alpha	No of item	Description
Knowledge of the community	0.791	5	accepted
The level of preference	0.850	6	good

From Table 7, it can be seen that community knowledge has acceptable reliability because Cronbach's alpha is above 0.70, while the preference level has good reliability because Cronbach's alpha is above 0.80.

3.3 Inter variable correlation

Based on Table 8, the conclusions can be made as follows: Based on significance value sig. (2-tailed), the value of sig is known, (2-tailed) between the variable of community knowledge (*X1*) with the preference level variable (*Y*) that is 0.000 <0.05, which means that there is a significant correlation between the variable of community knowledge and the variable of preference level. Based on the Pearson correlations, it is known that the value of *r* count for the relationship of community knowledge (*X1*) with the level of preference (*Y*) is 0.603> *r* table 0.195. Therefore it can be concluded that there is a relationship or correlation between the community knowledge variable and the preference level. Because *r* count or Pearson correlation in this analysis is positive, it means that the relationship between the two variables is positive or in other words, the increasing community knowledge will increase the level of community preference.

Table 8 Results of Pearson's bivariate correlation analysis

		KS	LP
Pearson correlation	KS	1.000	0.603
	LP	0.603	1.000
Sig. (1-tailed)	KS		0.000
	LP	0.000	
N	KS	100	100
	LP	100	100

3.4 Hypothesis test

Positive effect of community knowledge on the level of preference:

The t-test basically shows how far the effect of one independent variable individually explains the dependent variable [35]. The t-test is an individual fit test of the variable community knowledge on the level of preference. An independent variable affects the dependent variable can be seen from the significance value of the t-test. That value is said to be significant if the significance level is < 0.05. The results of this test indicate that the path analyzed has a significant effect. It can be seen from the result of the significance level that is smaller than 0.05.

Table 9 The t-test results of community knowledge with a level of preference coefficients [a]

Mode		R square	Adjusted R square	Std. error of the estimate	Change statistics				
l	R				R square change	F change	df1	df2	Sig. F change
1	0.603	0.364	0.358	3.48396	0.364	56.111	1	98	0.000

Table 10 Results of *R* value analysis of community knowledge with the level of preference model summary [b]

Mode		R square	Adjusted R square	Std. error of the estimate	Change statistics				
l	R				R square change	F change	df1	df2	Sig. F change
1	0.603	0.364	0.358	3.48396	0.364	56.111	1	98	0.000

The general value (*R*) is 0.603, while the adjusted *R* square value is 0.364. This means that 36.4% of the dependent variable (level of preference) can be explained by its independent variable (community knowledge). The remaining 63.6% is influenced by other variables not included in this research model.

From multiple linear regression analysis, it is known that the regression coefficient of each variable is positive, so that it can be said that community knowledge is positively related and significant with the level of preference.

4 DISCUSSION

This study discusses the effect of traditional knowledge on the level of *community's* preference in using *tritik* and *jumputan* motifs. This happens because traditional knowledge provides understanding to the community in encouraging interest and preference for using the craft products of *tritik* and *jumputan* motifs. The community in general already knows about traditional knowledge. Traditional knowledge as a public knowledge of the traditions exists around the supporting community. Through traditional knowledge, the community has an understanding of culture and traditions that have been inherited from generation to generation. One of the traditions and cultures of the community who still have existence is *tritik* and *jumputan*. *Tritik* and *jumputan* become a local cultural heritage with traditional knowledge, which with its existence it motivates the community to understand and apply *tritik* and *jumputan* in daily life. The analysis results show the large regression coefficient for the public knowledge variable is 0.681 with positive parameters. So that it can be said that community knowledge has a positive and significant effect on society preferences. Based on the significance test of multiple linear regression coefficients for the community knowledge variables, it was found that $t_{count} > t_{table}$ or 7.491 > 1.66071 and the significance value < 0.05, which is 0.000. The results of the determination coefficient (*R2*) are obtained at 0.364. Based on these data it can be concluded that community knowledge has a positive and significant effect on the level of community's preference in wearing the *tritik* and *jumputan* motifs. Conversely, if the traditional knowledge of the community is low, their interest or the level of community's preferences will be decreased, especially in using cultural products with *tritik* and *jumputan* motifs.

Cultural preservation is the main condition for strengthening character and national identity. In this case, a stimulus is needed to encourage interest as an effort to preserve culture. The provision of stimulus in the form of embedding traditional knowledge is needed, according to what was stated by Wardhana [37] who said that through efforts to cultivate traditional knowledge in the community, then interest will grow in preserving *jumputan* culture as one of the nation's cultural heritage. Utami & Irhandayaningsih [38] reinforced that traditional knowledge or *indigenous knowledge* needs to be owned by the community in order to encourage the preservation of the culture around them. If community's preference in *tritik* and *jumputan* as their own culture can be appreciated properly, then the culture of the community will strengthen. The application of traditional knowledge also needs to be instilled early to encourage the love of young people towards *tritik* and *jumputan*. This is in accordance with what was stated by Darmojo [39] that early childhood education can be applied to batik *jumputan* making so that it can foster the love of early childhood towards their culture. In his research, early childhood can be directly introduced to how to make batik by the teacher so that children can feel the sensation and indirectly explore their creativity so that their interests and talents can be well channelled. As an effort to strengthen cultural identity, especially in the conservation of *tritik* and *jumputan*, community also need to play an active role by using *tritik* products and *jumputan*. In this case, according to what was stated by Kusumadara [40] that cultural sustainability can be realized through the joy and pride of the community towards their culture. Appreciation of the community towards *tritik* and *jumputan* by wearing *tritik* motifs and *jumputan* indirectly encourages cultural preservation.

5 CONCLUSION

This research is an effort to investigate the effect of traditional knowledge towards the level of preference in using product with *tritik* and *jumputan* motif. Based on the analysis which had been conducted, it can be concluded that there is positive and significant effect of community knowledge towards their level of preference.

Traditional knowledge will have positive effect towards the improvement of level of interest in using the product of *tritik* and *jumputan* motif. Cultural preservation becomes the main requirement of strengthening the character and identity of the nation. In this case, it needs stimulus to people the interest as an effort of cultural preservation. Giving stimulus in the form of nurturing traditional knowledge is required. If society interest towards *tritik* and *jumputan* as her own culture and appreciated well, then the culture will be strengthened by itself.

6 REFERENCES

1. Kaleka N., Hartono E.T.: Various Crafts *Mendong,* Surakarta: Arcita, 2014, ISBN : 9786027849181
2. Dransfield J., Manokaran N. (Eds): Plant Vegetable Resources of South-East Asia, No 6: Rattans, Yogyakarta: Gadjah Mada University Press, 1996
3. Wasudewa G., Suartini L., Wardana, K.N.H.: Lontar leaf-based sandal craft at Adi Karya Bona village, Blahbatuh district, Gianyar regency (Kerajinan Sandal Berbahan Dasar Daun Lontar Di Perusahaan Adi Karya Desa Bona, Kecamatan Blahbatuh, Kabupaten), Jurnal Pendidikan Seni Rupa, Undiksha 4(1), 2014, pp. 1-12, http://dx.doi.org/10.23887/jjpsp.v4i1.4253
4. Forsyth, M.: Lifting the lid on “The Community”: Who has the right to control access to traditional knowledge and expressions of culture?, International Journal of Cultural Property 19(01), 2012, pp. 1-31, https://doi.org/10.1017/S0940739112000021
5. Leonidou L.C., Katsikeas C.S.: The export development process: An integrative review of empirical models, Journal of International Business Studies 27(1), 2003, pp. 517-551, https://doi.org/10.1057/palgrave.jibs.8490846
6. Whitbeck L.B., Hoyt D.R., Stubben J.D., LaFromboise T.: Traditional culture and academic success among American Indian children in the upper Midwest, Journal of American Indian Education 40(2), 2001, pp. 48-60, ISSN**:** ISSN-0021-8731
7. Carpenter K., Katyal S.K., Riley A.R.: In defense of property, The Yale Law Journal 118(6), 2009, pp. 1022-1125
8. Schmutz V., Faupel A.: Gender and cultural consecration in popular music, Social Forces 89(2), 2010, pp. 685-707, https://doi.org/10.1353/sof.2010.0098
9. Nurhayati N.: Preserving the culture of Palembang jumputan cloth art, Kalpataru: Jurnal Sejarah dan Pembelajaran Sejarah. 2(1), 2016, pp. 10-15, DOI: 10.31851/kalpataru.v2i1.1312
10. Wijaya M.: Multi commercial economy: The development of socio-economic network complexity of batik industry in Surakarta, Asian Social Science. 5(8), 2009, pp. 102-110, DOI:10.5539/ass.v5n8p102
11. Juwita H.S.: Jumputan cloth in Tahunan village, Umbulharjo Yogyakarta (Kain jumputan di kampung Tahunan Umbulharjo Yogyakarta), Jurnal Pendidikan Kriya 7(4), 2018, pp. 230-239
12. Masiswo M., Murwati E.S., Farida F.: Effect of stitching distance on tritik patterned fabrics (Pengaruh Jarak Jahitan terhadap Kualitas Desain Kain Bermotif Tritik), Dinamika Kerajinan dan Batik 24, 2007, pp. 23-29, http://dx.doi.org/10.22322/dkb.v24i1.1020
13. Kartikasari E.: Effect of fixator on noni root extract on jumputan staining (Pengaruh Fiksator Pada Ekstrak Akar Mengkudu Terhadap Pewarnaan Jumputan), Keluarga: Jurnal Ilmiah Pendidikan Kesejahteraan Keluarga 1(2), 2015, pp. 99-105, http://dx.doi.org/10.30738/keluarga.v1i2.608
14. Oktarizka P.H., Ramadhan M.S.: Development of technical engineering for textile sheets (Pengembangan Teknik Tritik Untuk Lembaran Tekstil), eProceedings of Art & Design 5(3), 2018, pp. 2487-2510, ISSN : 2355-9349
15. Titisari B., Kahdar K., Mutiaz I.R.: Development of Dye (Trick) Sewing Techniques with Geometric Patterns (Pengembangan Teknik Jahit Celup (Tritik) dengan Pola Geometris), ITB Journal of Visual Art and Design, 6(2), 2014, pp. 130-142, http://dx.doi.org/10.5614%2Fitbj.vad.2014.6.2.4
16. Setiawati E., Ningsih R.: Batik jumputan in improving children's creativity (Membatik Jumputan Dalam Meningkatkan Kreativitas Anak), Bidayah : Jurnal Studi Ilmu-Ilmu Keislaman 8(2), 2017, pp. 247-261
17. Keller I.: Batik: The Art and Craft, Charles E. Tuttle Company, 6th printing edition, Rutland, Vermont & Tokyo, Japan, 1971, ISBN: 978-4629-0957-5 (ebook)
18. Handayani D., Tjahjaningsih E., Santoso D.B.: Fabric motif design with tritik fold technique for scarf using indigo blue natural color (Desain motif kain dengan teknik lipat tritik untuk scarf menggunakan warna alam biru indigo), IKRA-ITH INFORMATIKA : Jurnal Komputer dan Informatika 2(1), 2018, pp. 87-93
19. Seiler-Baldinger A.: Textiles a Classification of Techniques, Smithsonian Institution Press, USA, 1994, ISBN: 1560985097
20. Handoyo J.D.: Batik and Jumputan (Batik dan jumputan), Y. Astuti (Ed.), Pertama, Yogyakarta: PT Macanan Jaya Cemerlang, 2008
21. Zulfa I., Karyaningrum A.E.: Application of training methods in jumputan basic ornamental motifs with cold coloring techniques in cultural arts learning and student skills at Sumongbangsri 1 Elementary School in Balongbendo, E-Journal 3(1), 2014, pp. 156-162
22. Widodo S.T.: Tie-dye textile craft (ikat celup): a popular aesthetic exploration media (Kriya tekstil tie-dye (ikat celup): sebuah media eksplorasi estetis yang populer), CORAK Jurnal Seni Kriya, 1(2), 2012, pp. 101-122, https://doi.org/10.24821/corak.v1i2.2316
23. Atmojo S.E.: Learning which oriented on local wisdom to grow a positive appreciation of batik jumputan (ikat celup method), Jurnal Pendidikan IPA Indonesia 4(1), 2015, pp. 48-55
24. Ulfa W.R., Lathif M.A., Khutobah K.: Increased fine motoric ability through activities of batik jumputan in children B Group Ash-Syafa'ah Jember 2015/2016 academic year (Peningkatan Kemampuan Motorik Halus Melalui Kegiatan Membatik Jumputan Pada Anak Kelompok B TK Asy-Syafa'ah Jember Tahun Pelajaran 2015/2016), Jurnal Edukasi 3(3), 2016, pp. 35-37, https://doi.org/10.19184/jukasi.v3i3.4307

25. Rusyana Y.: Language and Literature in Educational Gamitan, Bandung: Diponegoro, 1984
26. Wada Y.I, Kellogg Rice M., Barton J.: Shibori: The Inventive Art of Japanese Shaped Resist Dyeing: Tradition Techniques, Innovation, Kodansha International Ltd., 1999, ISBN: 0870115596
27. Mungmachon M.R.: Knowledge and Local Wisdom: Community Treasure, International Journal of Humanities and Social Science 2(13), 2012, pp. 174-181
28. Djoemena N.S.: Batik and Its Kind, Jakarta: Djambatan, 1990
29. Sahfitri V.: Designing online sales crafts "Kain Jumputan Palembang" (Rancang Bangun Sistem Penjualan Online Kerajinan Kain Jumputan Khas Palembang), Prosiding SnaPP, 2017, pp. 1-8
30. Alexon, Sukmadinata N.S.: Development of a culture-based integrated learning model to increase students' appreciation of local culture (Pengembangan model pembelajaran terpadu berbasis budaya untuk meningkatkan apresiasi siswa terhadap budaya lokal), Jurnal Cakrawala Pendidikan 6(2), 2010, pp. 189-203, https://doi.org/10.21831/cp.v2i2.339
31. Rosyidah N.I., Fatmawati N., Styorini N.E., Wulan R., Aisyah S.: Making batik jumput in Gluranploso Village, Benjeng District, Gresik City (Pembuatan Batik Jumput Di Desa Gluranploso Kecamatan Benjeng Kota Gresik), Jurnal Penamas Adi Buana 02(2), 2017, pp. 63-68
32. Syarifuddin D.: Cultural value of tasik parahiyangan batik as a West Java travel attraction (Nilai Budaya Batik Tasik Parahiyangan Sebagai Daya Tarik Wisata Jawa Barat), Jurnal Manajemen Resort dan Leisure 14(2), 2017, pp. 9-20, https://doi.org/10.17509/jurel.v14i2.8530
33. Sugiono: Educational Research Methods (Quantitative, Qualitative and R & D Approaches), Bandung: Alfabeta, 2011
34. Hair J.F., Anderson R.E., Tatham R.L., Black W.C.: Multivariate Data Analysis, Upper Saddle River: Prentice Hall International Inc., 1998
35. Ghozali I.: Multivariate Analysis Application with IBM SPSS 19 Program, Semarang: Diponegoro University Publisher, 2011
36. Sekaran U.: Research Methods for Business: A Skill-building Approach, John Wiley and Sons Inc., New York, 2003, ISBN: 0471384488
37. Wardhana M.: Growing interest in nusantara cloth through training in making dyed cloth (jumputan) in the community, Jurnal Desain Interior 1(2), 2016, pp. 95-100
38. Utami V.A., Irhandayaningsih A.: Knowledge preservation for indigenous sustainability knowledge of pati samin tribe community (Preservasi Pengetahuan Bagi Keberlangsungaan Indigenous Knowledge Masyarakat Suku Samin Kabupaten Pati), Jurnal Ilmu Perpustakaan 5(1), 2016, pp. 101-110
39. Darmojo K.W., Yuwono B.T., Marwati S.: Batik and keris as the basics of developing local characteristics of education in early childhood (PAUD) (Batik Dan Keris Sebagai Dasar Pengembangan Muatan Lokalpendidikan Berkarakter Padaanak Usiadini (PAUD), Jurnal Abdi Seni 8(1), 2017, pp. 50-58
40. Kusumadara A.: Maintenance and preservation of traditional knowledge and expressions of Indonesian traditional culture: Protection of intellectual property rights and non-intellectual property rights, Jurnal Hukum 18(1), 2011, pp. 20-41

SWEAT-MANAGEMENT PROPERTIES OF SEMI BLEACHED-SOCKS USING DIFFERENT MAIN YARN AND PLATING YARN COMBINATIONS

Hafiz Faisal Siddique[1], Adnan Mazari[1] and Muhammad Tanveer[2]

[1]*Technical University of Liberec, Studentska 2, 46117 Liberec, Czech Republic*
[2]*National Textile University, Faisalabad, Pakistan*
faisalsiddique3648@gmail.com; mazariadnanahmed@gmail.com;

Abstract: *The aim of the present work is to analyze the interaction of sweat with socks comprised of different main and plating yarn combinations. Main yarn selected of different blends Coolmax/cotton 50/50 (CC), 100% Coolmax (CM), 100% spun polyester (SP) and 100% micro spun polyester (MP) with linear density of 20 Nec (nominal english count) each. Plating yarns of two types i.e. nylon plated air covered (N_c) and polyester plated air covered (P_c) of linear densities 70 D and 75 D were used. The socks were prepared on a circular plain knitted machine with seven different yarn combination using main and plaiting yarns. Socks sample prepared abbreviated as CCN_c, CMP_c, CMN_c, SPP_c, SPN_c, MPP_c and MPN_c. Moisture management properties were measured MMT device. The liquid transport properties like wetting time, absorption rate, spreading speed, one way transportation capacity and overall moisture management capacity (OMMC) were measured and analyzed. The result shows that socks samples CCN_c containing hydrophilic materials like cotton so possess greater absorbency and least transportation of liquid. Socks samples especially CMP_c, MPP_c and SPP_c being hydrophobic materials exhibit 'good' moisture management properties.*

Keywords: *Socks, main yarn, plating yarn, moisture management.*

1 INTRODUCTION

Clothing comfort has become one of the widest concerns for the textile manufacturers. Most of the end users like to be comfortable in their garments that may help them for better thermoregulation system and freedom of movement. Freedom of movement directly relates with construction and properties of knitted fabric made up of, while body temperature related to vapors and air circulation [1].

Many studies are there about construction and performance characteristics of fabrics and their assessment how the comfort properties and comfort levels can be imparted or achieved. Most of them emphasized over blends of conventional cellulosic materials like cotton, wool, regenerated materials i.e. rayon & bamboo and synthetic materials i.e. polyester & aramid fabric materials but not purely the synthetic materials along with core of polyurethane as elastomeric yarn. Out of already worked materials, 100% cotton and polyester is top of the list [2-12].

The reason of high consumption of cotton is its higher heat releasing and heat absorption properties accompanying moisture absorption and desorption respectively. This strengthens the buffering effect of the clothing between the human body and the surrounding environment. But the limitations regarding cotton based socks is its higher absorbency level which acquire poor moisture transportation and release properties consequently causes discomfort, less wearer performance, irritation, itching or prickling. They keep up the perspiration in the fabric layer next to the skin, giving wearer an uncomfortable feeling of wet and cold depending on the environment. The location of moisture inside the textile products influences the skin wetness as well as skin/textile friction. It has been observed that wet textile materials have high value of coefficient of friction causes smelling of socks and wearer foot deceases [13]. It has urged the researcher to develop such type of socks that possess better comfort properties.

Socks are the most widely used textile garment usually inside the shoes. More often these are used to attain comfort, better performance characteristics and to provide ease against rasping between foot and footwear. Socks are used to keep foot dry, cool and warm depending on the climatic conditions, body requirements and its activities. Dryness of foot plays vital role to keep foot free of perspiration and bacteria that cause variety of foot problems including blisters and athletic deceases. That why the wearer will feel comfort if we able to manage to transport sweat away from the skin surface, in the form of liquid or vapor consequently the fabric touching the skin feels cause dryness. The transport of both moisture vapor and liquid away from the body is called moisture management [13].

The most commonly used classes of knitting patterns consist of warp knitting and weft knitting. Another class of less rampant knit is called a circular knit. Warp knit is a type of knitting in which the yarns are stitched lengthways, in a zigzag pattern. The loops are interlocked in a lengthwise direction [14]. Due to its zigzag knitting across different columns, the knits are usually done by machine. While weft knit is a type of knitting in which yarns are stitched width-wise, across the fabric. Some examples of weft knits are plain knits or rib knits [15]. The third class of knits that is relevant to this project is circular knit. These knits can produce tube forms that are seamless [16], since most knitted garments are in tube forms such as arm sleeves or socks. Similarly to weft knits, circular knits can be done either hand-made or by machine.

After all it is decided to compare comfort properties most likely to be moisture management of socks made up of synthetic materials along with different blended materials.

Moisture management in socks essentially refers to how well material is transporting moisture out and keeping the wearer dry. The moisture remaining in the socks can further increase body temperature leading to more perspiration. The ultimate objective of managing moisture in socks is to ensure moisture is transported to the outer surface in the shortest possible time. Once transporting outwards, the moisture should spread to a large surface area and evaporate as fast as possible with the wearer experiencing a feeling of dryness [17]. Moisture management has the following functions: regulation of body temperature – when core temperature of human body exceeds 37°C, it starts to sweat generation. Transporting the sweat away from the skin and evaporating it to the atmosphere, reduces body temperature [18].

Above mentioned problem of sweat poor transportation and release from the core of fabric structure has urged the researcher to develop such type of socks that possess best liquid management characteristics. The significance of this research is to provide comfort against perspiration produced inside our socks and its evaporation that may keep wearer skin dry. The moisture absorption and its transfer within the socks play an important role for evaluation of wearer comfort and performance of textile product against wetness, sweat and skin/textile friction.

The main objective of this study was to compare sweat management properties regarding liquid moisture management of socks made up of synthetic materials comprised of different blend on overall moisture management capacity of socks.

To measure moisture management properties of sportswear and dynamic liquid moisture properties, moisture management tester (MMT) was established. This tester is very unique in its construction and fulfills all the aspects of sweat management introduced here as different indices for fabric top and bottom sides [18].

The liquid management trend in the form of 'wetting time', 'absorption rate', 'one-way transport capability', 'spreading/drying rate' and 'overall moisture management capacity' (OMMC) were measured and then analysed. Wetting time is actually the ability of fabric to wet and is defined as the time [s] when the fabric happening to be wetted as test is started. 'Absorption rate' is the speed at which the mean quantity of generated sweat is absorbed during the initial change of water content. 'Spreading speed' is the accumulated rate of surface wetness to a maximum radius from the point at which the drop is fall. The 'maximum wetted radius' is the greatest water ring radius measured on the surface of fabric. 'Accumulative one-way transport capability' is the difference between the areas of the liquid moisture content curves of a fabric with respect to time [5]. 'Overall (liquid) moisture management capability' (OMMC) is an index is an intimation to instruct the overall ability of the fabric to manage the transport of liquid moisture and calculated using equation:

$$OWTC = C_1MAR_b + C_2OWTC + C_3SS_b \qquad (1)$$

where C_1, C_2, and C_3 are the weights of the indexes of the absorption rate.

2 MATERIALS AND METHODS

2.1 Yarns (type and properties)

Yarns of two types, main and plating, were deployed together side by side to prepare footy socks. Main yarn used is in direct contact with the skin and provides desired comfort while plating yarn, characterized by limited elasticity, provides lateral force to conjoin main yarn with the skin and clasp the socks avoiding slippage.

Main yarns of four types i.e. Coolmax/cotton 50/50 (CC), Coolmax 100% (CM), spun polyester 100% (SP) and micro spun polyester 100% (MP) of alike fineness (20/1 Ne) were used. While plating yarns (fixed linear densities & draft ratio of elastane) were of two types 1) nylon air covered elastane (N_C), 2) polyester air covered elastane (P_C) as shown in Figure 1.

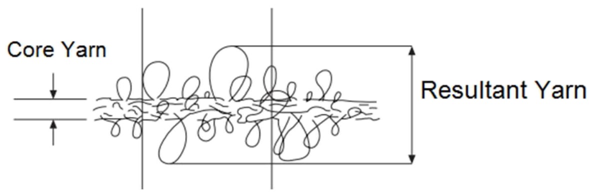


Figure 1 Side view of ACV yarn - resultant and elastane yarn [19]

Table 1 Main yarn testing results

Sr. No	Parameters	Standard test method/ Equipment	Main yarn 20/1 carded			
			*CM	*CC	*SP	*MP
1	Linear density [N_{ec}]	ASTM D1907	20.58	20.24	20.10	20.38
2	Turns/inch**	ASTM D1422	15.99	17.05	12.95	13.87
3	Tenacity [cN/tex]	ASTM D2256	16.09	14.07	30.02	33.83
4	Uniformity percentage [%]	USTER 5	9.42	8.97	8.97	87.22
5	Hairiness		7.14	6.15	5.77	8.78

**turns per inch means the number of twists per inches of main yarn *CM= Coolmax; *CC= Coolmax/cotton 50/50; *SP= spun polyester and *MP= micro polyester

Table 2 Plating yarn specifications

Sr. No	Sample ID	Yarn Description	Composition [%]	
			polyester/nylon	elastane
1	P_c	20D-75/36/1 D 100% polyester air covered elastane yarn (95/5)%	95.22	4.78
2	N_c	20D- 70/24/1 D 100% nylon air covered elastane yarn (95/5)%	95.52	4.48

Testing results of main and plating yarns (Tables 1 and 2) were measured under standard atmospheric conditions 21±1°C and 65±2% RH (ASTM- D1776).

2.2 Socks manufacturing

Total 7 socks samples were developed using different yarn combinations (CCN_c, CMP_c, CMN_c, SPP_c, SPN_c, MPP_c and MPN_c) on socks knitting machine of specifications (Lonati FL-454J, model 2004, gauge 12GG, diameter 4″, speed 250 rpm, feeders 2 and number of needles 144) as shown in Figure 2.

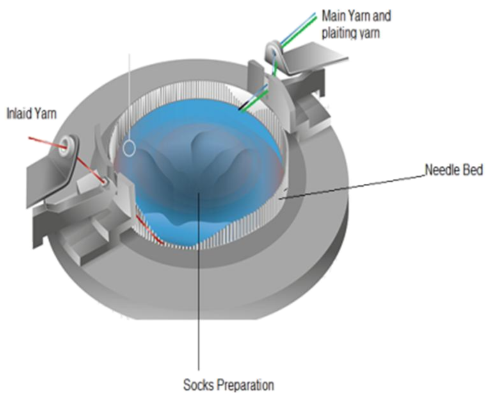


Figure 2 Internal view of knitting machine [20]

The selections of materials were done on the basis of their availability for development of socks samples.

All of the developed socks samples exhibit the same single jersey plain fabric structure as shown in Figure 3.

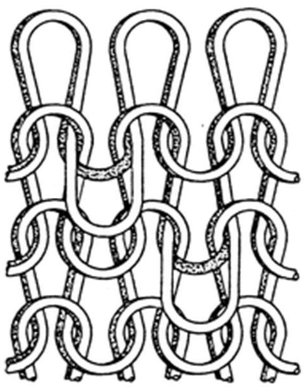


Figure 3 Structural of plaited socks sample [21]

Socks samples physical and composition results after half bleaching are given in Tables 3 and 4 using standard test method AATCC 20A.

Table 3 Physical testing of socks

Sr. No	Sample	Socks weight [GSM]	Body stretch [%]	Thickness [mm]	Tear strength [N]	Extension [mm]
1	CCN_c	331.64	21.88	1.52	306	135
2	MPP_c	332.3	20.5	1.52	437	112
3	MPN_c	331.5	20.25	1.38	398	133
4	CMP_c	332.9	21	1.54	369	125
5	CMN_c	331.75	21.56	1.38	299	137
6	SPP_c	332.3	21	1.5	376	109
7	SPN_c	332.5	20.94	1.6	406	139

Table 4 Quantitative fibre analysis of socks

Sr. No	Sample	Sample description (plating yarn + main yarn)	Composition [%]	Quantitative analysis [%]
1	CCN_c	20D Lycra (5%)-70/24/1 PA 95% + 20/1 Coolmax/cotton 50/50	PET/cotton/PA/Lycra	35.73+37.54+21.86+4.87
2	MPP_c	20D Lycra (5%)-75/36/1 PET 95% + 20/1 micro spun polyester 100%	PET/Lycra	95.09+4.91
3	MPN_c	20D Lycra (5%)-70/24/1 PA 95% + 20/1 micro spun polyester 100%	PET/PA/Lycra	74.45+21.29+4.26
4	CMP_c	20D Lycra (5%)-75/36/1 PET 95% + 20/1 Coolmax 100%	PET/Lycra	95.16+4.84
5	CMN_c	20D Lycra (5%)-70/24/1 PA 95% + 20/1 Coolmax 100%	PET/PA/Lycra	74.2+21.31+4.49
6	SPP_c	20D Lycra (5%)-75/36/1 PET 95% + 20/1 spun polyester 100%	PET/Lycra	95.44+4.56
7	SPN_c	20D Lycra (5%)-70/24/1 PA 95% + 20/1 spun polyester 100%	PET/PA/Lycra	74.57+21.05+4.38

3 RESULTS AND DISCUSSION

Developed socks samples were evaluated for their interaction to sweat generation using MMT tester.

3.1 Top and bottom fabric wetting time

Figure 4 demonstrating wetting time top (WT_{tp}) and bottom (WT_{bm}) of all socks sample. WT_{tp} and WT_{bm} is actually the time start to wet socks samples [5-9].

Figure 4 portrays that socks sample CCN_c exhibit highest values of wetting time than rest of six combinations of socks samples due to presence of cotton contents. Cotton fiber being hydrophilic retains the sweat for maximum time due to higher adhesion forces between sweat and fiber surface. This inherited behavior exhibit poor moisture release and transport consequently swells fiber reduces interspaces between fibers and yarns inside the sock structure.

Figure 4 also portrays least spending time samples CMP_c followed by MPNc, SPPc, MPP_c, CMN_c and SPN_c present swift flow of generated sweat through its structure.

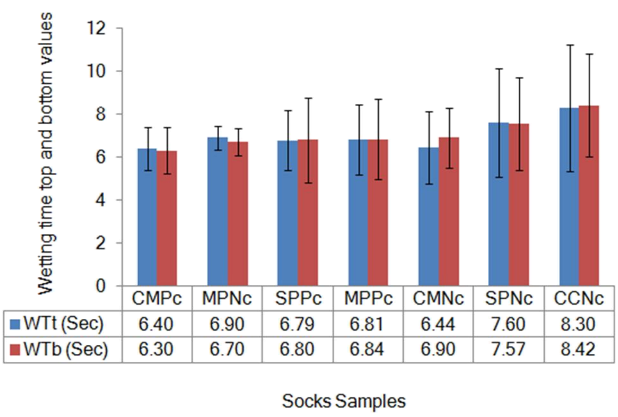


Figure 4 Mean comparison of wetting time top and bottom

As studies proved that wetting of the fabric corresponds fiber-air interface replaced by fiber-liquid sweat interface [19]. In this case, air spaces present context to extensibility values (139 mm and 137 mm) present inside socks structure entrapped the sweat contents exhibiting higher time to air voids and hydrophilicity of materials that enhance force of adhesion between fiber surface and water molecules` wettability to spend less time to absorb sweat. Another parameter TPI (turns per inches) in CM 100% is lower than MP 100% followed by SP 100% enhances the capacity to hold higher amount of sweat than MP 100% and SP 100% due to presence of air voids within the yarn structure between fibers [20].

3.2 Mean comparison of top and bottom absorption rate

Figure 5 reveals that socks sample CCN_c exhibit highest rate of absorption at top (AR_t) and bottom (AR_b) which is due to presence of cotton contents (highest regain). Out of rest 6 socks samples (synthetic material) react to sweat with varying rate of absorption at bottom side (skin side) can be ordered, MPN_c > MPP_c, SPN_c > SPP_c, CMP_c > CMN_c.

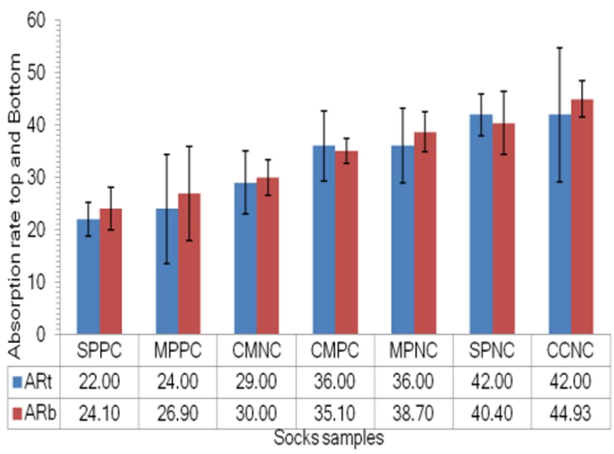


Figure 5 Mean comparison of absorption rate at top and bottom

Socks samples MPN_c and SPN_c (nylon plated) exhibit higher rate of absorption than MPP_c and SPP_c (polyester plated) because of higher nylon regain than polyester fiber. The reason of higher AR_b of nylon plated socks is also due to higher values of extension [mm] which portray the presence of dominant air voids than polyester plated socks.

Socks samples CMN_c and CMP_c have interacted the sweat in very different way. The AR_b in socks samples with plated polyester is higher than nylon plated socks. The reason is presence of cross sectional multi-channels enhance the rate of transportation of sweat water. Polyester plated socks sample (CMP_c) have also the thickness more than CMN_c so AR_b of the synthetic socks samples have the order MPN_c > MPP_c and SPN_c > CMP_c. Reason of higher AR_b in MPN_c than MPP_c is due higher value of extension [mm] indicates the presence of maximum air voids that hold maximum concentration of generated sweat. While SPN_c > CMP_c socks samples, it is due to presence of maximum air voids, higher thickness of fabric, higher values of imperfection and lower twist per meter values than CMP_c.

3.3 Mean comparison of spreading speed at top and bottom

In Figure 6, it is observed that socks sample CMP_c shows highest spreading speed followed by MPP_c, SPP_c CMN_c, MPN_c, SPN_c and CCN_c respectively. 'Spreading speed' is the accumulated rate of surface wetting from the center of the specimen where the test solution is dropped up to the maximum wetted radius [5, 9].

Per Figure 6 if we compared the spreading speed values of socks sample having similar main yarns of same specifications and different plating yarns (polyester and nylon), revealed that the socks samples CMP_c, MPP_c and SPP_c (polyester plated) shown greater spreading speed values at bottom side (SSb, contact with skin) than socks samples containing nylon plated yarns but trend is different in socks samples due to presence of cotton contents.

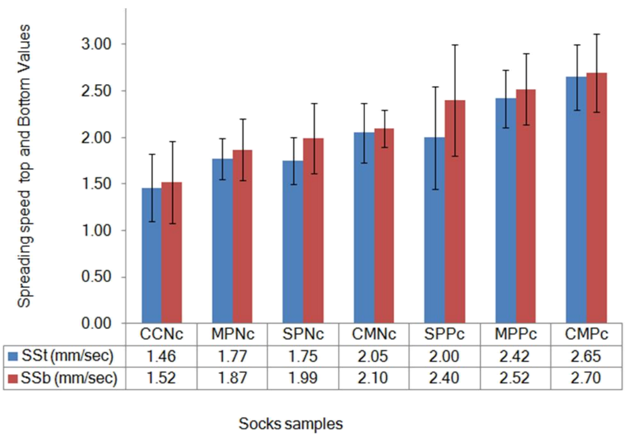


Figure 6 Mean comparison of spreading speed

Socks samples with highest spreading speed values at skin contacting side were evaluated and it was found that in socks sample CCN_c contains 38% cotton and 36% polyester (1:1). This sample exhibit the minimum value of the spreading speed at top and bottom sides of its fabric surface compared to rest of 6 different combinations of socks samples. It is all due to presence of cotton contents lead to absorb more water clinginess to the surface of cotton fiber and later its penetration to micro pores due to more of its amorphous region compared o manmade fibers.

On the other hand, socks sample SPP_c showed the greater value of spreading speed (SSb) than SPN_c at bottom side. Higher value of spreading speed at bottom (SSb) is due to higher polyester contents about 75% in SPPC than SPNC (75%), less fabric thickness and compactness than nylon plated socks samples (SPN_c).

3.4 Mean comparison of accumulative one-way transport index (AOWTI) and overall moisture management capacity (OMMC) of socks samples

Figure 7 representing AOWTI [%] and OMMC results of socks samples. OMMC is grading assigned to socks samples as 'excellent', 'good' or 'poor' in sweat management performance. Grading scale range is given in Table 5.

Table 5 Grading of moisture management indices tester [7]

Index	Grade				
	1	2	3	4	5
AOWTI	<-50	-50-99	100-199	200-400	>400
[%]	poor	fair	good	very good	excellent
OMMC	0.0-0.19	0.20-0.39	0.40-0.59	0.60-0.80	>0.80

Figure 7 interprets the performance of socks samples and portrays similar trend between OMMC and AOWTI. Excellent results against AOWTI and OMMC values are attained by socks samples can be ordered CMP_c followed by MPP_c, SPP_c, CMN_c, MPN_c, SPN_c and CCNc respectively.

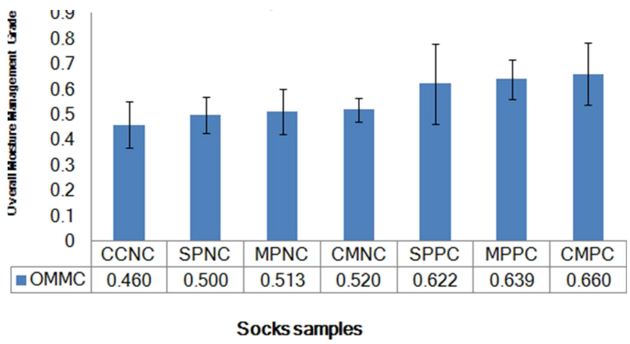


Figure 7 Mean comparison of OMMC values

Further, if we compare AOTI and overall moisture management capacity of socks samples context to plating yarn used inside the socks, the best results for OMMC and AOWTI are of Coolmax polyester (CMP_c) are good as compared to Coolmax nylon covered (CMN_c) while micro-polyester polyester covered (MPP_c) exhibit better moisture management characteristics compared to micro-polyester nylon covered (MPN_c), similarly spun polyester -polyester covered (SPP_c) exhibit better overall moisture management properties compared to spun polyester nylon covered and Coolmax cotton nylon covered exhibit least (poor) moisture management properties. This trend is due to higher content of polyester fiber being hydrophobic in nature suck away the sweat to fabric outer surface and due to higher values of extensibility values of socks samples. These higher values portray the presence of majority of free spaces within the socks structure consequently increasing its higher OMMC of values (Table 3).

OMMC and AOWTI values of developed socks were analyzed statistically using one way variance analysis and found that there is significant effect of TPI (p value is 0.046) and extension value (p value is 0.018). Main effect plot between OMMC, AOWTI, TPI and extension value [mm] are given in Figure 8.

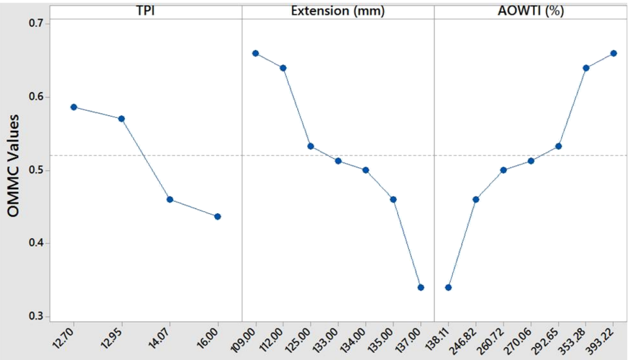


Figure 8 Main effect plot between TPI vs extension [mm] and AOWTI [%]

Unable to attain OMMC rating as 'excellent' samples were first processed and allow them to be relaxed to retain strain energy due to different tensions in spinning and knitting. This chemical treatment of socks has affected the fabric density due to contraction consequently reducing air void and moisture accumulation capacity in socks.

Das B., et al. [10] mentioned in his work that sweat peeing through socks samples involves the two processes which are diffusion and sorption-desorption. Water vapor diffuses through socks samples involves openness within the yarn as well as free voids inside the fabric correspond to inter-fiber interstices in yarn along fiber itself while moisture transport through sorption-desorption process will increase with the hygroscopicity of the material [10].

4 CONCLUSION

In this research we have mainly emphasized over moisture management properties of plated socks samples produced by using different type of four main yarns and two plated yarns with total 7 combinations (CMPc, CMNc, MPPc, MPNc, SPPC, SPNc and CCN_c). All of the combinations were analyzed for their overall moisture management performance and found that best socks samples combination were CMP_c, MPP_c and SPP_c. According to the results we concluded that including yarn and socks parameters i.e. TPI and extension [mm] significantly influence overall moisture management and accumulative one-way transport index values of plated socks samples and samples CMP_c, MPP_c and SPP_c are rated as 'good' in moisture interaction.

Acknowledgement: *This work was supported by the Ministry of Education, Youth and Sports of the Czech Republic and the European Union – European Structural and Investment funds in the frames of operational program Research, Development and Education – Project Hybrid Materials for Hierarchical Structures (HyHi, Reg. No. CZ.02.1.01/0.0/16_019/0000843).*

5 REFERENCES

1. Hatch K.L.: Textile Science, West Publishing Co, New York, 1993
2. Layton J. M., Li, Y.: The Science of Clothing Comfort, The Textile Institute, Manchester, UK, 2001, 138 p., ISBN 1870372247
3. Dias T., Delkumburewatte G.B.: The influence of moisture content on the thermal conductivity of a knitted structure, Measurement Science and Technology 18(5), 2007, pp. 1304-1314, https://doi.org/10.1088/0957-0233/18/5/016
4. Laing R.M., Wilson C.A., Gore S.E., Carr D.J., Niven B.E.: Determining the drying time of apparel fabrics, Textile Research Journal 77(8), 2007, pp. 583-590, https://doi.org/10.1177/0040517507078232
5. Das A., Ishtiaque S.M.: Comfort characteristics of fabrics containing twist-less and hollow fibrous assemblies in weft, Journal of Textile and Apparel, Technology and Management 3(4), 2004, pp. 1-7
6. Prahsarn C., Barker R.L., Gupta B.S.: Moisture vapour transport behaviour of polyester knit fabrics, Textile Research Journal 75(4), 2005, pp. 346-351, https://doi.org/10.1177/0040517505053811
7. Zhuang Q., Harlock S.C., Brook D.B.: Transfer wicking mechanisms of knitted fabrics used as undergarment for outdoor activities, Textile Research Journal 72(8), 2002, pp. 727-734, https://doi.org/10.1177/004051750207200813
8. Mangat A.E., Hes L., Bajzik V., Mazari A.: Thermal absorptivity model of knitted rib fabric and its experimental verification, AUTEX Research Journal 18 (1), 2018, pp. 20-27, https://doi.org/10.1515/aut-2017-0003
9. Zhou L., Feng X., Du Y., Li Y.: Characterization of liquid moisture transport performance of wool knitted fabrics, Textile Research Journal 77(12), 2007, pp. 951-956, https://doi.org/10.1177/0040517507083518
10. Das B., Das A.., Kothari V., Fangueiro R., De Araujo M.: Moisture flow through blended fabrics – effect of hydrophilicity, Journal of Engineered Fibers and Fabrics 4(4), 2009, pp. 20-28, https://doi.org/10.1177/155892500900400405

11. Yoo S., Barker R.L.: Moisture management properties of heat-resistant workwear fabrics - effects of hydrophilic finishes and hygroscopic fiber blends, Textile Research Journal 74(11), 2004, pp. 995-1000, https://doi.org/10.1177/004051750407401110
12. Majumdar A., Mukhopadhyay S., Yadav R.: Thermal properties of knitted fabrics made from cotton and regenerated bamboo cellulosic fibres, International Journal of Thermal Science 49(10), 2010, pp. 2042-2048, https://doi.org/10.1016/j.ijthermalsci.2010.05.017
13. https://textiles.ncsu.edu/tatm/wp-content/uploads/sites/4/2017/11/cottoninc_fulldocument-1.pdf
14. Emily: Weft and warp knitting differences, Machine Knitting Advice, 4 July 2012, http://machineknittingadvice.com/weft-and-warp-knitting-differences/
15. Allen F.: Knitting, Fibre2Fashion 2013, http://www.fibre2fashion.com/industryarticle/10/918/knitting1.asp
16. Moisture Management, Textile Auxiliaries, Textilchemie Dr. Petry GmbH, Germany, 2008
17. Fan J., Szeto Y.C., Sarkar M.K.: Fabric simulating the plant structure for moisture management, US Patent 8,486,847 B2. Washington, DC: US Patent and Trademark Office, 2013, http://hdl.handle.net/10397/6305
18. Salgado C.: Moisture management in fabrics, http://www.tecnitex.es
19. Siddique H.F., Mazari A., Havelka A., Hussain T: Effect of elastane linear density on compression pressure of V-shaped compression socks, Industria Textila 69(2), 2018, pp. 118-127
20. Siddique H.F., Mazari A.A., Havelka A., Mansoor T., Ali A., Azeem M.: Development of V-shaped compression socks on conventional socks knitting machine, Autex Research Journal 18(4), 2018, pp. 377-384, https://doi.org/10.1515/aut-2018-0014
21. https://www.iso.org/obp/ui/#iso:std:iso:8388:ed-1:v1:en

METHOD OF CONTROL OF THE COMPATIBILITY OF THE CHILDREN'S CLOTHING DESIGN USING COEFFICIENTS OF DIMENTIONAL FEATURES GRADATION

Alla Slavinskaya, Oksana Dombrovska, Viktoriia Mytsa, Julia Koshevko, Anatolii Dombrovskyi and Tetiana Ivanishena

Khmelnitskyi National University, Instititska str. 11, Khmelnitskyi, Ukraine
juliakoshevko@gmail.com

Abstract: *The problem of controlling the proportionality of clothing design by the gradation method of typical figures of preschool age children is investigated. Set of dimensional features for the determination of intermediate control measurements is analytically grounded. The use of the gradation algorithm for the tasks for scaling the geometric model of the body surface into a geometric model of garment details has been proved. The interrelation of gradation coefficients from dimensional standards with the estimated values of the dimensions of the constructional dimensions of shoulder clothing dimensions is experimentally investigated. The regression analysis confirmed the gradation coefficients for design development and control of the dimensionality of the finished product.*

Keywords: *proportionality, design, children's clothing, gradation, dimensional feature, constructive section, coefficient, age group, formula, regression.*

1 INTRODUCTION

One of the most important tasks facing the manufacturers of clothing is the preparation of high-quality design and technological documentation. The initial stage of creating a sewing product is the development of design drawings, on the basis of which a basic set of pattern parts is created. The unsuccessful choice or incorrect application of the method of making drawings and the further development of the basic patterns of parts, despite the adherence to all principles of design, can significantly affect the quality of the result of the finished sewing product.

A significant place in the design preparation of production is the gradation of patterns of the garments' parts. The use of grading methods to develop patterns of different sizes and heights simplifies and accelerates the process of preparing working documentation for the manufacture of clothing.

There are two principal approaches to the implementation of the gradation: gradation by diagrams and parametric gradation. Modern automated clothes systems provide a fairly rapid construction of templates of various sizes and heights, both according to known gradation schemes, and by the primary algorithm of anthropometric modification of the basic design in a given morphological type of the figure, which simplifies the process of obtaining the template of the required sizes.

Nowadays, the question of the gradation process of clothes patterns for children despite numerous studies, remains open, which is largely due to the lack of methods for checking the quality of gradation of patterns, taking into account the preservation of the anthropometric proportionality of products in the personalized parameterization of the sexual and age groups of the children's population.

2 DISCUSSION OF IDEAS

The construction of the geometric model of the garment surface is based on the logical spatial relationship between the displacements of the anthropometric points of the body surface to the design points of the garment details. The information model of the design details must be identical or close to the property of the proportionality of the surface of the body section [1-3].

The promising application of three-dimensional visualization software products to create an objective system of anthropometric dimensional features is confirmed by works [4-6].

The Julivi Clo 3D program contains electronic mannequins of typical figures of various morphological types, which are re-formatted for children's clothing in an anthropometric database of current national standards [6]. However, the singular dimension of the control measurements of the dimensions of the structure is not confirmed by the preservation of the coefficients of gradation of dimensional features in the non-uniform scaling of the shape of the product.

An example of the use of non-uniform scaling as a prototype of gradation is considered in the construction of structures of various types of clothing in CAD Julian by calculating the scaling coefficients using the computer program Scale factor [7]. However, in the information database of increments, there is no differentiation of the gradation coefficients for dimensional groups. An analytical way of systematizing the types of figures at the level of classification by factoring of proportionality, considered in [8], complements the anthropometric database of current dimensional standards for the tasks of parameterization of the clothing proportionality.

The mechanism for obtaining projective dimensional features of a person through the use of feedback between the drawing and dimensional features in the CAD of clothing for the technical possibilities of changing the coordinates of the main points of the figure outline is given in [9, 10] on the example of CAD "Gracia".

The disadvantage of using shape outlines to form an anthropometric database is inability to take into account the level of displacement of anthropometric heights in the configuration of sections of the design given by the girths.

Investigations [11] on the construction of shoulder wear for girls in pre-school and junior school groups revealed contractions of contours of the loops in volumes 332, 352 in increments requiring clarification of the calculation formulas of the standardized method of clothing design used by the members of economic assistance matching the use of the dimensional feature of the anterior-posterior diameter of the hand T 57 in calculations of the armhole width.

Analytical study of the same-size features of the typical figures of boys and girls in the preschool age group shows their independent variability, both with change in size and with a change in height [12]. This causes the anthropometric discrepancy of structures constructed on a typological series of dimensions of the gradation coefficients.

Adaptation of anthropometric information to the control measurements of sections of the finished product requires the study of the calculation formulas of the main structural segments. The first priority is the intermediate control of coherence by measurements of length and width, which characterizes the dimensions of the product and confirms the relevance of the research.

3 METHODS

The flat design of the garment details is presented as a set of straight and curvilinear sections forming a closed loop.

Construction of a geometric model of clothing surface is theoretically grounded in the study [1].

In the working documentation for the sewing product, the measurement table provides the quality control of the finished product by measurements in the size-growth groups. The name and number of basic measurements vary from 2 to 21 depending on the range of products [13]. Accordingly, the main design document for manufacturing a product in a given range of size of the groove is a graduation drawing, which must meet the requirements for the quality of the design [14, 15].

While grading patterns changes on certain sections lead to similarity, which belongs to the group of linear and corresponds to the affine method of changing the scale of the contour of the part in the regulated amount of compression (stretching) of the anthropometric sign in the form of the coefficient of gradation [1, 16, 18].

The affine transformation in the gradation of the patterns means any change in the scale of the curve simultaneously in one or two axes. In this case, the straight lines remain linear, parallel - parallel, the ratio of the segments, located on the same straight line (or on parallel lines), remain unchanged, the algebraic order of the curve does not change.

Thus, the principle of gradation is based on the use of a group of linear geometric transformations of the contour of the construction part by increasing the coordinates in the main constructive points [14, 16].

$$(x_1; y_1) \rightarrow [(x_0+\Delta x_0); (y_0+\Delta y_0)] \quad (1)$$

where: x_0, y_0 are the coordinates of the constructive points of the original construction [cm]; Δx_0, Δy_0 - values of moving of corresponding constructive points in a construction of another size.

It is known that the designer anthropometric standard contains information on the uniform increase of subordinate dimensional attributes in a number of typical figures and reproduces sufficiently well the morphological status of different in the age, national and sex characteristics of the population for the problems of the ready-made clothes market.

However, at a significant number of sewing enterprises, designing products for children of nursery and preschool age groups is often performed without taking into account the gender of the child, which has a significant impact on the size and shape of the areas of static contact of clothing and, thus, the quality of planting products on the figure.

Therefore, the main condition of anthropometric studies of the body surface of children for the gradation of patterns is the inclusion of age groups: in particular, preschool one - 3 years – 6 years 11 months [16].

In accordance with the current system of standards for typical children’s shapes [13] and taking into account the opportunities of the industry and the conditions of trade for the design of clothing for preschool age children, an optimal number of typical figures is provided, which includes 8 typical male figures and 8 typical female figures of the preschool age group (Table 1).

Table 1 Classification of typical figures of boys and girls of the preschool age group

Dimensional feature	Size of the dimensional feature [cm]		
Chest circumference	52	56	60
Waist circumference	48	51	54
Height	98	98	
	104	104	
		110	110
		116	116

Note: Basic size is highlighted

For children of the preschool age group, the regression equation after linearization of the calculation of subordinate dimensional attributes has the following entries:

Before the linearization:

$$x_i = a + bx_1 + cx^2_{16} + ex_1 \times x_{16} \quad (2)$$

After the linearization:

$$x_i = a + b.x_1 + c.x_{16} \quad (3)$$

where: x_i is any subordinate dimensional sign; x_1 is body length (height); x_{16} - chest circumference; a, b, c are coefficients of regression.

As a rule, the calculation formulas of the design methods establish the dependence of the size of the structure on the values of dimensional features. In particular, the main type of constructive segments in the standardized method of clothing design used by the members of economic assistance has also a form of linear regression:

$$A\text{-}B = c_n T_i + a_n + A \quad (4)$$

where: c_n is a coefficient, which determines the proportion of dimensional feature in the segment; T_i is the magnitude of the dimensional feature; a_n - free member of the formula with the index of the number of the system of basic structural segments, which take into account the features of the body structure of sex-age groups and A - the total value of constructive increments and technological allowances.

Since in the structure of the calculation formulas, constructive increments are constant for all sizes and increments, it is expedient not to consider them in the studies of gradation coefficients.

The system of the main constructive sections of the unified method of designing the clothes of the Council for Mutual Economic Assistance contains information about the segments that are output for the construction of the basis of the design of clothing, and contains a unified sequence and method of construction, the initial solution of the main constructive nodes [16], so it is necessary to study the application of the design of the product of dimensional features and compare with the corresponding gradation factors in the standards.

The express method of analyzing the reasons for the anthropometric inconsistency of gradation increments along the lines of the chest and thighs in the basic designs of shoulder products for preschool age children is based on the verification of the formula for calculating the width of the product along the breast line, since this particular area of the basic structures of the shoulder products determines the overall dimensions of the shoulder products in width [17].

The width of the shoulder product along the line of the chest consists of the width of the back (area/31-33/), the width of the front (area/35-37/) and the width of the perimeter (area/33-35/). The following formulas [15, 16] are used in the calculation of the values of these sections of the design in the only method of designing the clothes of the Council for Mutual Economic Assistance:

$$/31\text{-}33/ = 0.5T47 - 0.5 + A_{31\text{-}33} \quad (5)$$

$$/33\text{-}35/ = T57 + 1.0 + A_{33\text{-}35} \quad (6)$$

$$/35\text{-}37/ = 0.5(T45 + T15 - T14) - 0.5 + A_{35\text{-}37} \quad (7)$$

where: $T47$ is the width of the back [cm]; $A_{31\text{-}33}$, $A_{33\text{-}35}$, $A_{35\text{-}37}$ - structural additions to the corresponding sections of the design [cm]; $T57$ - anterior-posterior diameter of the hand [cm]; $T45$ - breast width [cm]; $T15$ - the second circumference of the chest [cm]; $T14$ - the first circumference of the chest [cm].

Formula (5) can be attributed to the formulas of the 1st type, because the size of the area is determined by the corresponding dimensional type of the figure and the increase. Formulas of the 1st type provide the correspondence of increments of gradation to gradation coefficients.

Formula (6) refers to the formulas of the 2nd type, since for the calculation of the size of the area of the construction of the size of the product; a dimensional feature that characterizes a certain parameter of the hand is applied. Consequently, on the area of an armhole, the increments of the gradation characterize not the area of the body but the change in the diameter of the hand.

Formula (7) consists of dimensional features that characterize the chest belt, so it also refers to the formulas of the 1st type.

Consequently, from the considered formulas only formula (6) contains the dimensional sign *T57*, which does not characterize the size of the chest belt of the figure. In addition, *T57* is excluded from the current children's size standards [13]. Therefore, it is advisable to establish the dependence of the armhole width on the corresponding area of the chest belt, that is the influence of the dimensional feature of the size of armhole *T109* (Figure 1), which is included in the state standards of the typical figures of the children's population GOST 17916-86, GOST 17917-86.

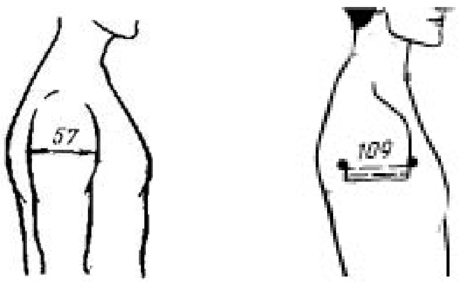


Figure 1 Diagram of measuring the dimensions of the "anterior-posterior hand diameter" (*T57*) and „armhole width" (*T109*) in the typical figures of boys and girls

Since this dimensional feature is included in the circumferential dimensions of the child's chest belt, it can be assumed that the calculated width parameter of the armhole of the basic structure should correspond to the parameters of the body part and, accordingly, the increment of the gradation in the area of the projections will characterize the change in the body area.

Taking into account that the line of transition of the trunk to the upper limb in products with a sewing sleeve characterizes the combination of contours of the holes and the cap of the sleeve, it is necessary to establish the relationship between the parameters of the armhole and the parameters of the sleeve.

In the unified method of designing the clothes of the Council for Mutual Economic Assistance [15], the length of the armhole in shoulder products for children is calculated by the formula:

$$LA = 0.96T38 + (A_{33\text{-}13} + A_{35\text{-}15}) + \\ + 0.57(T57 + 1.0 + A_{33\text{-}35}) + 2/33\text{-}331/ \qquad (8)$$

where: T_{38} is an arc through the highest point of the shoulder joint [cm]; /33-331/ - magnitude of the armhole increase [cm].

The width of sleeve cap (*WSC*) in shoulder products for children is calculated by the formula:

$$WSC = T57 + 3.0 + A \qquad (9)$$

Consequently, the structure of formulas (8-9) indicates the absence of a section of the width of the plain in the control dimension of the width of the product at the level of the armhole depth, which suggests a mismatch with the gradation coefficients after calculation.

4 EXPERIMENTAL PART

After the replacement of the size feature *T57* into *T109* in formulas (6, 8, 9) the research of anthropometric correspondence of sizes of structural parts along the width of the product along the breast line of shoulder products for children of the preschool age group has been performed.

For this purpose, the size of the sections of the structures along the breast line has been calculated, depending on the size and height of the typical figures of boys and girls of the preschool age group. Then the comparison of the obtained values with the corresponding gradation coefficients has been made.

The dimension of changes in the size of the constructive sections along the breast line on the typical figures of boys and girls in the preschool age group, depending on the change in size, are given in Table 2.

The dimension of changes in the size of the constructive sections along the breast line on the typical figures of boys and girls of the preschool age group, depending on the change in height, are given in Table 3.

Table 2 Estimated coefficient of gradation of constructive sections according to the height of preschool age group

Constructive section		The dimensions of the change in the size of the constructive sections [cm]							
		98		***104***		***110***		***116***	
		52-48 56-51	***56-51 60-54***	***52-48 56-51***	***56-51 60-54***	***52-48 56-51***	***56-51 60-54***	***52-48 56-51***	***56-51 60-54***
1		*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
/31-33/	girls	0.65	0.6	0.6	0.55	0.6	0.5	0.55	0.5
	boys	0.6	-	0.65	0.35	0.7	0.45	0.75	0.5
/33-35/	girls	0.4	0.4	0.4	0.4	0.5	0.5	0.6	0.6
	boys	0.5	-	0.5	0.4	0.5	0.5	0.6	0.4
/35-37/	girls	0.55	0.7	0.65	0.7	0.65	0.65	0.6	0.65
	boys	0.6	-	0.6	0.7	0.55	0.75	0.7	0.7
/31-37/	girls	1.6	1.7	1.65	1.65	1.75	1.65	1.75	1.75
	boys	1.7	-	1.75	1.45	1.75	1.7	2.05	1.6

Table 3 Estimated coefficient of gradation of constructive sections according to the size of preschool age group

Constructive section		The dimensions of the change in the size of the constructive sections [cm]								
		52-48			56-51			60-54		
		98-104	*104-110*	*110-116*	*98-104*	*104-110*	*110-116*	*98-104*	*104-110*	*110-116*
1		*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	10
/31-33/	girls	0.25	0.2	0.25	0.2	0.2	0.2	0.15	0.15	0.2
	boys	0.25	0.25	0.25	0.3	0.3	0.3	-	0.4	0.35
/33-35/	girls	0	-0.1	-0.1	0	0	0	0	0.1	0.1
	boys	0	-0.1	-0.1	0	-0.1	0	-	0	-0.1
/35-37/	girls	0	0.05	0.15	0.1	0.05	0.1	0.1	0	0.1
	boys	0.05	0.1	0	0.05	0.05	0.15	-	0.1	0.1
/31-37/	girls	0.25	0.15	0.3	0.3	0.25	0.3	0.25	0.25	0.4
	boys	0.3	0.25	0.15	0.35	0.25	0.45	-	0.5	0.35

Table 4 Comparison of dimensions of changes in size of structural sections with a change in size with coefficients of gradation (girls and boys)

Constructive section	The dimensions of the change in the size of the constructive sections [cm]							
	98		104		110		116	
	52-48 56-51	*56-51 60-54*	*52-48 56-51*	*56-51 60-54*	*52-48 56-51*	*56-51 60-54*	*52-48 56-51*	*56-51 60-54*
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
/35-37/ girls	1.6	1.7	1.65	1.65	1.75	1.65	1.75	1.75
/35-37/ boys	1.7	-	1.75	1.45	1.75	1.7	2.05	1.6
Coefficient of gradation	2	2	2	2	2	2	2	2

Table 5 Comparison of dimensions of size's change of constructive sections with height change with gradation coefficients

Constructive section	The dimensions of the change in the size of the constructive sections [cm]								
	52-48			56-51			60-54		
	98-104	*104-110*	*110-116*	*98-104*	*104-110*	*110-116*	*98-104*	*104-110*	*110-116*
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	10
/35-37/ girls	0.25	0.15	0.3	0.3	0.25	0.3	0.25	0.25	0.4
/35-37/ boys	0.3	0.25	0.15	0.35	0.25	0.45	-	0.5	0.35
Coefficient of gradation	0	0	0	0	0	0	0	0	0

The comparison of the dimensions of the change in the size of the design sections along the line of the breast, depending on the change in size and height with the gradation coefficients on the typical figures of boys and girls of the preschool age group, is given in Tables 4 and 5.

As a result of the comparison of the dimensions of changes in the size of the design sections along the line of the breast, depending on the change in size and height with the gradation coefficients, it has been found out that the dimensions of change the size of the constructive sections along the breast line does not correspond to gradation coefficients.

In the single method of designing the clothes of the Council for Mutual Economic Assistance, when calculating the width of the front, the dimensional feature "Breast Width" (*T45*) is used and the difference in dimensional features is "first breast chest" (*T14*) and "second breast chest" (*T15*).

Since the measuring tape is located in an inclined plane on the breast area, both in measuring the circumference of the chest of the first one and in measuring the circumference of the second breast, it is assumed that this precludes the inconsistency of increments of the gradation along the width of the product by the coefficients of gradation. Therefore, it is recommended to express the width of the front through the dimensional features: "the third breast" (*T16*), "the width of the back" (*T47*), "the width of the armhole cavity" (*T109*).

Then the formula for calculating the width of the front (section/35-37/) in the basic structures of shoulder products for the typical figures of boys and girls has the following view:

$$/35\text{-}37/ = 0.5(T16 - T47) - T109 + A_{35\text{-}37} \qquad (10)$$

The dimensions of the change in the size of the constructive sections along the line of the chest for the typical figures of boys and girls, depending on the change in size, was calculated using the improved formulas for calculating the width of the front and the width of the armhole, and the results are shown in Tables 6 and 7.

Table 6 The dimensions of the change in the size of constructive sections with a size change

Constructive section		The dimensions of the change in the size of the constructive sections [cm]							
		98		104		110		116	
		52-48 56-51	*56-51 60-54*	*52-48 56-51*	*56-51 60-54*	*52-48 56-51*	*56-51 60-54*	*52-48 56-51*	*56-51 60-54*
1		*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
/31-33/	girls	0.65	0.6	0.6	0.55	0.6	0.5	0.55	0.5
	boys	0.6	-	0.65	0.35	0.7	0.45	0.75	0.5
/33-35/	girls	0.4	0.4	0.4	0.4	0.5	0.5	0.6	0.6
	boys	0.5	-	0.5	0.4	0.5	0.5	0.6	0.4
/35-37/	girls	0.95	1.0	1.0	1.05	0.9	1.0	0.85	0.9
	boys	0.9	-	0.85	1.25	0.8	1.05	0.65	1.1
/31-37/	girls	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	boys	2.0	-	2.0	2.0	2.0	2.0	2.0	2.0

Table 7 The dimensions of the change in the size of the constructive sections with the change in height

Constructive section		The dimensions of the change in the size of the constructive sections [cm]								
		52-48			56-51			60-54		
		98-104	*104-110*	*110-116*	*98-104*	*104-110*	*110-116*	*98-104*	*104-110*	*110-116*
1		*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
/31-33/	girls	0,25	0,2	0,25	0,2	0,2	0,2	0,15	0,15	0,2
	boys	0,25	0,25	0,25	0,3	0,3	0,3	-	0,4	0,35
/33-35/	girls	0	-0,1	-0,1	0	0	0	0	0,1	0,1
	boys	0	-0,1	-0,1	0	-0,1	0	-	0	-0,1
/35-37/	girls	-0,25	-0,1	-0,15	-0,2	-0,2	-0,2	-0,15	-0,25	-0,3
	boys	-0,25	-0,15	-0,15	-0,3	-0,2	-0,3	-	-0,4	-0,25
/31-37/	girls	0	0	0	0	0	0	0	0	0
	boys	0	0	0	0	0	0	-	0	0

Comparison of changes in the width of the design along the breast line, depending on the change in size and height with coefficients of gradation for the typical figures of boys and girls, confirmed the retention of the gradation coefficient for the width of the product /31-37/, which is 2.0 cm.

Thus, the change in the structure of the calculation formulas of the design methodology, namely, the calculation of the width of the perimeter due to the dimensional feature "armhole width" (*T109*), and the calculation of the width of the front, due to the dimensional features of the "third breast" (*T16*), "back width" (*T47*) and "armhole width" (*T109*) ensures the correspondence of the constructive dimensions changes in width of the product, which improves the proportionality of shoulder products for typical figures of boys and girls of the preschool age group.

5 RESULTS

The results of the research are presented by the conditions for ensuring the reliability of the parameters of the anthropometric correspondence of the values of the structural dimensions of the measurement of the product width after making changes to the structure of the calculation formulas of the methodology of clothes' design of the Council for Mutual Economic Assistance [16].

The first condition is compliance with the gradation rules when choosing a calculation and analytical method for grading the structural sections of the width of the product along the chest line. Since the constructive sections /11-31/, /31-33/, /33-37/ after the changes are located in a rectangular coordinate system, the gradation value is defined as the difference between the points of a certain graded row $\Delta X_z\Gamma_j$ and ΔX_zE_j (Figure 2). So, the dimensions of gradation of points are calculated by the formulas:

$$\Delta X_z\Gamma_j = 1/k(X_z\Gamma_j^K - X_z\Gamma_j^0) \quad (11)$$

$$\Delta X_zE_j = 1/k(Y_z\Gamma_j^K - Y_z\Gamma_j^0) \quad (12)$$

where: *k* is the serial number of the size, counting from the zero initial size of a certain graded row; $X_z\Gamma_j^K$, $X_z\Gamma_j^0$, $Y_z\Gamma_j^K$, $Y_z\Gamma_j^0$, the coordinates of points of *k*-th size and zero initial size; *z* - index of major dimensional features *T1, T16*.

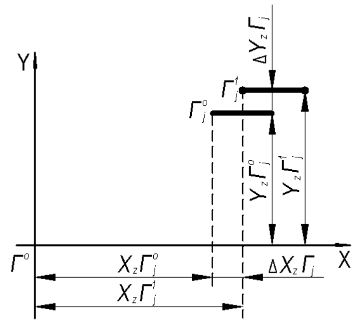


Figure 2 Scheme for determining the dimensions of the gradation $\Delta X_z\Gamma_j$ and ΔX_zE_j

In the calculation-analytical method, grading figures are calculated on the basis of gradation coefficients, which, in the anthropometric (constructive) standard, fix the difference between the values of dimensional characteristics, in particular for children of the preschool age group, between adjacent sizes, heights and their combinations. Dimensions from standards are called anthropometric coefficients of gradation.

By the experimental studies of the constructive sections of the product's width on the breast line /11-37/ (Tables 2 and 3) of the product the calculative coefficients of gradation parts have been defined.

For the consideration of the plane of the oblique section in the area of the posterior angle of the armhole, in which the *T15* (Figure 3) is measured, the calculations are performed according to the recommendations [16].

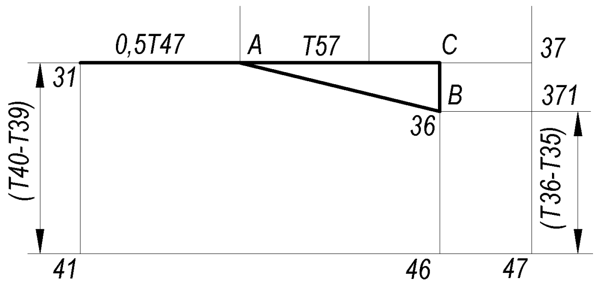


Figure 3 Scheme for determining the width of the front at the posterior angle of the armhole

In accordance with Figure 3:

$$AB = 0.4(T15 - 0.5T47) \quad (13)$$

$$BC = (T40\text{-}T39) - (T36\text{-}T35) \quad (14)$$

$$AC = \sqrt{AB^2 - BC^2} = a_8 \quad (15)$$

The indices of the dimensional features *T* correspond to the dimensional standards; the free member a_8 is the serial number of the system of the main structural segments. The dimension a_8 defines a decrease in the size feature *T15* for matching the width of the front along the horizontal line.

Calculations are made on the base size 110-56-51 for children of preschool age group using 1st standard – state one (anthropometric 1986), the second standard - branch one (designer 1977). These standards are used to study dimensional characteristics. After calculations the following values of a_8 are received:

For boys: (1)a_8 = 0.057; (2)a_8 = 0.037;

For girls: (1)a_8 = 0.05; (2)a_8 = 0.04.

The second condition is the observance of the necessary accuracy of the allowable deviations at the design stage of the product.

In accordance with the system of allowances [16], the average figures of allowances in the design process are 0.05 cm, rounding at design calculations up to 0.05 cm.

Consequently, the value a_8 < 0.1 cm which confirms the expediency of the exclusion of a_8 from the calculation of the width of the front for the younger children and the use of the dimensional feature *T16* instead of *T15*. Then the formula has the form:

$$35\text{-}37 = 0.5(T45 + T16 - T14) + A_{35\text{-}37} \quad (16)$$

The third condition is to ensure the unification of constructive elements of construction of approximating curves.

The analysis of the geometric construction of the conjugation of the armhole [1.1] confirms the expediency of replacing the dimensional feature *T57* with *T109*, since t. 352, which fixes the armhole width in the segment /33-35/, in the calculations shifts towards the narrowing for the base size 110-56-51 (to 0.5 cm for boys and 0.7 cm for girls). This is confirmed by Figure 4.

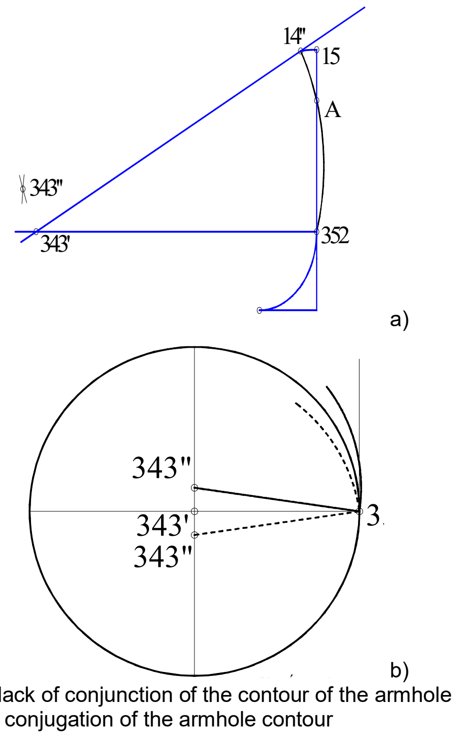


Figure 4 Scheme of contraction of the conjugation of the radiusography of the armhole contour: a) on the example of the design, b) possible variants

With the use of *T109*, the center of the circle for the design of the upper part of the armhole is on the extension of the contours from the points of change of the contour 332 (back), 352 (in front) as the vertex of an equilateral triangle. The method for drawing up the contour of the upper portion of the armhole is shown in Figure 5 and definitely ensures the conjugation of the lower and upper parts of the armhole.

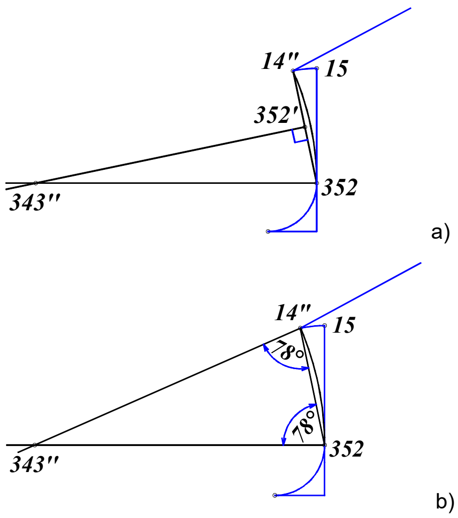


Figure 5 The design of the contour of the upper part of the armhole: a) the first way; b) the second method

Since in the formula (8) for calculating the width of the armhole the dimension *T57* is replaced by the dimensional feature *T109*, then the structure of the calculation formula for the *LA* and *WSC* takes the following form:

$$LA = 0.96T38 + (A_{33\text{-}13} + A_{35\text{-}15}) + \\ + 0.57(T109 + 1.0 + A_{33\text{-}35}) + 2/33\text{-}331/ \quad (17)$$

or

$$LA = 0.96T38 + (A_{33\text{-}13} + A_{35\text{-}15}) + \\ + 0.57/33\text{-}35/ + 2/33\text{-}331/ \quad (18)$$

$$WSC = T_{109} + a_{71} + A \quad (19)$$

The verification of these formulas is performed for the base size 110-56-51. According to the recommendations [16] a_{71} = 3.0 cm, and is calculated by the formula:

$$a_{71} = 0.5T_{28} - T_{57} \quad (20)$$

As the research shows $a_{71} = 0.5T_{28} - T_{109}$

respectively for T_{57} $a_{71}{}^{G}$ = 2.4; $a_{71}{}^{B}$ =2.3;

and for T_{109} $a_{71}{}^{G}$ =2.9; $a_{71}{}^{B}$ =2.6.

So, for T_{57}, T_{109} $a_{71} < 3.0$. The value of the deviation for T_{57} does not meet the condition of observance of accuracy A_{gen} = 0 3 mm. For T_{109} there is a compromise. Then for T_{109}:

WSC_G = 8.9 cm; WSC_B = 8.7 cm.

The minimum sleeve width is checked with:

$$WSC = T_{28} + A_{min} \quad (21)$$

where: A_{min} allows to bend the arm at the elbow.

The results of checking the design and minimum width of the sleeves confirmed the condition:

$WSC^{calc}{}_G$ = 8.9 cm; $WSC^{con}{}_G$ = 8.9 cm;

$WS^{calc}{}_B$ = 8.7 cm; $WSC^{con}{}_B$ = 8.7 cm.

Therefore, we support the recommended formula (19).

The condition of the approximation of the contour is achieved by the unification of the centers of radiusography.

The fulfilment of the formulated conditions ensures the check how the measurements of the width of the product along the chest line and the width of the sleeve under the armhole correspond to the coefficients of the anthropometric gradation in the values of the calculated grading coefficients.

A systematized number of sizes of structural segments in typical size groups of leading dimensional features and basic sizes of typical figures for girls and boys are given in Table 8 and thus, forms an anthropometric database for controlling the dimensions of the product.

Table 8 Anthropometric base of output dimensions of the main structural segments (without allowances) of shoulder clothes for typical figures of young children

Constructive section	Dimensions [cm]							X	S	BF1	BF2	BF3
T1	98		104		110							
T16	52	56	52	56	52	56	60	55.75				
T18	48	51	48	51	48	51	54					
/31-33/	11.05 11.05	11.7 11.65	11.3 11.3	11.9 11.95	11.5 11.7	12.1 12.25	12.6 12.7	g 12.26 b. 12.0	0.4 0.5	12.5 12.6	12.5 12.75	12.5 12.75
/33-35/	6.7 6.6	7.1 7.1	6.7 6.6	7.1 7.1	6.6 6.6	7.1 7.0	7.6 7.5	g 7.12 b. 7.05	0.6 0.5	6.7 6.5	6.7 6.5	6.0 6.0
/35-37/	8.75 8.65	9.7 9.75	8.5 8.4	9.5 9.45	8.4 8.35	9.3 9.25	10.3 10.25	g 9.41 b. 9.45	0.5 0.5	10.9 10.9	11.1 11.0	10.65 10.7
/31-37/								g 28.79 b. 28.5	1.5 1.5	30.1 30.0	30.3 30.0	29.15 29.45

Deviations /31-37/ from *T15* is for girls – 0.3 and for boys – 0.4, which correspond to the second condition. According to the specified method, the design sections are calculated according to the formulas:

$$31\text{-}33 = 0.5T47 - 0.5 + A \tag{22}$$

$$33\text{-}35 = T109 + 1.0 + A \tag{23}$$

$$35\text{-}37 = 0.5(T16\text{-}T47) - T109 + A \tag{24}$$

The arithmetic mean and the *S* variance confirmed the expediency of using the segment /31-37/ of the base figure to detect patterns of segments change /33-35/ in the parameters of the sleeve.

A criterion estimation of the influence of gender on the dimensional features was made by regression analysis of the dimensions of structural segments in the set of basic figures of the researched dimensional row: *X, BF1, BF2, BF3* (Figures 6 and 7).

According to the results of studies of the constructions 110-56-51 for girls and boys, a gender variability of 0.3 cm has been found, which corresponds to the value of the total allowance.

Anthropometric coefficients of gradation of dimensional features for the control of design stages of products for preschool age children are shown in Table 9.

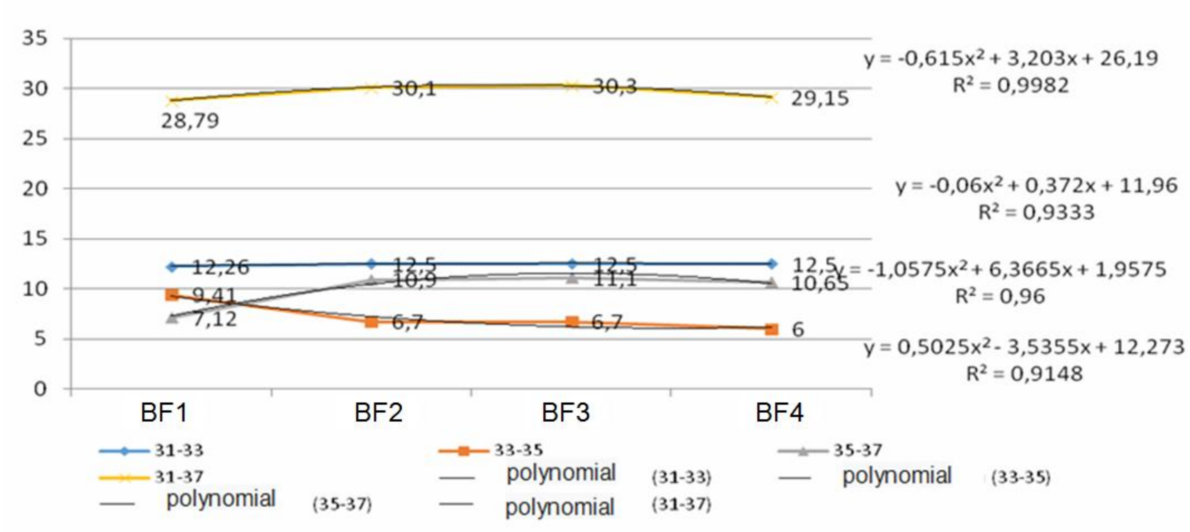


Figure 6 Regression dependences of gender changes in dimensional characteristics of girls

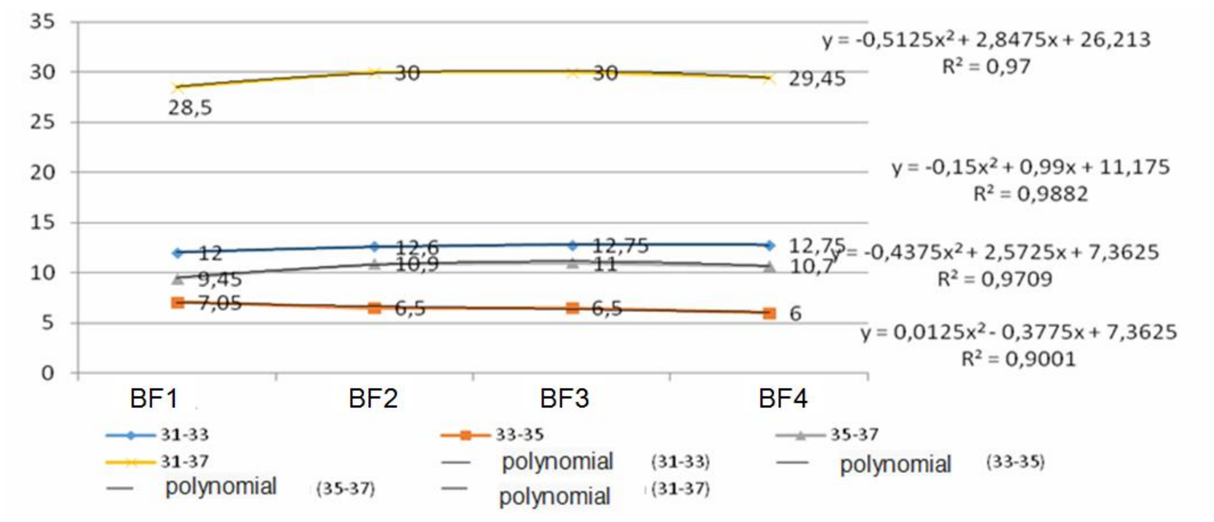


Figure 7 Regression dependences of gender changes of boys' dimensional characteristics

Table 9 Gradation coefficients of dimensional characteristics of control measurements of the shoulder product, size 110-56-51

Dimensional feature	Girls			Boys			Common		
	T1	*T16*	*T1+T16*	*T1*	*T16*	*T1+T16*	*average value*		
T29	0	0.5	0.5	0	0.5	0.5	0	0.5	0.5
T15	0.4	3.6	4.0	0.2	3.8	4.0	0.3	3.7	4.0
T57	0	0.6	0.6	0	0.5	0.5	0.5	0.55	0.55
T15	0.2	3.8	4.0	0.4	3.6	4.0	0.3	3.7	4.0
T45	0.4	1.0	1.4	0.2	1.0	1.2	0.3	1.0	1.3
T47	0.6	0.8	1.4	0.6	1.0	1.6	0.6	0.9	1.5
T40	1.1	0	1.1	1.1	0.2	1.3	1.1	0.1	1.2
T39	0.5	-0.2	0.3	0.5	-0.3	0.2	0.5	0.05	0.25
T109	0	0.8	0.8	0	0.6	0.6	0	0.7	0.7
T36	1.1	0.5	1.6	1.0	0.7	1.7	1.05	0.6	1.65
T35	0.6	0.2	0.8	0.5	0.6	1.1	0.55	0.4	0.95

6 CONCLUSIONS

As a result of the use in the method of design the improved formulas for calculating the parameters of the width of the armhole and the width of the front, the concordance of the values of the change in the size of the structural sections along the width of the product and along the breast section with the corresponding grading coefficients in the basic structures of the shoulder products for the typical figures of boys and girls of the preschool age group has been achieved.

Completed developments can be used for baby clothing design techniques that use an anterior-posterior hand diameter to calculate armhole widths.

In order to ensure the relationship between the width of the armhole and the parameters of the sleeve, the relationship between the armhole width of and the armhole length of the product's armhole and the width of the armhole and the width of the sleeve's cap have been established.

The representativeness of the method for assessing the reliability of control measurements in the structure construction is confirmed by the quadratic equations of variability of leading standard features.

This allows using the algorithm to verify the proportionality of the products in the choice of chart grading patterns, taking into account design techniques and current dimensional standards.

7 REFFERENCES

1. Slavinska A., Zakharkevich O., Kuleshova S., Syrotenko O.: Development of a technology for interactive design of garments using add-ons of a virtual mannequin, Eastern-European Journal of Enterprise Technologies 6/1(96), 2018, pp. 28-39, https://doi.org/10.15587/1729-4061.2018.148984
2. Vovk J.V., Slavinska A.L.: Identification of anthropometric information of the outline of a female figure and drawings of belt line products, Bulletin of Khmelnitskyi National University № 4, 2012, pp. 153-166
3. Porterfield A., Lamar T.A.M.: Examining the effectiveness of virtual fitting with 3D garment simulation, International Journal of Fashion Design, Technology and Education 10(3), 2016, pp. 320-330, https://doi.org/10.1080/17543266.2016.1250290
4. Sayem A.S.M., Kennon R., Clarke N.: 3D CAD systems for the clothing industry, International Journal of Fashion Design, Technology and Education 3(2), 2010, pp. 45-53, https://doi.org/10.1080/17543261003689888
5. Dāboliņa I., Viļumsone A., Dāboliņš J., Strazdiene E., Lapkovska E.: Usability of 3D anthropometrical data in CAD/CAM patterns, International Journal of Fashion Design, Technology and Education 11(1), 2017, pp. 41-52, https://doi.org/10.1080/17543266.2017.1298848
6. Baranova T.M.: Automation of the process of formation of the anthropometric database for the design of constructions in the conditions of mass production, Problems of the Light and Textile Industry of Ukraine №1, 2010, pp. 5-8
7. Zakharkevich O.V., Kuleshova S.G.: Development of the method of scaling patterns and virtual garments forms, Vlakn a Textil (Fibres and Textiles) 24(4), 2017, pp. 34-40
8. Kudryavtseva N.V.: Method of determining the types of human figures for "targeted" designing of shaping elements of belt clothing, Bulletin of the Khmelnitskyi National University № 4, 2013, pp. 73-78
9. Zalkind V.V.: Obtaining projective dimensional features of human figure by means of CAD clothes, Bulletin of the Khmelnitskyi National University № 3, 2014, pp. 224-227
10. Aileni R.M., Farima D., Ciocoiu M.: Simulating cloth in realistic way using vertices model based, 7th International Conference TEXSCI 2010, Liberec, CZ, 2010, https://doi.org/10.13140/rg.2.1.2518.3440
11. Dombrovskaya O.M., Pryimak N.V.: Improvement of the method of geometric construction of conjugation of the armhole, Bulletin of the Khmelnitskyi National University №. 5, 2009, pp. 150-153
12. Dombrovskaya O.M., Mitsa V.V.: Study of basic clothing designs for boys and girls of the preschool age group, Bulletin of the Khmelnitskyi National University №. 5, 2015, pp. 54-57

13. Slavinskaya A.L.: The Methods and Ways of Anthropometric Research for Designing of Clothes: Monograph, Khmelnitskyi: KhNU, 2012, 189 p
14. Masalova V.A., Shildt E.V.: Gradation by the method of scaling of patterns of sewing products, Clothing Industry №.5, 2005, pp. 38-41
15. Razdomahin N.N.: Aspects of anthropometric clothing provision: technology of searching for anthropometric points on photographs of a human figure, Clothing Industry №2, 2006, pp. 24-25
16. The unified methodology for designing the clothes of the CMEA (UMCD CMEA), Theoretical basis, Moscow, TsNIITEIlegprom, 1988, 163 p
17. Basiluk E.V., Bannova I.M.: Development of the method for grading the patterns of female shoulder outfits with differentiation of gradation schemes by silhouettes, Bulletin of Khmelnitskyi National University №5, 2008, pp. 17-21
18. Koshevko J., Yakymchuk D., Yakymchuk O., Chepeliuk O., Myrhorodska N., Orlenko O., Nosova I.: Study of cutting presses in designing a women's costume for hospitality industry, Eastern-European Journal of Enterprise Technologies 5/1(89), 2017, pp. 26-36, https://doi.org/10.15587/1729-4061.2017.110962

FIXATION OF REINFORCING FABRIC FOR ION EXCHANGE MEMBRANE

Eliška Stránská and David Nedĕla

MemBrain s.r.o., Pod Vinici 87, Straz pod Ralskem 47127, Czech Republic
Eliska.Stranska@membrain.cz

Abstract: *A reinforcing fabric is an integral part of heterogeneous ion exchange membranes (IEMs). It guarantees the mechanical resistance of IEMs. Thermal fixation of the fabric is one of the most important refining operations, which is also reflected in the production of IEMs during lamination on heated cylinders. The influence of the fixation temperature (grey variant, 120, 160 and 215°C) of the Ulester 31HDA polyester fabric with a twill weave on the production of IEMs was studied. DSC, iodine sorption value measurement and dimensional stability during the additional heat load were studied for commercially supplied fabrics Ulester 31HDA. The values were compared with a model series of fabrics prepared in laboratory drying under precisely defined conditions (temperature and time). The principle of fixation is the rearrangement of the internal fiber structure associated with the change of the crystalline phase. The reinforcing fabric is dimensionally stable up to the fixation temperature. Iodine sorption value decreased with the increasing temperature of fixation. No changes were seen from SEM images or density measurements. DSC analysis did not show the predicted dependence for the model series of fabric. Dimensional changes after temperature loading increased with temperature.*

Keywords: *heterogeneous ion exchange membrane, preparation of membrane, reinforcing fabric, iodine sorption value, differential scanning calorimetry, shrinkage of reinforcing fabric.*

1 INTRODUCTION

Heterogeneous ion exchange membranes (IEMs), which are used in electroseparation processes, consist of a polymeric matrix, an ion exchange resin which contributes to the transport of ions through the membrane and also a reinforcing fabric that guarantees good mechanical properties [1-3]. Heterogeneous IEMs can be prepared by extrusion of a polymer and ion exchange resin mixture, with the simultaneous incorporation of a reinforcing fabric on heated rolls [2, 3]. In this manufacturing process, it is important to have a properly fixed fabric in terms of temperature. If the reinforcing fabric is insufficiently fixed, additional shrinkage occurs during lamination of IEMs, which affects the quality of the produced IEMs, decreases the free area of the reinforcing fabric and thus also increases the electrical resistance of the manufactured IEMs [4]. Production is more demanding - extending the runway time, adjusting the entire production line, quality of the fabric is transferred to the manufactured IEMs quality. It is also necessary to buy a larger width of fabric to keep the required width of the manufactured IEMs. These factors increase the price of the reinforcing fabric and the IEMs.

For synthetic fiber fabrics, fixation is one of the most important refining operations. The desired touch and shape stability is a result of simultaneous heat-fixation and stretching of the fabric. The main change in synthetic fibers during fixation is the increase of the content of the crystalline fraction [5]. The fabric should be dimensionally stable up to the fixation temperature. The degree of fixation can be determined by several procedures, for example, by measuring DSC (differential scanning calorimetry), ISV (iodine sorption value), fiber density, critical time measurement, temperature, concentration or measurement of dimensional changes before and after thermal loading in a laboratory press.

The aim of the work was to characterize the commercially supplied grey reinforcing fabric and fixed fabrics at 120, 160 and 215°C and then to test them in the process of manufacturing IEMs. First, it was necessary to create a model line of fixed fabrics at defined temperatures and times, which was characterized by DSC and ISV. The commercially available reinforcing fabrics Ulester 31HDA were compared to the model series and additionally the dimensional changes at 120, 140 and 160°C, mechanical properties and density were determined. Cylinders used for laminating IEMs are normally set to these temperatures.

2 EXPERIMENTAL

2.1 Materials

The reinforcing woven fabric Ulester 31HDA (Silk & Progress, Czech Republic) in 4 variants was used to test the degree of fixation and quality of IEM preparation. Basic parameters of the fabrics are shown in Table 1.

Table 1 Properties of used reinforcing fabrics

Reinforcing fabric	Temperature of fixation [°C]	Thickness [μm]	Warp/weft [1 cm^{-1}]	Free (open) area [%]
Ulester 31HDA grey	-	263	27.7 / 30.5	40.6
Ulester 31HDA 120	120	249	28.5 / 30.5	39.8
Ulester 31HDA 160	160	260	29.8 / 30.2	39.2
Ulester 31HDA 215	215	242	29.2 / 30.4	39.1

Ulester 31HDA is a polyester woven fabric with a twill (2:2) weave, consisting of a monofilament of 150 μm in warp and 100 μm in weft direction. Ulester 31HDA grey was not washed and fixed. Other fabrics (Ulester 31HDA 120, 160 and 215) were already washed and fixed at 120, 160 and 215°C at Alligard (Czech Republic). The fabrics were stretched to the frame during the fixation, the duration of the heat was 2 minutes. Ulester 31HDA grey was used to prepare the model fabric series that were fixed at 120 - 215°C for 1 or 2 minutes in the laboratory drying oven.

2.2 Methods

Model reinforcing fabrics were characterized by DSC and ISV. Commercially supplied reinforcing fabrics (Ulester 31HDA grey, 120, 160 and 215) were characterized using SEM (scanning electron microscopy) and DSC. Dimensional changes before and after the thermal loading in the laboratory press, the ultimate force and strain, ISV and the density by pycnometry were determined. All commercial reinforcing fabrics were subsequently tested in the production of IEMs on the continuous lamination line in MemBrain s.r.o. and the influence of the degree of fixation on the production and quality of IEMs was evaluated.

SEM – scanning electron microscopy

The structure of the reinforcing fabrics was investigated using a FEI Quanta 250 FEG scanning electron microscope. The SEM measurement conditions were 10 kV voltage, in low vacuum (80 Pa) with LFD (large field detector) for secondary electrons.

Dimensional changes during temperature loading

Shrinkage in the warp and weft direction was determined at 120, 140 and 160°C for all fabrics according to ČSN 80 0823 [13] in the laboratory press. Testing was only in dry conditions; the reinforcing fabrics were placed between cold metal sheets.

DSC – differential scanning calorimetry

The purified sample was placed in a DSC PT 10 (Linseis) pan. DSC analysis was performed during heating and cooling. Two cycles of heating and cooling were measured in Ar atmosphere. The heating rate was 15°C min^{-1}, the cooling rate was 2°C min^{-1}. The maximum temperature was 305°C. The melting point and melting enthalpy were evaluated from DSC curves. Crystallinity [%] was calculated using the enthalpy of melting ΔH_m from the 1st cycle according to the equation:

$$\text{Crystallinity} = \frac{\Delta H_{\mathrm{m}}}{\Delta H_{\mathrm{m}}^{0}}\ 100\ \% \quad (1)$$

where ΔH_m^0 is the enthalpy of melting for 100% crystallinity of polyester from 2nd cycle.

ISV – iodine sorption value

Sorption of I_2 [5-8] into the amorphous regions of the fabric was determined by the iodine sorption value (ISV) [mg I_2.g^{-1}]. First the solution of 40 g KI + 5 g I_2 + 50 ml of water was prepared. The samples were degreased and dried. 1.2 ml of the prepared solution was added to 0.2 g reinforcing fabric. After 5 minutes, 100 ml of water was added. After 1 hour, 75 ml of the solution was taken and titrated with 0.02 M sodium thiosulphate of the exact concentration. Starch was used as an indicator. ISV was calculated according to the equation:

$$\mathrm{ISV}\left(\frac{\mathrm{mg\ I_2}}{\mathrm{g}}\right) = \frac{\left(V_{\mathrm{blind}} - \frac{V\ (101{,}2)}{V\ (75)} V_{\mathrm{titer}}\right) c\ (\mathrm{Na_2S_2O_3})\ M\ (\mathrm{I_2})}{m} \quad (2)$$

where V_{blind} is the volume of blind sample, V_{titr} is the volume of titer with sample, c ($Na_2S_2O_3$) is the concentration of sodium thiosulfate, M (I_2) is molar weight of iodine.

Mechanical properties

The mechanical properties of the reinforcing fabric were measured with samples of dimensions of 50x200 mm (clamping length) according to the ISO 13934-1 [14] using an H5KT (Tinius Olsen) tensile testing machine with a test speed of 100 mm.min^{-1}. The stress was in the warp and weft direction.

Density

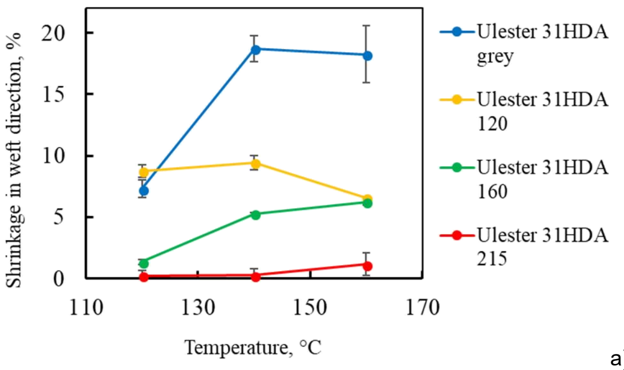
Density was measured using the Pycnomatic ATC automatic helium pycnometer (ThermoFisher Scientific).

Preparation of IEMs

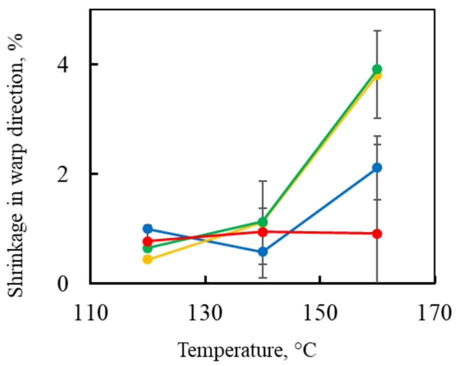
IEMs were prepared from an anion exchange resin and polyethylene. The mixture was extruded through a flat head between the rolls, onto which the Ulester 31HDA (grey, 120, 160 and 215°C) commercially available fabric was introduced. The temperature of the rolls for all fabrics was 140°C, the temperature of the extruded mixture was 136°C. The continuous lamination line speed was 1 m.min^{-1}. IEMs were laminated on both sides. IEMs were rolled up after cooling [9].

3 RESULTS AND DISCUSSION

The dimensional changes (length - warp direction, width - weft direction, thickness) of commercial Ulester 31HDA after additional heating at 120, 140 and 160°C was tested by the laboratory press. The reinforcing fabric was fixed by cold metal sheets and was inserted into the heated press to the desired temperature. Sample sizes were determined before and after exposure. The results for the warp and for the weft are shown in Figure 1.



a)



b)

Figure 1 Shrinkage of reinforcing fabrics Ulester 31HDA in the weft (a) and warp (b) direction

The thickness of the samples increased in all cases due to the shrinkage of the fibers in the crossing of fabric. During the IEMs lamination, additional shrinkage occurred only in the weft direction. The warp is stretched by the roll from which it is unwound. Dimensional changes increased with higher temperature in the warp and weft directions. Dimensional changes in the warp direction were much lower than in the weft direction. This is due to the process of fixation and weaving, where the anisotropy of the reinforcing fabric properties occurs [10]. Ulester 31HDA grey had the highest shrinkage. The shrinkage decreased with the increasing Ulester 31HDA fixation temperature, which we anticipated.

The results did not show significant differences of fabric density and mechanical properties. Average values for ultimate force have an increasing tendency, but they are within the measurement error. The ultimate strain in the weft direction also showed a slight increase (Table 2). The anisotropy of mechanical properties in the weft/warp direction was already published by many authors [10-12]. The impact of stress on mechanical properties is enormous. The anisotropy of fabric properties is given by the fabric structure based on the perpendicular threads in the warp and weft. It can also affect the relative shifts of individual threads and the interaction of the threads at the bonding points.

During the fixation, the internal structure is rearranged, increasing the content of the crystalline fraction. From a thermodynamic point of view, it is the establishment of new conformational equilibria of the polymer chains in the threads deformed during the refining operation. I_2 sorption is the basic method for determining the degree of fixation of synthetic fibers. I_2 is absorbed only into the amorphous regions of the threads at polar sites (NH, CO). The proportion of crystalline regions in the fiber increases with the increasing degree of fixation and the sorption of I_2 decreases [5-8]. From the model series and commercially available fabric Ulester 31HDA, it is seen that ISV decreased with the increasing fixation temperature. The decreasing dependence is well evident in Figure 2. The ISV is determined with a relatively high error. For more accurate measurement of the fabric with an unknown fixation temperature, the method should be adjusted.

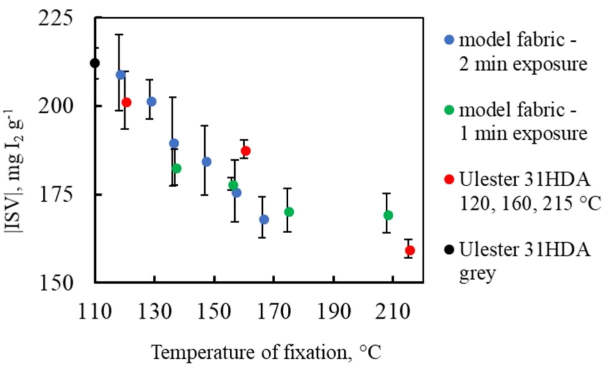
From DSC analysis, it was possible to calculate the crystallinity of the material, which varied according to the temperature history of the sample. There was a melting peak in the DSC curve, which did not change with the temperature of the fixation of the reinforcing fabric. Crystallinity was calculated from the 1st cycle (heating and cooling) when the sample still had a temperature history due to the fixation temperature. The problem with DSC measurement for fabrics was the small sample weight at the detection limit and poor heat transfer from the pan to the sample. The heat transfer was improved in the 2nd cycle (fabric is in the sheet form), but the temperature history of the sample was not visible on the DSC curve.

Table 2 Density, ultimate force and strain for commercial reinforcing fabrics

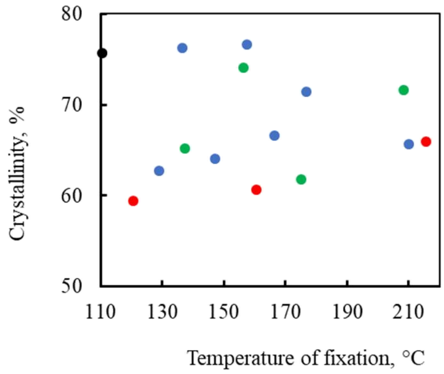
Reinforcing fabric	Density - pycnometry [g.cm^{-3}]	Ultimate force - warp/weft [N 5 cm^{-1}]	Ultimate strain - warp/weft [%]
Ulester 31HDA grey	1.380	1260±25 / 543±12	46±3 / 28±2
Ulester 31HDA 120	1.393	1240±35 / 571±13	46±3 / 28±1
Ulester 31HDA 160	1.380	1330±16 / 621±9	44±1 / 34±3
Ulester 31HDA 215	1.385	1290±65 / 635±6	42±4 / 36±1

An increasing proportion of the crystalline phase to temperature was only apparent for commercially available Ulester 31HDA samples (Figure 2). For the model series of samples, the increasing proportion of the crystalline phase was not confirmed. This was probably due to insufficient heat transfer from the pan to the sample or low sensitivity of the DSC.

SEM pictures of commercially supplied Ulester 31HDA are shown in Figure 3. No significant changes during fixation were visible on the threads. The increasing fixation temperature only slightly decreased of the free (open) area of the reinforcing fabrics (Table 1) in the order of percentages.



a)

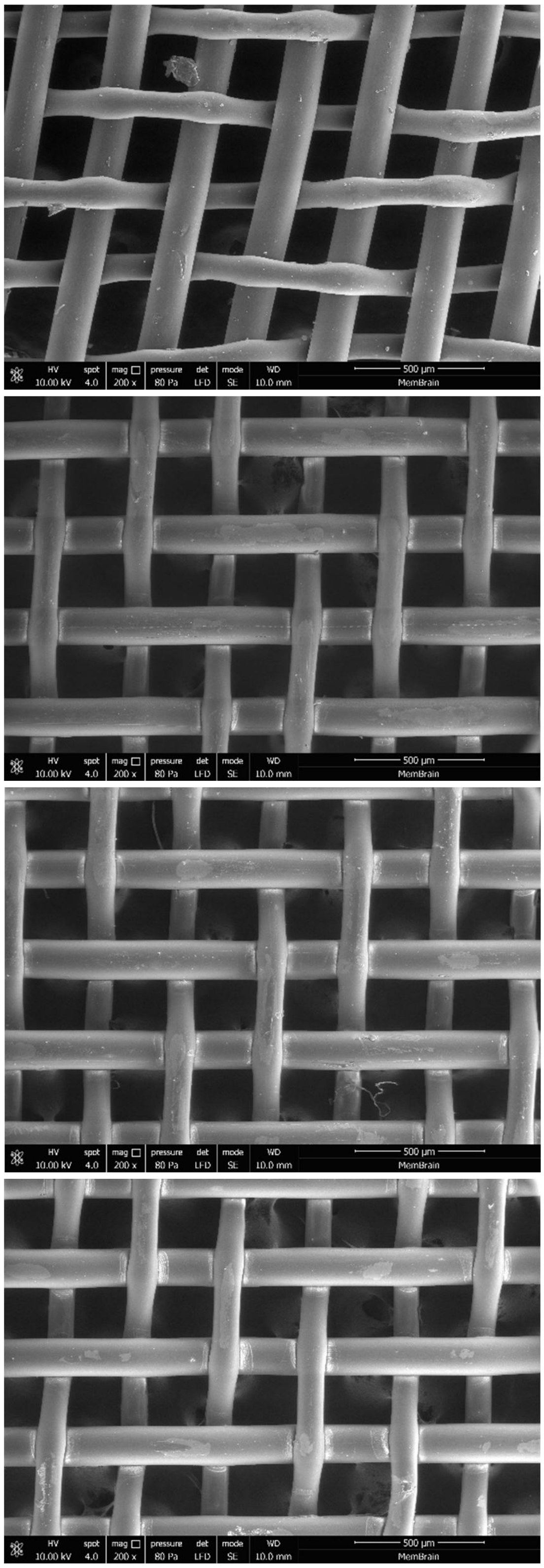


b)

Figure 2 Iodine sorption value ISV (a) and crystallinity (b) of model fabric and commercially supplied Ulester 31HDA

The production of IEMs with Ulester 31HDA 215 and 160 took place without any significant problems. The Ulester 31HDA 215 and Ulester 31 HDA 160 on 140°C warm rolls had a shrinkage of 0.4%, respectively 2.6% in the weft direction. Values correspond to the measured data from the laboratory press at 140°C. Production of IEMs took place at lower temperatures (140°C) than the temperature of the fixation of the reinforcing fabric (160 and 215°C). Textiles were stable at this temperature.

IEM production with Ulester 31 HDA grey and 120 was more problematic. Greater parameter changes and setting of pressures on rolls had to be done. The Ulester 31HDA grey and Ulester 31 HDA 120 on 140°C warm rolls shrinked by 16.7%, respectively 10.2% in the weft direction. These values also correlate with the measured data presented in Figure 1.



a) b) c) d)

Figure 3 SEM pictures of Ulester 31HDA grey (a), Ulester 31HDA 120 (b), Ulester 31HDA 160 (c) and Ulester 31HDA 215 (d)

The formation of wrinkles and fabric duplication occurred with high shrinkage of the reinforcing fabrics on the rolls, where there is uneven tension and material distribution. The defects are visible in Figure 4. In some places, the reinforcing fabrics were folded and rolled into the IEM in two layers. Another problem was the formation of surface wrinkles formed by the imprinting of PET foil which is used to separate IEM from heated rolls. The reinforcing fabric rumpled the PET foil because of its high shrinkage and wrinkles from PET foil were imprinted on the IEM surface.

a)

b)

c)

Figure 4 Images of unsatisfactory production of IEMs; wrinkles caused by high shrinkage of the fabric on the warm rolls

These IEMs were then marked as unsatisfactory. Despite the difficulties, it was eventually possible to start production with this type of reinforcing fabric, so all variants would be used in the production of IEMs.

4 CONCLUSIONS

The effect of the fixation temperature of reinforcing fabric Ulester 31HDA on IEM production and their characterization was investigated using basic methods such as DSC, ISV measurements or dimensional changes before and after the temperature exposure.

ISV decreased with the fixation temperature due to lower sorption of iodine in crystalline regions. However, the method is not sensitive enough to determine the precise fixation temperature of reinforcing fabrics. Dimensional changes at temperatures below the fixation temperature of the fabric were within 5%. Shrinkage increased with increasing temperature. Below the fixing temperature, the fabric is still thermally stable. The crystallinity was determined from DSC analysis. An increasing trend was demonstrated only in commercial samples Ulester 31HDA. From SEM, density, or ultimate force and strain measurements, there was not visible difference between reinforcing fabrics treated at different temperatures. All types of Ulester 31HDA textiles can be used in the manufacture of IEMs by lamination. In some cases, it is necessary to increase the correction of the individual parameters of continuous lamination line. The price of fixation of the reinforcing fabric is around 20% of the purchase price of the reinforcing fabric. Production problems with the reinforcing fabric fixed at lower temperature than the production temperature of the IEM are large and there is the large amount of unsatisfactory production. Thus, other IEM components are also drawn. The price of fixation of the reinforcing fabric thus appears to be more advantageous. It is also recommended to fixation at 160 or 215°C.

ACKNOWLEDGEMENT: *The work was carried out within the framework of the project No. LO1418 "Progressive development of Membrane Innovation Centre" supported by the program NPU I Ministry of Education Youth and Sports of the Czech Republic, using the infrastructure Membrane Innovation Centre.*

5 REFERENCES

1. Ariono D., Khoiruddin Subagjo Wenten I.G.: Heterogeneous structure and its effect on properties and electrochemical behavior of ion-exchange membrane, Materials Research Express 4(2), 2017, pp. 1-11, https://doi.org/10.1088/2053-1591/aa5cd4

2. Kariduraganavar M.Y., Nagarale R.K., Kittur A.A., Kulkarni S.S.: Ion-exchange membranes: preparative methods for electrodialysis and fuel cell applications, Desalination 197(1-3), 2006, pp. 225-246, https://doi.org/10.1016/j.desal.2006.01.019
3. Nagarale R.K., Gohil G.S., Shahi V.K.: Recent developments on ion-exchange membranes and electro-membrane processes, Advances in Colloid and Interface Science 119(2-3), 2006, pp. 97-130, https://doi.org/10.1016/j.cis.2005.09.005
4. Stránská E., Neděla D.: Reinforcing fabrics as the mechanical support of ion exchange membranes, Journal of Industrial Textiles 48(2), 2017, pp. 432-447, https://doi.org/10.1177/1528083717732075
5. Weiner J., Průšová M., Kryštůfek J.: Chemical-textile analyzes (Chemicko-textilní rozbory), in Czech, Technical University of Liberec: Liberec, 2008
6. Nelson M.L., Rousselle M.A., Cangemi S.J., Trouard P. The iodine sorption test. Factors affecting reproducibility and a semimicro adaptation, Textile Research Journal 40(10), 1970, pp. 872-880, https://doi.org/10.1177/004051757004001002
7. Pušić T., Soljačić I., Iskerka B., Vojnović B.: Study of Iodine Sorption Value of cotton fabrics after washing (Istraživanje jodnog broja pamučne tkanine nakon pranja), in Croatian, Tekstil 63(1-2), 2014, pp. 41-48
8. Weaver J.V. (Ed.): Analytical Methods for a Textile Laboratory, AATCC: Research Triangle Park, N.C., 1984
9. Stránská E.: Relationship between transport and physical-mechanical properties of ion exchange membranes, Desalination and Water Treatment 56(12), 2015, pp. 3220-3227, https://doi.org/10.1080/19443994.2014.981413
10. Stránská E., Zárybnická L., Weinertová K., Neděla D., Křivčík J.: Anisotropy of mechanical properties of heterogeneous ion exchange membrane, Chemické Listy 110(7), 2016, pp. 498-503
11. Adomaitienė A., Kumpikaitė E.: Analysis of mechanical properties of fabrics of different raw materials, Materials Science (Medžiagotyra) 17(2), 2011, pp. 168-173
12. Zouari R., Amar S.B., Dogui A.: Experimental characterization of anisotropic mechanical properties of textile woven fabric, International Scholarly and Scientific Research & Innovation 2016, 10(2), pp. 409-415
13. ČSN 80 0823: 2014 Textile fabrics - Determination of dimensional changes after damp pressing
14. ISO 13934-1: 2013 Textiles - Tensile properties of fabrics - Part 1: Determination of maximum force and elongation at maximum force using the strip method.

REGIONAL ICON MOTIFS: RECENT TRENDS IN INDONESIA'S BATIK FABRIC DEVELOPMENT

Eko Sugiarto[1], Ahmad Nizam bin Othman[2], Triyanto[1] and Meina Febriani[3]

[1]Universitas Negeri Semarang, Art and Language Faculty, Visual Art Department, Semarang, Indonesia
[2]Universiti Pendidikan Sultan Idris, Faculty of Arts, Computer & Creative Industry, Creative Media Department, Perak, Malaysia
[3]Universitas Negeri Semarang, Art and Language Faculty, Language Department, Semarang, Indonesia
ekosugiarto@mail.unnes.ac.id; ahmad.nizam@fskik.upsi.edu.my; triyantoma57@gmail.com; meinafebri@mail.unnes.ac.id

Abstract: *Batik is a traditional textile that has developed in Indonesia. UNESCO's recognition of Indonesian traditional textiles (batik) as a cultural heritage is driving the development of batik trends in Indonesia to become not only a fabric, but also a regional identity. This study aims to explain how the identity of the region is manifested in a specific motif in each region in Indonesia that can be identified from fabric and clothing products. This research employed artistic research approach with multiple-case study design in five batik industry areas, namely Semarang, Kudus, Cirebon, Surabaya and Malang as the center of the people's batik industry. The research was carried out through the steps of: a) visual data collection and batik creation process, b) visual analysis, c) synthesis and d) verification. Product data were collected through batik product documents and were corroborated through observation. The data were then analyzed using an interactive model. Batik motifs are based on guiding elements and design principles. There are findings of the structure of motifs from the regional icons during batik making both in the form of cloth and clothing. This has become the trend of Indonesian batik today*

Keywords: *batik, icon, identity, motif, textile.*

1 INTRODUCTION

This article was written based on the results of a research in the past year about Indonesian Batik. Batik is a traditional Indonesian textile art that has developed since the 18th century. Batik as a traditional textile has been handed down from one generation to the next for centuries [1]. Batik is a traditional textile which was originally only worn by the royal or aristocratic groups in Java. The tradition of making batik textiles is considered a sacred thing that can only be done inside the palace and the results are for the clothes of the king, his family and his followers, which are symbols of Javanese feudalism [2]. Javanese feudalism appears in the types of batik that can only be worn by kings and aristocrats, which distinguishes batik from those used by ordinary people or ordinary people.

UNESCO's recognition of Indonesian traditional cloth (batik) as a cultural heritage on October 2, 2009 became a booster of the growth of the batik industry in Indonesia [3]. As one of the traditional arts and culture, Indonesian batik is currently increasingly has its own attraction for foreign communities. The success of batik textiles attracted international attention [2]. The application of batik design that is increasingly developing shows the creativity of batik designers in the traditional textile industry that is in line with the target audience [4]. Batik developed rapidly in Java Island, which was integrated in the north coast culture.

Batik in the north coast of Java, besides being popular for its creativity and uniqueness, also has a strong historical background of traditional textiles, started from the regions of Cirebon, Semarang, Kudus, Surabaya, to Malang. The phenomenon of the development of batik today is not only as a piece of cloth with a sprinkling of ornaments or motifs, but has developed into a legitimacy or identity of an area. In Indonesia, nowadays, creations of batik products have now begun to appear, including Semarang Batik (Semarang-style batik), Kudus Batik (Kudus-style batik), Cirebon Batik (Cirebon-style batik), Surabaya Batik (Surabaya-specific batik) and Malang Batik (batik typical of Malang citizens). Thus, research is needed on the development of Javanese batik which is becoming the current trend. Research related efforts to develop the batik industry sector, which can be said as an effort to lift the image of traditional textile art based on local culture [5].

Currently, the research related to batik has been done, but there is no research that discusses the batik textile industry from the perspective of regional identity which is becoming a clothing trend in Indonesia lately. This research has a novelty in the form of empirical disclosure about the perspective of regional identity in the process of traditional textile production and its implications in the form of regional clothes. The construction of regional identity is inherent in the depiction of iconic motifs.

This research is useful as it does not only conserve monumental batik in Indonesia, but also emphasize the difference between traditional batik textiles in Indonesia and other countries that contain educational values based on traditional culture. Indonesian textile batik is not only a textile material product in the form of cloth, but also it has cultural values in the form of knowledge, attitudes and skills that are passed on from one generation to the next through the educational process in society. Additionally, this study is useful to: 1) improve the reproduction of motifs, fabrics and batik clothes based on regional identities; 2) publish batik as a cultural heritage, especially the noble values in it; and 3) encourage the development of the batik industry as a medium for visual arts education.

2 METHODOLOGY

This paper is based on field research which is oriented to empirical and theoretical analysis of educational values in batik textile works as a product of local culture, therefore the research approach employed artistic research [6]. It relates to the specific purpose of the research which is to analyze the design of Javanese batik motifs and the construction of identity that is contained. This research was conducted with a multiple-case study design [7] in five traditional batik industry areas studied, namely Cirebon Batik, Semarang Batik, Kudus Batik, Surabaya Batik and Malang Batik. The object of research is batik textiles in the form of fabric or clothes. The research locations are five traditional batik industry centers, namely: 1) CV Cipta Karya Mandiri, 2) Kampung Batik Semarang, 3) Kampung Batik Trusmi, 4) Virdes @ Batik Collection and 5) CV Batik Antique Malang.

The research was carried out through the following steps: a) visual data collection and batik creation process through observation of the creation process, b) mapping of motif specifications from various regions in Indonesia, c) aesthetic visual analysis of batik motifs, and d) verification. Product data were collected through batik product documents and corroborated through observation. Data analysis used qualitative approach using an interactive model. The analysis of batik motifs is carried out based on the guidelines of the elements and design principles.

3 RESULTS AND DISCUSSION

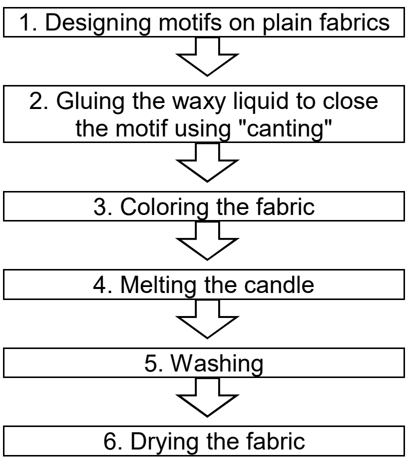
3.1 *Process of batik creation*

Indonesia has many popular batik industries in the form of small and medium businesses. The batik industry in Indonesia is generally a small and medium industry which is the livelihood of some people [8]. Widespread batik art belongs to the people of Indonesia and Javanese, especially after the end of the XVIII century or the beginning of the XIX century. The batik industry in Indonesia is spread in several regions on the island of Java which later became the name of the types of batik [9].

Traditional batik which is still continuously preserved and developed openly are Batik from the Cirebon (West Java Province), Semarang (Central Java Province), Kudus (Central Java Province), Surabaya (East Java Province) and Malang (Central Java Province). Four of the five regions are in the northern Javanese cultural region. The characteristics of traditional textiles in the north coast of Java are open, dynamic and creative in terms of motifs and patterns [9]. These characteristics differ greatly from traditional-classical textiles in the interior (Solo and Yogyakarta) which are very rigid and obedient with very strict motive structures, because they were influenced by the power of the Javanese kingdom in the past [10].

In the current development, iconic motifs in Indonesia are sourced from cultural and philosophical backgrounds also come from physical buildings. The existence of regional icons becomes the main source of ideas in making motifs. Palace Gate and the vehicle of the king of Cirebon are specific form icons in Cirebon, Central Java. The building of Lawang Sewu and the Tugu Muda monument are the icon of Semarang, Central Java. Monument of Kudus Tower is the icon of Kudus, Central Java. While on the eastern part of Java Island there is the Surabaya Monument as the Surabaya icon and the Monument of Malang as the icon of the city of Malang, East Java.

The process of making batik is very unique and different from the traditional textile creation in other countries. The process is done for many times, at least five times. Making motifs is done on a piece of cotton or silk fabric using a pencil. The sticking process of wax liquid that has been heated to 59°C on a piece of cotton or silk cloth by following the motif functions to cover up the motif. Coloring process can be done naturally or chemically.



Natural dyes are produced from the colors that we can get from a variety of plants, for example fruit, roots, leaves, or tree bark [11]. Chemical dyes are processed / produced chemically by industry. These chemical dyes can be classified into seven color ingredients namely Napthol, Indigosol, Rapide, Ergan Soga, Soga Couplings, Soga Chroom and Prosion. The next process is to melt the wax by boiling it in boiling water. The motif part that is covered by wax will be seen after the wax is dissolved with boiling water. The last process is washing the fabric using water. Water has an irreplaceable role in the textile industry. Every textile production depends on water and the adequacy of good quality water. Washing is one of the most important activities in the process of making textiles [12]. Figure 1 shows the photos of the batik making process.

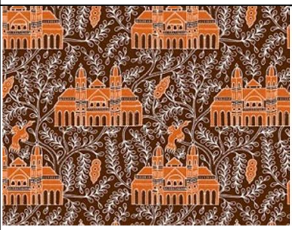
a) b)

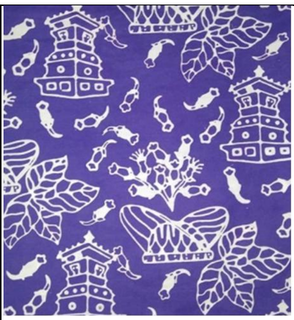
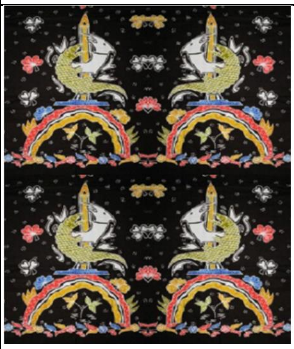
Figure 1 Process of making batik traditionally

3.2 *Iconic motif structure as regional identity*

Batik motifs are analyzed based on their forming structure, namely the main motif, companion motif, and filler motif (*isen-isen*). Table 1 explains how batik regional icons were analyzed for their shape and structure.

Table1 Visual analysis of motif designs with regional icons

No	Developing Batik Motif	Analysis of Motif Structure	Icon Description	Regional Icon
1	 Batik Motif of *Gapura Keraton*	• Main motif: palace gate and veranda (Kingdom of Cirebon) • Companion motifs: cloud motifs and fence motifs. • Filler motif: line and point elements • Motif structure uses parallel-repeat technique • Using white fabric as background and brown color on the motif	• The source of the idea of motifs is the Cirebon area icon, which is the palace gate of Cirebon in Central Java • The gate is a landmark in Cirebon, Central Java	 Palace Gate of Cirebon Central Java
2	 Batik Motif of *paksi naga liman*	• Main motif: *paksi naga liman* • Companion motifs: bird and soil motifs • Filler motifs: line and point elements • Motif structure uses opposite-repeat technique • Using white fabric as background. Brown, yellow and black on the motif	• The source of the idea of motifs is the traditional vehicle of Cirebon Palace in the past • The shape of the vehicle is the imagination of the *paksi naga liman* (a combination of elephants, eagles, and dragons) • The icon of *paksi naga liman* vehicle is the identity of the Cirebon area	 The vehicle of the king of Cirebon in Cirebon, Central Java
3	 Batik Motif of *Lawang Sewu*	• Main motif: lawang sewu • Companion motif: Javanese tamarind plant motif (*Tamarindus Indica*) • Filler motif: line and point elements • Motif structure uses diamond-repeat technique • Use *sogan*-brown color as background. White color is used in the tamarind motif outline and orange in the motif	• The idea source of the motif is the Lawang Sewu building, an icon in Semarang, Central Java area • This building is a building with a Dutch architectural style that is in the center of Semarang City as the icon of Semarang City	 The building of Lawang Sewu in Semarang, Central Java
4	 Batik Motif of *Tugu Muda*	• Main motif: Tugu Muda • Companion motif: Javanese tamarind plant motif (*Tamarindus Indica*) and bird motif • Filler motif: line and point elements • Motif structure uses opposite-repeat technique and red as a background. Green and blue colors are on the main motif	• The idea source of the motif is the Tugu Muda building which is also an icon of Semarang Central Java and is located besides Lawang Sewu • This building is located in the center of Semarang City, as one of the icons of Semarang City	 The monument Tugu Muda in Semarang, Central Java

5	 Batik Motif of Kudus Tower	• Main motif: Kudus Tower• Companion motif: tobacco leaf and tobacco flower motif (*Nicotiana Tabacum*) • Filler motif: point elements • Motif structure uses quarter-drop technique • It only uses one main color which is blue as background • The white color of the fabric is used for outline motifs	• The idea source of the motif is the Kudus Tower which is an icon of Kudus City, Central Java • This building is a protected historical building (artifact) in Kudus City • This building is a religious symbol of Islam in Java	 Monument of Kudus Tower, in Kudus, Central Java
6	 Batik Motif of *Surabaya Monument*	• Main motif: monument, shark and crocodile • Companion motif: flora motif (leaves and flowers). • Filler motif: point and line elements • Motif structure uses parallel-repeat technique • It uses five color variations, including black on the background, white, green, blue, and red on the motif	• The idea source of the motif is the Surabaya monument, an important icon of Surabaya City, in East Java • The word "Surabaya" comes from the Javanese language, consisting of the words "suro" and "boyo", meaning "shark" and "crocodile" • This building is located in the center of Surabaya City, East Java	 Surabaya Monument
7	 Batik Motif of *Malang Monument*	• Main motif: Malang Monument• Companion motif: tendril motif • Filler motifs: points, lines, square • Motif structure uses parallel-repeat technique • It uses black on the background and brown on the motif	• The idea source of the motif is the monument of Malang city, an icon in Malang City, East Java • This monument is located in the center of Malang City, East Java	 Monument of Malang City

When in the beginning of batik, depicted in particular motifs, served as the identity of the Royals, later on it has evolved into a medium to showcase one's regional identity [13]. The trend of batik motifs that are developing in Indonesia at this time shows many local icons. The phenomenon is actually motivated by the interests of one region's identity with each other. The strong importance of identity (brand image) in several regions has implications for creativity in developing the iconic motifs of each region. Basically, the motifs that are developed originate from the idea of regional landmarks (physical environment or artifacts).

When we refer to the historical view, batik was originally an art form from the Javanese kingdom which later became popular among the people, not only the nobles but also ordinary people. Through a piece of batik fabric, the cultural meaning is conveyed and preserved. Through visual forms and symbols, batik also conveys cultural meanings handed down from generation to generation. Batik *keraton*, batik *paksi naga liman*, batik lawang sewu and batik *malang* were made with a repetitive stamp technique through laying wax with a stamp, coloring and removing wax. The stamp technique was chosen because the motif has symmetry so that it can be produced faster when stamped. Different from the *kudus* motif and *suro-boyo* motif made with written techniques. This technique uses a canting tool (a traditional stationery containing wax ink). This process requires a longer duration, but the result of motives is more dynamic.

3.3 *Application of regional icon motifs on clothes or uniforms*

Here is an example of the application of batik fabric with motifs on formal clothes presented in Figure 2 and Figure 3. The applications can be presented on the collar, arms and body on formal clothes for men and women.

Batik cloth with regional icon motifs is more appropriate to be applied to formal clothes or uniforms. The application of motifs on formal clothes for women is usually in the form of formal dresses, while for men it is usually in the form of a shirt with short and long sleeves. People wear formal clothes in various situations, such as at work, meeting someone new, or in a job interview [14]. Formal dress is often worn to follow the norm, gain respect, signify professionalism and maintain social distance [15].

Figure 2 Example of motif placement on long-sleeved pattern of menswear

Figure 3 Example of motif placement on womenswear

For the Javanese, batik is a traditional cloth which is integral to their cultural identity [16]. The application of motifs and fabrics to clothing is very flexible and varied [17]. The examples in Figures 2 and 3 apply to the Surabaya monument motif, which can also be applied to other batik motifs. The batik motifs that will be applied to the fabric are adjusted according to the design of the clothes. Based on the results of visual analysis, the application of batik motifs on clothes adjusts the structure of the collar, arms and body. The shape of the clothes, which can be produced from the application of the regional icon batik motifs, can be broader for other motifs (motif of *gapura kraton*, motif of *paksi naga liman*, motif of Lawang Sewu, motif of Tugu Muda, motif of Kudus tower, motif of Surabaya monument and motif of Malang monument). The fabric can also be applied to dresses or skirts by adding plain cloth as a complement. Additionally, the size of motifs can be further reduced so that the composition of the motif can be more complicated and complex. The application of colors, especially women's clothing, can use bright colors as another variation.

4 CONCLUSION

Based on the research discussions, it could be concluded that the phenomenon of batik from the regions of Cirebon, Semarang, Kudus, Surabaya and Malang, which illustrates motifs in the form of regional icons, shows a growing trend at the moment. Regional identity was depicted in specific motifs in each region in Indonesia which can be identified from fabric and clothing products. The motifs are the *paksi naga liman, Gapura* Cirebon*, tugu muda* Semarang, *Lawang Sewu* Semarang, Kudus tower, Surabaya monument and Malang monument. The developed motif structure consists of the main motifs, companion motifs and filler motifs (*isen-isen*) originating from the idea of the environment of physical icons or local area artifacts. Development of basic motifs into patterns employs parallel-repeat technique, opposite-repeat technique and diamond-repeat technique. After the motifs and patterns are arranged into batik fabric, that's where it starts to be considered how to apply it to clothing aesthetically.

The admission of batik as one of the world's intangible cultural heritages had an impact on extensive development in several regions in Indonesia (Java). The trend of developing the motifs is motivated by the interests of the identity of one region against another. The importance of identity in some areas of Java has implications for creativity in developing iconic motifs.

This research can be significantly used as a theoretical reference and practice of batik motif design and its application in formal menswear and womenswear. The pattern of its application in clothing design is done by considering the collar model, the shape of the arms and the shape of the body parts.

ACKNOWLEDGMENTS: *This article is the result of research funded by Universitas Negeri Semarang and Dikti. Special thanks are given to Prof. Dr. Tjetjep Rohendi Rohidi, all of informants and the Batik Art Education Laboratory in Visual Art Department.*

5 REFERENCES

1. Indonesia K.: Batik Nusantara, Kina, Jakarta, 2013, pp. 1-112
2. Dinata R.: Philosophy and contemporary exploration on designing batik motif for JAVAJAZZ promotion poster application, IOP Conference Series: Materials Science and Engineering 453, International Conference on Design, Engineering and Computer Sciences 20189, August 2018, Jakarta, Indonesia, 2018, pp. 1-11, https://doi.org/10.1088/1757-899X/453/1/012039
3. Syamwil R., Sugiarto E., Rohidi T.R., Nurrohmah S.: Weeds as a source of development idea on batik motive" Vlakna a textil (Fibres and Textiles) 26(2), 2019, pp. 69-73
4. Sugiarto E.: Kreativitas, Seni & Pembelajarannya. Yogyakarta: LKiS, 2019
5. Kishore N., Paul S., Grover E., Maurya S.: Adaptation of monumental motifs for textile application, Asian Journal of Home Science 8(2), 2013, pp. 726-730
6. Rohidi T.R.: Metodologi Penelitian Seni. Semarang: Cipta Prima Nusantara, 2014
7. Yin R.K.: Case Study Research: Design and Methods, Thausand Oaks, CA: Sage, 2013
8. Prameswari N.S., Suharto M., Afatara N.: Long-sleeved shirt pattern as guidelines for designing a sanggit motif batik shirt, Vlakna a textil (Fibres and Textiles) 25(4), 2018, pp. 61-70
9. Nuraenun N., Rasyimah R., Heriyana H.: Analisis Industri Batik di Indonesia, Fokus Ekonomi 7(3), 2008, pp. 124-135
10. Riani A.L., Sarungu J.J., Margana: The acceleration of traditional batik (creation and combination) through integrated management to support the acceleration in regional economic development, Strategic Management Quarterly 4(4), 2016, pp. 53-72, https://doi.org/10.15640/smq.v4n4a4
11. Widyatmono N., Sundari A.A.E.: Eco - friendly of natural color technique of traditional Javanese batik, in Conference: 2nd Asia Future Conference, August 2014, Bali, pp. 13-18,
12. Bayerova P, Hrubesova V., Burgert L., Cerny M., Hrdina R.: Evaluation of selected developmental samples of chelating agents on model washing, Vlakna a textil (Fibres and Textiles) 25(1), 2018, pp. 8-13
13. Krisnawati E., Sunarni N., Indrayani L.M., Sofyan A.N., Nur T.: Identity exhibition in batik motifs of Ebeg and Pataruman, SAGE Open 9(2), 2019, pp. 1-7, 2019, https://doi.org/10.1177/2158244019846686
14. Slepian M.L., Ferber S.N., Gold J.M., Rutchick A.M.: The cognitive consequences of formal clothing, Social Psychological Personality Science 6(6), 2015, pp. 661-668, https://doi.org/10.1177/1948550615579462
15. Laitala K., Boks C., Klepp I.G.: Making clothing last : A design approach for reducing the environmental impacts, International Journal of Design 9(2), 2015, pp. 93-107
16. Tresnadi Ch., Sachari A.: Identification of values of ornaments in Indonesian batik in visual content of Nitiki game, Journal of Arts & Humanities 4(8), 2015, pp. 25-39, http://dx.doi.org/10.18533/journal.v4i8.797
17. Choudhary K.: Engineered digital textile print design for customized curves, Journal of Textile and Apparel, Technology and Management 10(3), 2018, pp. 1-9

MECHANISM FOR DETERMINING OPTIMAL MANAGEMENT OF USE OF PRODUCTION CAPACITY AT THE TEXTILE ENTERPRISES

Bobir Ortikmirzaevich Tursunov

Management Department, Tashkent State University of Economics, I. Karimov Street 49, 100003 Tashkent, Republic of Uzbekistan
tursunov-bobir@mail.ru

Abstract: *This article attempts to create a mechanism for determining the optimal management of the use of production capacity in the textile industry. The peculiarity of this mechanism is that it is based on the hierarchy method using the choice of a Pareto-effective set of alternatives. The method of analyzing hierarchies in such systems has two rather important advantages. On the one hand, it allows stakeholders to express their subjective view on the system of values of the enterprise. On the other hand, on the contrary, the method minimizes subjectivity (including lobbying) in relation to specific alternatives. Indeed, after defining specific criteria with a system, it is rather difficult to present an essentially non-objective comparison of alternatives on them. Based on the proposed methodology, has been developed the software that allows you to calculate alternatives and making the best decision. The proposed methodology is universal and can be used in all types of industry for selecting the optimal strategy and for further improving of an enterprise development strategy.*

Keywords: *textile industry, optimal management, hierarchy analysis method, internal material flows, capacity utilization, evaluating alternative solutions, multistep decision choice.*

1 INTRODUCTION

Despite the fact that rich experience has been accumulated in the history of the world economy in organizing industrial production and managing the efficient use of production capacities, the possibilities of rational use of production capacities in large industrial companies have not been fully utilized. Textile products account for 5.0% of world trade and 6.4% of industrial exports [26]. At the end of 2017, the use of production in this industry amounted to 88.0% in India, 81.2% in the Netherlands, 81.0% in China and 78.9% in Turkey [27]. In other developing countries with lively labor, an even lower rate is observed.

World scientific research centers conducted research in the field of optimizing the use of production capacities at textile enterprises, managing resources at an enterprise, and improving the supply chain of products at textile enterprises. Currently, research is being carried out in priority areas for making managerial decisions to increase the efficiency of capacity utilization, the introduction of modern automatic control systems MRP II, ERP in the management of capacity utilization, strategic planning of capacity utilization, developing an enterprise development strategy and improving management efficiency at textile enterprises.

In recent years, Uzbekistan has pursued a policy of accelerated modernization of the textile industry. However, the level of utilization of production capacities of textile enterprises in the republic remains low. Incomplete use of available production capacities at textile enterprises negatively affects the financial condition of the enterprise, which leads to a decrease in the return on investment. The Strategy for Action on Five Priority Directions of Development of the Republic of Uzbekistan in 2017-2021 defines priority tasks for "further modernization and diversification of the industry by moving it to a qualitatively new level, aimed at accelerating the development of high-tech manufacturing sectors, primarily for the production of finished products with high added cost based on deep processing of local raw materials" [28]. The effective implementation of these tasks requires the development of proposals and recommendations to improve the efficiency of use of production capacities at textile enterprises of the country.

2 LITERATURE REVIEW

The last twenty years have been studies in the study of production capacity, the organization of production at industrial enterprises and the management of production processes were analyzed by Y. Levin, et al [1], A. Sebastiano, et al [2], A. Golmohammadi, et al [3], C. Chien, et al [4], M. Davis, et al [5], Kupriyanov Sergey V., et al [6], Dadalova MV [7], K.S. Kryvyakin [8], E. Milewska [9]. D. Huang, et al [10], Jingfeng Shao, et al [11] and T. Koltai, et al [12]. The foundations of production management were laid by P. F. Drucker [13], R. Mayer [14], W.R. Chestnut, et al [15], and the strategic management of production capacity in enterprises has been deeply studied by scientists Y. Khojasteh [16], J. H. Blackstone, et al [17], J. V. Bon, et al [18] and A. A. Thompson, et al [19].

On the part of M. Dadalova, the concept of "capacity management" has been investigated, interrelated functions have been examined, the implementation of which is the management of production capacity. In his work, the author analyzed the stages of development of production capacity management strategies and types of production capacity management strategies in accordance with the capabilities of the enterprise related to its current activities and future plans. He proposed a methodology for integrated assessment of production capacity management, which is based on qualitative and effective indicators of production capacity management. Methodology for assessment the efficiency of production capacities management at textile enterprises were investigated by B. O. Tursunov in other works [25] and this research is a logic continue of last research part.

K.S. Krivyakin studied the organization of the use of production capacity at machine-building enterprises, proposed a model and algorithm for the effective organization of the use of production capacity, developed a methodological approach to the organization of the balance of use of production capacity, based on an analysis of the balance of components of production capacity in the scale of the workshop. But the author did not take into account the goals of the head and stakeholders of the enterprise, which would significantly complicate the implementation of the developed methods if the stakeholders could not come to a unified consensus.

The Saaty method was successfully applied by T. Tsibizova and A. A. Karpunin [20] in assessing the quality of management processes, in particular to assess the quality of the work of teachers. The proposed approach provides an objective assessment of the quality of the daily work of a teacher associated with the current performance and student attendance, and not only with the results of intermediate final assessments.

But in all the above-mentioned research papers, the mechanism for determining the optimal management of the use of production capacity at the textile industry enterprises was not considered, and we made an attempt to develop a mechanism for determining the optimal management of the use of production capacity, which was tested on the textile industry. The mechanism is based on a hierarchy method that uses the choice of a Pareto-effective set of alternatives, which allows interested parties to express a subjective view of an enterprise's value system. On the other hand, on the contrary, the method minimizes subjectivity with respect to specific alternatives.

3 METHODOLOGY

The hierarchy analysis method (MAI) is a mathematical tool for a systematic approach to complex decision making problems. This method was developed by the American mathematician Thomas L. Saaty [21], who wrote books about him, developed software products and has been conducting ISAHP symposia for 20 years (the International Symposium on Analytic Hierarchy Process). MAI is widely used in practice and actively developed by scientists around the world. Along with mathematics, it is also based on psychological aspects. MAI allows to structure the complex problem of decision making in the form of a hierarchy in a clear and rational way, to compare and quantify alternative solutions. The hierarchy analysis method is used throughout the world to make decisions in a variety of situations: from management at the interstate level to solving industry and private problems in business, industry, health care and education [22].

4 ANALYSIS AND RESULTS

In conditions of globalization economy, an important activity of the enterprise is the constant analysis of the requirements of the consumer market and the use of the information obtained to develop corrective measures aimed at the effective management of the use of production capacity.

It should be noted that the efficiency of industrial production directly depends on the volume, structure, technical condition and level of use of fixed production assets. It is an increase in capital productivity and ensuring full utilization of facilities and equipment is an important direction in improving the efficiency of enterprises and a condition for ensuring its competitiveness.

The current state of the economy of Uzbekistan and all currently existing problems confront enterprises, the need to formulate strategies to increase the efficiency of using production capacity corresponding to the specifics and characteristics of a market economy, pursuing a balanced, reasonable policy to produce products of adequate quality and the necessary volumes required by the consumer market.

The development of market relations, the need to adapt the enterprise to changes in the external environment brings to the fore the solution to the problem of the effective management of the use of production capacity [8].

Industrial enterprises are systems of high complexity, the elements of which at the entrance and at the exit are subsystems of a great variety. The whole complex of activities within the enterprise is so complex that it cannot be fully interpreted. Therefore, the formation of a mechanism to control the use of production capacity uses only a systematic approach and analysis.

The mechanism for managing the use of production capacity of an enterprise should solve the main and complex problem - the realization of the functions of enterprise management as a mechanism of equilibrium of the internal components of the enterprise under the influence of environmental conditions. The solution to a complex problem is its decomposition in aspects of consideration [24].

The object of the proposed mechanism for managing the use of production capacity is the production potential of the enterprise.

Improving the efficiency of capacity utilization requires continuous planning. Moreover, the plans are needed, of course, both operational and strategic. The formation of the mechanism for controlling the use of production capacity takes its basis in strategic planning, since the achievement of the desired result depends on a number of interdependent decisions.

The basis of the proposed mechanism for managing the use of production capacity (Figure 1) is the process of forming a strategy to improve the efficiency of the use of production capacity, implemented through a method of analyzing hierarchies.

The strategy to improve the efficiency of the use of production capacity is based on the results of coordinated actions in the field of planning, organizing and monitoring activities for the use of production capacity of the enterprise. The above activities are cyclical in nature, according to the result of which the management entity makes decisions on making the appropriate changes, focusing on the achievement of planned indicators and factors of the external and internal environment of the enterprise.

The subject of management of the process of using production capacity in an enterprise in order to make a rational managerial decision requires the decomposition of a complex problem into simpler particular tasks. This is the focus of the hierarchy analysis method (analytic-hierarchical process). The method is based on ordinal processing, i.e. “Soft” information that comes to the decision maker (DM), and on the basis of this incomplete information, allows us to determine a number of alternative solutions [20].

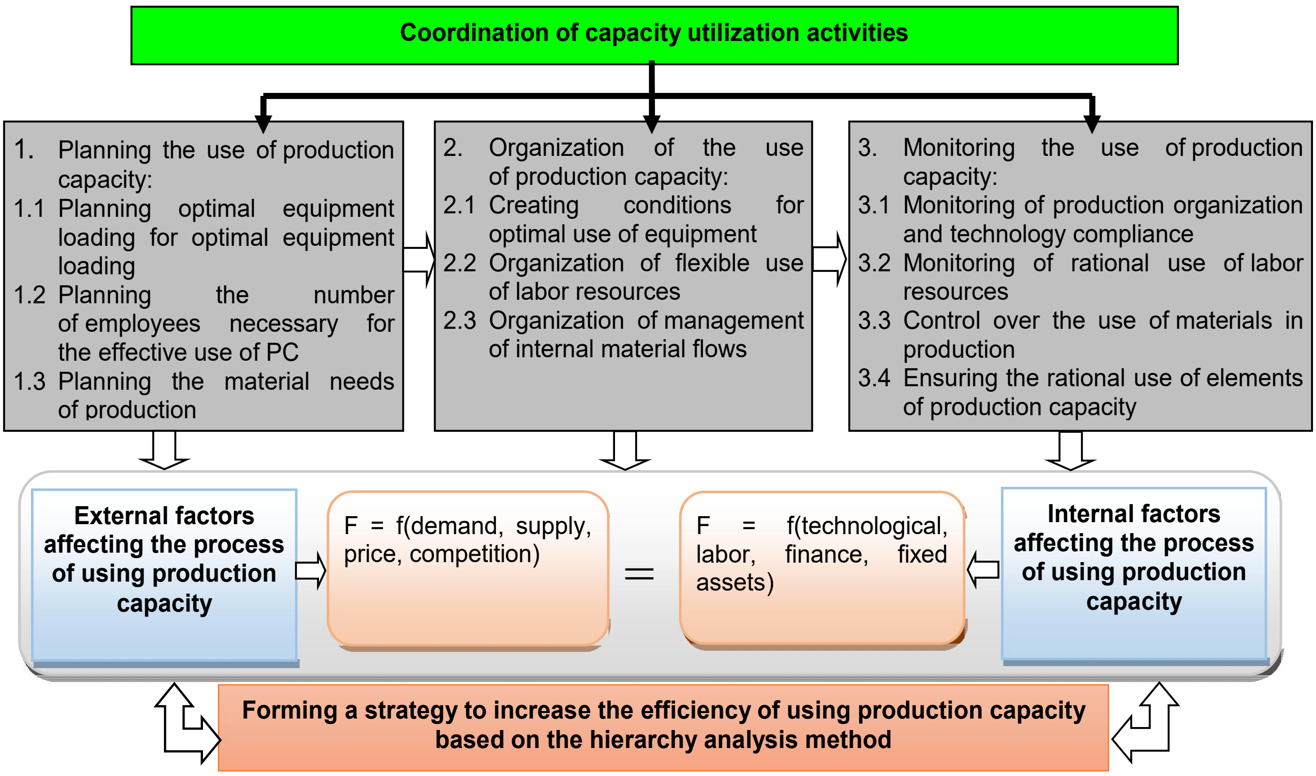


Figure 1 Mechanism of managing the use of production capacity of a textile enterprise (Source: author`s elaboration)

The whole mechanism is focused on the choice of the strategy of the enterprise; here the formation of a strategy to improve the efficiency of the use of production capacity is a key element. It should be noted that external and internal factors influence the formation of a strategy for increasing the efficiency of production capacity utilization.

The system of goals for making strategic decisions does not always have a specific form; moreover, it is first necessary to develop the targets required for making a decision. In the course of the sequential identification and formulation of the main goals through the definition of sub-goals, a hierarchical target system is created. At the same time, it is also necessary to establish differences in the importance of goals of one hierarchical level. However, with the growing number of criteria taken into account when evaluating alternative solutions, the ability of the decision maker (DM) to analyze problems decreases [23].

For optimization, it is reasonable to use a multistep decision choice using a modified hierarchy analysis method [13] using rapid estimates of dominance and different weights of experts depending on their qualifications and consistency. Such approaches allow to exclude the least significant variants of the criteria and get rid of the analysis of obviously losing alternatives. A fairly large number of papers are devoted to theoretical methods for substantiating such approaches [4-19]. An interesting example of using the combined multi-stage method to simplify the management of competitiveness is given in [20].

In this article, we will call the "analysts" a group of experts working on the adoption of an optimal mechanism for managing an enterprise. "Stakeholders" will name all interested persons whose opinion will be taken into account when searching for the appropriate solution. All together we will call "experts."

In some cases it is important to take into account the different significance of the opinions of experts. For this purpose, we introduce the concept of the weight of the expert, v_i, $i=1,\dots,m$, where m - the total number of experts. For simplicity, further calculations will assume that the weights of the experts are normalized: $v_1+v_2+\dots+v_m=1$.

To select the optimal solution in these systems, it is proposed to use the following multi-stage mechanism for choosing the optimal solution, built on a combination of survey methods, analysis of dominance and analysis of hierarchies.

Stage 1 Formation of a preliminary extended list of alternatives and criteria and their rapid assessment.

Stage 2 Optimization of the number of alternatives based on the choice of their Pareto-effective set.

Stage 3 Determining the weights of the significance of the criteria and optimizing their number by eliminating the extremely insignificant.

Stage 4 Stakeholder survey with a view to pairwise comparison of alternatives by criteria. Determination of the final weights of alternatives using the Saaty method and various weighting factors of the stakeholders, adjusted to the consistency of the assessment. [24]

If necessary, alternative leaders obtained in the final stage can be analyzed using more labor and financially costly methods.

Stage 1 Analysts present their options for criteria and alternatives for management decisions

A set of criteria and alternatives are proposed to complement the stakeholder. After offering their options, they also give a preliminary assessment on a 5-point scale to the criteria and alternatives for the tables (see below). Having collected all the offers, a similar 5-point evaluation is carried out by analysts.

Table 1 Criteria rating scale

Score	The importance of the criterion
5	Very important criterion
4	Important criterion
3	Criterion can be considered
2	Criterion can be ignored
1	The criterion is not worthy of consideration or the criterion is not named by this stakeholder

Table 2 Scale of preliminary assessment of alternatives

Score	Quality alternatives
5	One of the best management solutions
4	Good management decision
3	Acceptable management decision
2	Bad management decision
1	Very bad management decision option or Alternative not named by the respondent stakeholder

As a result, after the end of the first stage, we obtain two matrices of preliminary estimates:

$$\mathbf{A}_0=\left(a_{ij}\right) \quad (1)$$

where a_{ij} – evaluation of the j-th alternative by the i- expert; $j=1,\dots,N_a$, N_a - total number of alternatives.

$$\mathbf{C}_0=\left(c_{ik}\right) \quad (2)$$

assessment of the k-th criterion by i-the expert; $k=1,\dots,N_c$; N_c - total number of criteria.

If it is clearer, you can write: We get two tables of rapid assessment:

Table 3 Scale of preliminary assessment of alternatives

$\mathbf{A_0}$	**Alternative 1**	**Alternative 2**	**…**	**Alternative** N_a
Expert 1	a_{11}	a_{12}	…	a_{1N_a}
Expert 2	a_{21}	a_{22}	…	a_{2N_a}
…	…	…	…	…
Expert *m*	a_{m1}	a_{m2}	…	a_{mN_a}

$\mathbf{C_0}$	**Criterion 1**	**Criterion 2**	**…**	**Criterion** N_c
Expert 1	c_{11}	c_{12}	…	c_{1N_c}
Expert 2	c_{21}	c_{22}	…	c_{2N_c}
…	…	…	…	…
Expert *m*	c_{m1}	c_{m2}	…	c_{mN_c}

Stage 2 A Pareto-optimal set of alternatives is selected

An alternative string p is considered to be dominated if there is another row in the same table such *q* that all its indicators are not worse than the indicators of the row k and there is at least one better:

$$\forall i : a_{qi} \geq a_{pi}\,; \quad \exists l : a_{ql} > a_{pl} \tag{3}$$

Dominated alternatives can be removed from consideration. Indeed, they are inferior to other alternatives in the opinion of all experts. As a result of the stage, the matrix of alternatives can significantly decrease and take the form:

$$\mathbf{A} = \left(a_{ij}\right) \tag{4}$$

$j = 1,\ldots,n_a$, where n_a – new number of alternatives, $n_a \leq N_a$.

It should be noted that it is impossible to do the same with criteria because even less significant criteria can influence the choice if the indicators of alternatives are equal by the leading criteria.

Stage 3 Determined by the weight criteria

In this case, the comparison of criteria according to the Saaty method [21] is carried out with the only difference that pairwise comparison of criteria based on an expert survey is not carried out, and previously obtained express estimates are used for comparison matrices. To translate the assessments of each expert into quantitative points of comparisons, it is proposed to use the following relationships:

Table 4 Scale schedule for the assessments of each expert into quantitative points of comparisons

Difference between estimates	**Qualitative interpretation**	**Number indicator**
$c_{iq} - c_{ip} = 0$	The criterion *q* is equivalent to the criterion *p*	1
$c_{iq} - c_{ip} = 1$	The criterion *q* is a little more important than the criterion *p*	3
$c_{iq} - c_{ip} = 2$	The criterion *q* is a little more important than the criterion *p*	5
$c_{iq} - c_{ip} = 3$	The criterion is much more important than the criterion	7
$c_{iq} - c_{ip} = 4$	The criterion *q* is fundamentally more important than the criterion *p*	9

If the ratio is inverse, the quantitative indicators are set accordingly: $1, 1/3, 1/5, 1/7, 1/9$.

Thus, for each i-expert, a matrix of pairwise comparisons is constructed:

$$\mathbf{B^i} = \left(b_{kl}^i\right) \tag{5}$$

where always $b_{kk}^i = 1$ and $b_{lk}^i = 1/b_{kl}^i$; $k,l = 1,\ldots,N_c$.

As a result, according to the standard formulas for determining the approximate eigenvalues of this matrix, weights w_k^i of each criterion k are determined according to the i-expert of the:

$$W_k^i = \left(b_{k1}^i \cdot b_{k2}^i \cdot \ldots \cdot b_{kN_c}^i\right)^{1/N_c} \tag{6}$$

$$S_W^i = W_1^i + W_2^i + \ldots + W_{N_c}^i \tag{7}$$

$$w_k^i = W_{ik} / S_W^i \tag{8}$$

It can be shown that with this definition of comparisons they will all be consistent. Based on the weights obtained for each expert, we construct a common weight column for the criteria as a weighted average of experts with regard to their weights:

$$w_k = v_1 w_k^1 + v_2 w_k^2 + \ldots + v_m w_k^m \tag{9}$$

If there are a lot of criteria, then it is possible to carry out a screening procedure. It is proposed to assume unimportant and in the future not to use criteria for which the weights satisfy the following system of restrictions:

$$\begin{cases} w_k < \varepsilon \\ w_k^i < \delta, \quad \forall i \end{cases} \tag{10}$$

where ε and δ are the criteria for screening criteria.

We recommend taking $\varepsilon = 0,05$ and $\delta = 0,1$, but these parameters can be adjusted upwards with too many remaining criteria and downward in the opposite case. After screening off unimportant criteria, it is necessary to repeat the procedure for determining the weights of criteria, starting with the construction of comparison matrices $\mathbf{B^i}$. As a result, we obtain a set of n_c significant criteria ($n_c \leq N_c$) with a weight column *w*:

$$\mathbf{w}^T = \left(w_1, w_2, \ldots, w_{n_c}\right) \tag{11}$$

Stage 4 With an optimized set of alternatives, we perform a pair-wise comparison procedure using significant criteria.

The classical procedure of the Saaty method with a 9-point scale [22] is used. We conduct a survey of experts and compile matrices of pairwise comparisons of alternatives for each criterion for each expert:

$$\mathbf{D^{ki}} = \left(d_{pq}^{ki}\right) \tag{12}$$

where superscripts denote *i*-th expert's opinion on the *k*-th criterion.

$d_{pq}^{ki}=1$	if, in i -the expert's opinion, the alternative p and q alternative are indifferent from the point of view of the k -th criterion;
$d_{pq}^{ki}=3$	if, in i -the expert's opinion, the alternative p is slightly better than the alternative q in terms of k -the roth criterion;
$d_{pq}^{ki}=5$	if, in i -the expert's opinion, the alternative p is better than the alternative q in terms of the k -th criterion;
$d_{pq}^{ki}=7$	if, in the opinion of i -the expert, the alternative p is significantly better than the alternative q in terms of the k _th criterion;
$d_{pq}^{ki}=9$	If, in the opinion of i -the expert, the alternative p is fundamentally better than the alternative q in terms of the k -th criterion;

always:

$$d_{pp}^{ki}=1,\quad d_{pq}^{ki}=1\big/d_{qp}^{ki} \tag{13}$$

Next is the procedure for determining the weights of alternatives:

$$G_p^{ki}=\left(d_{p1}^{ki}\cdot d_{p2}^{ki}\cdot\ldots\cdot d_{pn_a}^{ki}\right)^{1/n_a} \tag{14}$$

$$S_G^{ki}=G_1^{ki}+G_2^{ki}+\ldots+G_{n_a}^{ki} \tag{15}$$

$$g_p^{ki}=G_p^{ki}\big/S_G^{ki} \tag{16}$$

In addition, consistency relationships are defined to compare each expert for each criterion [22]:

$$\Sigma_q^{ki}=d_{1q}^{ki}+d_{2q}^{ki}+\ldots+d_{n_aq}^{ki} \tag{17}$$

$$L^{ki}=\Sigma_1^{ki}\cdot g_1^{ki}+\Sigma_2^{ki}\cdot g_2^{ki}+\ldots+\Sigma_{n_a}^{ki}\cdot g_{n_a}^{ki} \tag{18}$$

$$CI^{ki}=\frac{L^{ki}-n_a}{n_a-1} \tag{19}$$

$$CR^{ki}=\frac{CI^{ki}}{RI} \tag{20}$$

where RI - random index of consistency, which is determined depending on the number of alternatives on the table:

Table 5 Values of the random consistency index

n_a	3	4	5	6	7	8	9	10	11	12	13	14
RI	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57

As is known, comparisons are considered consistent if *CR ≤0.1*; poorly matched comparisons for *0.1<CR≤0.2* and inconsistent for large values *CR*.

In order to take into account consistency, it is proposed, when weighing the weights of alternatives, to multiply i -the expert's weight v_i by an additional "coefficient of consistency" z^{ki} of his opinion on the k -th criterion, defined as follows:

$$z^{ki}=\begin{cases}1\quad, & CR^{ki}\le 0,1\\ 0,5\quad, & 0,1<CR^{ki}\le 0,2\\ 0\quad, & CR^{ki}>0,2\end{cases} \tag{21}$$

So, the weights of alternatives according to all criteria are obtained as weighted average by weight of experts, taking into account the consistency of their opinions:

$$g_p^k=g_p^{k1}\cdot v_1\cdot z^{k1}+g_p^{k2}\cdot v_2\cdot z^{k2}+\ldots+g_p^{km}\cdot v_m\cdot z^{km} \tag{22}$$

where g_p^k - weight alternative p by criterion k .

As a result, we determine the matrix of weights of alternatives by the criteria:

$$\mathbf{G}=\left(g_p^k\right) \tag{23}$$

Multiplying matrix G by w vector, we get the final column of weights of alternatives to achieve our goal:

$$\omega=G.w \tag{24}$$

or if to paint on elements:

$$\begin{pmatrix}\omega_1\\ \omega_2\\ \vdots\\ \omega_{n_a}\end{pmatrix}=\begin{pmatrix}g_1^1w_1+g_1^2w_2+\ldots+g_1^{n_c}w_{n_c}\\ g_2^1w_1+g_2^2w_2+\ldots+g_2^{n_c}w_{n_c}\\ \vdots\\ g_{n_a}^1w_1+g_{n_a}^2w_2+\ldots+g_{n_a}^{n_c}w_{n_c}\end{pmatrix} \tag{25}$$

The alternatives with the greatest weights ω_p are accepted as alternatives-leaders and are recommended for implementation in production.

The approbation of the mechanism shows that it is necessary to take the necessary measures to improve the efficiency of the use of production capacity at the enterprise Namangan Tukimachi LLC. The proposed method of forming a strategy for increasing the efficiency of using production capacity based on the hierarchy analysis method is universal and can be used in other industries.

5 CONCLUSIONS

In this study, we tried to create a mechanism for determining the optimal management of production capacity in the textile industry. The basis of the mechanism is the formation of the company's strategy, which are defined by goals. AHI is used to select the optimal control. In its original form, the AHI implies the use of the original approach by T. Saati to calculate the relative significance of the signs and the formation of estimates of the relative importance of alternatives in terms of signs, as well as using the majority principle for the final calculation of the weights of alternatives. However, the method does not provide for taking into account the presence of problem situations; on this basis, we used the choice of a Pareto-effective set of alternatives.

And so, the method of analyzing hierarchies in such systems has two rather important advantages: it allows stakeholders to express a subjective view of an enterprise's value system, and the method minimizes subjectivity (including lobbying) in relation to specific alternatives. Indeed, after defining specific criteria using the system, it is rather difficult to imagine a substantially non-objective comparison of alternatives to them. The results are important for decision-making in textile enterprises, as well as for other sectors of the economy.

Acknowledgements: *I am thankful for rector of Tashkent State University of Economics D.Sc. professor Khodiev Bakhodir for funding this project. Also, I am hereby to D.Sc. professor of Tashkent State University of Economics Sherzod I. Mustafakulov, Candidate of sciences in Technology at National Research Nuclear University MEPhI Anna N. Tikhomirova, Ph.D of Tashkent State University of Economics Khakimov Ziyodulla for his advices in preparing in methodology of this research.*

6 REFERENCES

1. Levin Y., Nediak M., Topaloglu H.: Cargo capacity management with allotments and spot market demand, Operations Research 60(2), 2012, pp. 351-365, https://doi.org/10.1287/opre.1110.1023
2. Sebastiano A., Belvedere V., Grando A., Giangreco A.: The effect of capacity management strategies on employees' well-being: A quantitative investigation into the long-term healthcare industry, European Management Journal 35(4), 2017, pp. 563-573, ttps://doi.org/10.1016/j.emj.2016.12.001
3. Golmohammadi A., Hassini E.: Capacity, pricing and production under supply and demand uncertainties with an application in agriculture, European Journal of Operational Research 275(3), 2019, pp. 1037-1049, https://doi.org/10.1016/j.ejor.2018.12.027
4. Chien C., Dou R., Fu W.: Strategic capacity planning for smart production: Decision modeling under demand uncertainty, Applied Soft Computing 68, 2018, pp. 900-909, https://doi.org/10.1016/j.asoc.2017.06.001
5. Davis M., Dempster M., Sethi S., Vermes D.: Optimal capacity expansion under uncertainty, Advances in Applied Probability 19(01), 1987, pp. 156-176, https://doi.org/10.2307/1427378
6. Kupriyanov Sergey V., Dadalova Margarita V., Dubrovina Tatyana A.: Assessment of the industrial enterprises competitiveness in terms of import placement, Scientific result, Series: Economic Research, CyberLeninka; Federal State Autonomous Educational Institution of Higher Education, Belgorod State National Research University, No. 4, 2015, pp. 20-26
7. Dadalova M.V.: Management of production capacity in the enterprises of the glass industry, Thesis for the assignment of the degree of candidate of economic sciences, Belgorod, 2009, 175 p., http://www.dissercat.com/content/organizatsiya-effektivnogo-ispolzovaniya-proizvodstvennoi-moshchnosti-predpriyatiya
8. Krivyakin K.S.: The organization of effective use of production capacity of the enterprise, Thesis for the assignment of the degree of candidate of economic sciences, Voronezh, 2010, 267 p. http://www.dissercat.com/content/upravlenie-proizvodstvennoi-moshchnostyu-na-predpriyatiyakh-stekolnoi-promyshlennosti
9. Milewska E.: IT systems supporting the management of production capacity, Management Systems in Production Engineering 25(1), 2017, pp. 60-67, https://doi.org/10.1515/mspe-2017-0009
10. Huang D., Lin Z., Wei W.: Optimal production planning with capacity reservation and convex capacity costs, Advances in Production Engineering & Management 13(1), 2018, pp. 31-43, https://doi.org/10.14743/apem2018.1.271
11. Shao J.F., Li Y.: Multi-agent production monitoring and management system for textile materials and its applications, Journal of Industrial Textiles 40(4), 2010, pp. 380-399, https://doi.org/10.1177/1528083710380428
12. Koltai T., Stecke K.: Route-independent analysis of available capacity in flexible manufacturing systems, Production and Operations Management 17(2), 2008, pp. 211-223, https://doi.org/10.3401/poms.1080.0017
13. Drucker P.F.: The practice of management, Oxford, UK, Elsevier Butterworth-Heinemann, 2007
14. Mayer R.: Production management, New York, McGraw-Hill, 1968
15. Chestnut W.R., King P.: Production management, Melbourne, Oxford University Press, 1994
16. Khojasteh Y.: Production management: Advanced tools, models, and applications for pull systems, Harvard, 2018
17. Blackstone J.H., Cox J.F.: Capacity management, Cincinnati, OH, South-Western College Pub., 2002
18. Bon J.V., van der Veen A.: Capacity management: a practitioner guide, Zaltbommel, Van Haren Pub., 2009
19. Thompson A.A., Strickland A.J., Gamble J.: Strategic management: concepts and cases, Maidenhead, McGraw-Hill Education, 2006
20. Tsibizova T.Yu., Karpunin A.A.: Application of the method of analysis of hierarchies in the evaluation of the quality of management processes, Modern problems of science and education № 2-1, 2015, http://www.science-education.ru/ru/article/view?id=20847
21. Saaty T.L.: Relative measurement and its generalization in decision making why pairwise comparisons are central in mathematics for the measurement of intangible factors the analytic hierarchy/network process, RACSAM - Review of the Royal Spanish Academy of Sciences, Series A, Mathematics 102(2), 2008, pp. 251-318, https://doi.org/10.1007/BF03191825
22. Saaty T.L.: Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World, University of Pittsburgh, Pennsylvania: RWS Pubns., 1999, ISBN: 096203178X

23. Mustafakulov Sh.I., Zarova E. V., Tikhomirova A.N., Tursunov B.O.: Research of efficiency of use of production capacity at the enterprises of textile industry on the basis of methods of multivariate statistical analysis: On the example of Namangan Region of the Republic of Uzbekistan, Journal of Advanced Research in Dynamical and Control Systems 11(7), 2019, pp. 886-899, https://doi.org/10.5281/zenodo.3756255
24. Khodiev B.Y., Mustafakulov S.I, Tursunov B.O., Sigidov Y.I., Khavrova K.S.: Methods for control efficiency evaluation of the production capacities application at the textile enterprises and the mechanism for optimal control, ASTRA Salvensis, Supplement no. 1, 2019, pp. 499-521, https://doi.org/10.5281/zenodo.3666484
25. Tursunov B.O.: Methodology for assessment the efficiency of production capacities management at textile enterprises Vlakna a textil (Fibres and Textiles) 26(2), 2019, pp. 74-81, https://doi.org/10.5281/zenodo.3756262
26. WTO. International Trade Statistics, 2017, URL: http://www.wto.org
27. http://www.ceicdata.com
28. www.lex.uz

50th ANNIVERSARY OF ESTABLISHMENT THE RESEARCH INSTITUTE FOR TEXTILE CHEMISTRY IN ŽILINA

Jozef Šesták

VÚTCH-CHEMITEX, spol. s r.o., Rybníky 954, 011 68 Žilina, Slovak Republic
jozef.sestak@vutch.sk

50 years from establishment of the Research Institute for Textile Chemistry (VÚTCH) will elapse on March 1, 2020. The institute was established on the base of Decision of the Ministry of Economy of the Slovak Socialist Republic No. 10/1970. The research institute started its activity originally in rented premises of the national enterprise Slovena Žilina. It picked up on a long-standing, nearly 18 years' tradition of the company research department and later branch research department at the national enterprise Slovena, which was one of the biggest textile research workplaces in Slovakia. Originally, 22 workers worked in the newly established institute; 6 of them with university education and 10 of them with secondary professional education. 17 workers worked directly in the research. The rented premises covered 862 m^2. Ing. Rastislav Šalma has been appointed managing director of the institute and he remained in his office until 1979. Principal acitivity of the institute focused mainly on development and application of new technologies and textile auxiliaries for finishing, development of new textile products, development and construction of machinery for non-traditional finishing processes and evaluation of care and quality of home textiles.

The period of 1980-1989 was a significant stage for VÚTCH not only with regard to further development of the research activity, but also construction of new working spaces and widening the material base of the institute. The research activity focused on inter-branch and inter-sectorial field. Ing. Alojz Strýček, CSc. has been appointed managing director of the institute and, after his promotion to the function of general director of the national enterprise Slovena, Ing. Peter Jerguš, CSc. has been appointed managing director on 1.1.1985. Increasing number of projects included in the state plan of development of the science and technology points to a permanently growing technical level of the solutions. The most important projects were as follows: New textile auxiliaries and technologies from aqueous and non-aqueous media, New directions of special textile finishes, Development of new assortments of home textiles, Advanced methods for recovery of textile waste. Results of the technical solutions have been implemented in many enterprises: Slovena n.p. Žilina, BZVIL n.p. Ružomberok, Merina n.p. Trenčín, Závody 1. mája n.p. Liptovský Mikuláš, Tatrasvit n.p. Svit, Petrochema n.p. Dubová, Duslo n.p. Šaľa, NCHZ n.o. Nováky, LTZ n.p. Revúca, ĽKZ n.p. Holíč etc. On the base of successful solution of a project a production line for manufacture of shaped car carpets designed for passenger cars Š-742 as well as a line for manufacture of car carpets for passenger cars Škoda-Favorit has been introduced. At a given time all requirements for deliveries of the shaped car carpets up to a quantity of 180 thousand assemblies/year were satisfied. The production lines were manufactured without requesting foreign currency and exclusively from domestic components and materials. Costs of importing one line from capitalist states represented 20-25 million valuta crowns.

For the first 20 years of existence of the institute total of 159 research tasks and projects have been solved in following structure: state projects – 12, sectorial tasks – 8, branch tasks (financed by the Directorate-General Slovakotex) – 33, company tasks – 43, others (study works, services etc.) – 63. An integral part of creative activity of the workers were also results achieved in the field of innovatory movement. In total, the workers of the institute submitted 102 patent applications and 143 proposals for innovation in the period of 1975-

1989. Out of that total, 64 author's certificates have been granted and 99 proposals for innovation have been adopted. In the late 1980s, 202 employees worked in the institute and useful area of own premises in three buildings was 4 450 m^2.

A strong turbulent period was marked in the institute in the first half of the 1990s. It was caused by serious all-society changes in the frame of Slovakia. In September 1989, Ing. Jozef Šesták was appointed managing director on the base of elections of the employees. He held the above-mentioned office constantly until December 2018. Fate of the industrial research organizations became uncertain. Privatisation process of the state enterprises has begun. The state enterprise VÚTCH has been privatised by own management on 1.9.1994. A period of uncertainity since 1990 was over. The period brought about also a significant reduction of employees up to a level of 108 (on 31.12.1993) as well as decrease of turnover to about 23 mil. Sk. We continued on a limited scale to solve state as well as so-called economic research tasks in the field of research and development in spite of declining support by the state and decreasing interest of the manufacturing enterprises after liquidation of VHJ Slovakotex Trenčín. Research works of that time fosued on elaboration of projects as follows: TECHNITEX – Development and application of technical textiles, EKOS – Solution of environmental problems in consumer industry, INTEGRA – Integrated and composite textile materials, OLEOCHÉMIA – Application of oleochemical raw materials in manufacture of industrial auxiliaries etc.

There was a significant change in structure of the activities of the research institute in the period of 1995-1999. At the end of the period there was significant reduction of the research activities mainly due to economic problems in many textile enterprises, which were subsequently liquidated or which did not cope up with the transformation process after privatisation. Besides, at the end of the 1990s there was further reduction of support of research and development in the form of state government grants. Therefore, it was necessary to work intensively on development of new activities which would contribute towards economic stabilisation of the institute, exploitation of creative potential of the professional team as well as technical potential in the chemical and textile laboratories. Two years after establishment of the authorized testing laboratory SKTC-119 (established on 1.1.1993) it has been noted that it was a correct step. The process of accreditation for selected tests performed by the Slovak National Accreditation Service (SNAS) has been handled as a result of a responsible approach. Share of turnover from testing and certification services amounted to cca 20-25% from total turnover of the institute in 1995-1996. Reputation of the authorized testing laboratory SKTC-119 has grown continuously amongst the professionals as well as non-expert public in the frame of the Slovak Republic in the above-mentioned period. A remarkable turnaround and growth of turnover in the field of testing and certification activities has occured since the introduction of compulsory certification of textiles and clothing on 1.7.1997. For example, in 1998 even 3 243 certificates were issued and share of turnover from testing and certification of products amounted to 55-60% from total turnover of the institute in 1998-1999.

The first contacts with the representatives of the International OEKO-TEX® Association for textile human ecology through a partnership with ÖTI Vienna have been established in the above-mentioned period. The aim was to establish SKTC-119 in an appropriate form on the international level. The institute succeded in making this intention in 1999 when it became a co-opted member of the OEKO-TEX® Association. At that time share from these activities amounted to 7.5% from total turnover of the testing laboratory.

In 1995-1999 an important contribution to stabilisation of the economical results of the institute had also in-house manufacture of chemical specialties, small scale textile and engineering manufacture.

This manufacture was notable also due to the fact that a high share of products constituted implemented results from own research projects, solved in the past. The assortment of textile auxiliaries included mainly washing, softening, levelling and other agents for textile finishing. The production volume was 100-150 t/year. Special electroconductive and antibacterial additives with trade mark BIOSTAT® were manufactured later.

In the beginning of the 21st century situation in the institute was associated mainly with expansion of the testing and certification activities. Legislation, laying down obligatory certification of textiles and clothing in the frame of the Slovak Republic has been applied until 2004. This situation has changed fundamentally after entry of the Slovak Republic to the European Union on 1.5.2014. A sharp drop of outputs in this field has been recorded. It was necessary to seek new opportunities for the testing laboratories in the frame of the international OEKO-TEX® system in accordance with the valid EU-legislation and to focuse also on safety evaluation of the personal protective equipment.

In the field of research and development we continued to focuse on elaboration of projects aimed at development of various special products, articles designed to protect consumer`s health and life as well as on development of co-operation with the basic research in the field of application of new advanced technologies (e.g. application of low-temperature plasma, nanotechnologies, nanoparticles) etc. Among the most important were projects as follows: AMBT – Antimicrobial fibres and textiles, PROTECTION – Research and development of assortment of special protective clothing, NANOTEX – Nanostructural surface modification of fibrous and textile materials, TENETEX – Nonwovens for advanced technical applications. Direct financial support of the international projects was ensured by the 6th Frame Programme of the European Commission. In particular, the international projects titled ENVITEX and ITE focused on creation of a database of textile enterprises and a benchmarking study.

Gradually we transfered our activities and experience in the research also to the field of testing. We obtained means to complement the laboratories; we purchased equipment for special tests (flammability, hydrophobic properties, rubbing resistance). Besides, new test methods for finishes applied using nanotechnologies, e.g. in the field of personal protective equipment, have been introduced. The research project ZDRAVIE (HEALTH) – Assessment of influence of selected chemical substances in textiles on consumer`s health - was important for further development of the testing activity in the field of assessment of content of harmful substances, constituting a health hazard, in textiles.

After 2005, possibilities for funding the research activities also from support sources of the European structures expanded considerably. We succeeded in obtaining financial means to supplement infrastructure of the testing laboratories through the project IMPLEMENTÁCIA (IMPLEMENTATION). Besides, we took advantage of the first structural funds available for the Slovak Republic upon entry to the European Union. The project INOVATEX – Innovation of testing textiles and clothing to increase the competitiveness of VÚTCH-CHEMITEX, spol. s r.o. - was very important for us. The financial means obtained in the frame of the project significantly contributed to replenishment of technical infrastructure of the testing laboratories, mainly with orientation on inorganic analytical methods and establishment of a laboratory for evaluation of antibacterial efficiency of textile materials.

A significant process of establishment of the notified bodies for selected regulated field of products and services according to the EU Directives was implemented in the period of 2004-2005, which was linked to the entry of the Slovak Republic to the European Union on 1.5.2004. Our institute has been notified under number 1296 for the assortment of personal protective equipment (PPE) by the Slovak Office of Standards, Metrology and Testing (ÚNMS SR). Later, notification for toys has been added to this.

So far the last decade in the 50-year`s history of the institute has its specific attributes as well.

During these ten years there have been periods of progress and troubles. We have succeded in obtaining financial support for 12 key projects with a government grant in the frame of public calls of the Slovak Research and Develoment Agency (APVV). An important achievement was acquiring a major project supported from the EU structural funds of 1.25 mil. Eur in the period of 2011-2014. We obtained also financial support for renewal and replenishment of the infrastructure of the laboratories of over 175 thousand Eur in the frame of this project. Topics in the field of research and development became nanotechnologies, application of low-temperature plasma on textile materials and research in the field of smart textiles and clothing. In the above-mentioned period there was a significant change in structure of incomes of our commercial company. The original share 70/20/10 (research and development/ services of SKTC-119/ manufacture) has gradually changed to 30/60/10 (research and development/services of SKTC-119/ others).

Change in orientation of research and development mainly on advanced technologies and products is evident from following research projects: NANSÓL – Research, preparation and introduction of nanosol manufacture for nanostructural modification of textile materials, AMBIPOL – Research and preparation of antimicrobial nanosol and methods for evaluation of antimicrobial properties of textiles, VY-INTECH-TEX – Research of technologies and products for smart and technical textiles, NANO-MULTI-TEX – Research of nanotechnologies and preparation of multifunctional textiles for soldier protection at the battlefield, PLAZ-NANO-TEX – Research of influence of low-temperature plasma on enhancement of permanency of surface finish applied on textile materials using nanosols, INTELIGENTEX – Smart textiles and clothing for mobile monitoring of human vital functions. Many of the above-mentioned themes are being investigated also at present in the frame of research projects focusing mainly on the field of smart textiles and clothing and/or protection of quality and originality of products as well as health protection.

Intensity of work in the field of competencies of the Notified Body No. 1296 for personal protective clothing increased, on the other hand volume of R&D works decreased. Applications for assessment of PPE comformity with technical regulations, submitted by the tendering authorities (state bodies, wholesalers trading in PPE etc.) showed an increasing trend every year; at present the Notified Body has even 20-25 big applications/year. The largest turnover and increase in the number of certificates showed certification in the international OEKO-TEX® system in the last 10 years. Co-operation with the OEKO-TEX®

Association started already in 1998-1999, but only after audit performed by the representatives of OEKO-TEX® in August 2013 we received status of an associated member of the OEKO-TEX® Association with authorisation to issue certificates for textiles and clothing according to the STANDARD 100 by OEKO-TEX® with world-wide validity.

Services provided by the accredited testing laboratories are covered completely by the Accreditation Certificate No. S-068, issued by the Slovak National Accreditation Service.

At present 380 accredited methods are used to test textile raw materials, textile and clothing products, personal protective equipment, toys, skins, leather, paper, paper tissue, carboard, plastics, washing, cleaning and cosmetic agents. The testing laboratories are accredited also on an international level, in the U.S. Consumer Product Safety Commission as CPSC Accepted Testing Laboratories under registration number Lab ID 1513.

Services provided in the field of testing and certification of products, in so-called legally regulated sphere, require expertise, training and skill of the team, therefore we work hard in expert working groups established by the Slovak Office of Standards, Metrology and Testing and participate in the meetings of the Horizontal Committee of the notified bodies directly in Brussels. The goal is to ensure direct application of the European legislation in conditions of manufacturers of PPE on the territory of the Slovak Republic.

Very important is also our active participation in the Technical Commission for PPE established by the Slovak Office of Standards, Metrology and Testing focusing on application of the latest knowledge in the field of technical standards for PPE applied in the processes of PPE conformity assessment.

In conclusion, I would like to say thank you to my staff whose hard work, enthusiasm, creative invention and professional skill contributed during the 50 years` history of the institute to its reputation and acceptation at home and abroad. Ing. Dana Rástočná Illová, PhD. became managing director of the company VÚTCH-CHEMITEX, spol. s r.o. in January 2019.

I would also like to thank all manufacturing enterprises and companies co-operating closely with the institute in the past. Some contacts have been terminated over time, but we received new requirements from the business sector which confirm repeatedly positive sense of our activities. In the past as well as at present we co-operated with the academic sphere, colleges, universities and institutes of the Slovak Academy of Sciences. We benefited from exchange of expertise and new theoretical knowledge, acquired in the frame of the co-operation, on their application in industrial practice.

I believe that also in the next years we shall keep the high credit among the co-operating companies and organisations to full satisfaction of the concerned parties.

Ing. Jozef Šesták, CSc.

Managing Director of VÚTCH and VÚTCH-CHEMITEX, spol. s r.o.
in the period of September 1989 – December 2018

INSTRUCTIONS FOR AUTHORS

The journal ,,**Vlákna a textil**" (**Fibres and Textiles**) is the scientific and professional journal with a view to technology of fibres and textiles, with emphasis to chemical and natural fibres, processes of fibre spinning, finishing and dyeing, to fibrous and textile engineering and oriented polymer films. The original contributions and works of background researches, new physical-analytical methods and papers concerning the development of fibres, textiles and the marketing of these materials as well as review papers are published in the journal.

Manuscript

The original research papers are required to be written in English language with summary. The advertisements will be published in a language according to the mutual agreement.

The first page of the manuscript has to contain:

The title of the article (16 pt bold, capital letters, centred)

The full *first name* (s) and also *surnames* of all authors (11 pt, bold, centred).

The complete address of the working place of the authors, e-mail of authors (9 pt, italic, centred)

Abstract (9 pt, italic)

Key words (9 pt, italic)

The manuscript has to be written in A4 standard form, in **Arial, 10 pt**.

The text should be in ***one-column format in single line spacing***.

Page margins: up and down 2.5 cm; left and right 2.0 cm.

Do not number the pages and do not use footnotes. Do not use business letterhead.

Figures, tables, schemes and photos (centered) should be numbered by Arabic numerals and titled over the table and under the figure or picture.

Photos and schemes have to be sufficiently contrastive and insert in text as pictures.

Mathematical formulae should be centred on line and numbered consecutively on the right margin.

Physical and technical properties have to be quantified in **SI units**, names and abbreviations of the chemical materials have to be stated according to the IUPAC standards.

References in the text have to be in square brackets and literature cited at the end of the text. References (9 pt), have to contain names of all authors.

[1] Surname N., Surname N.: Name of paper or Chapter, In Name of Book, Publisher, Place of Publication, YYYY, pp. xxx-yyy, ISBN

[2] Surname N., Surname N.: Name of paper, Name of Journal Vol. (No.), YYYY, pp. xxx-yyy, doi number

[3] Surname N., Surname, N.: Title of conference paper, Proceedings of xxx xxx, conference location, Month and Year, Publisher, City, Surname N. (Ed.), YYYY, pp. xxx-yyy

[4] Surname N., Surname N.: Name of Paper, Available from http://www.exact-address-of-site, Accessed: YYYY-MM-DD

The final template of manuscript is available on **http://www.vat.ft.tul.cz**

Authors are kindly requested to deliver the paper (in Word form) to be published together with information about at least 3 recommended reviewers from institutions others than the parent (name, e-mail, institution and department) by e-mail: marcela.hricova@stuba.sk

After successful review procedure there is charged fee (article processing charge) of EUR 100. All articles after review process are freely available online and this fee helps to cover the costs of taking a manuscript and turning it into a finished article.

Address of the Editor Office:

Marcela Hricová

Faculty of Chemical and Food Technology,

Slovak University of Technology in Bratislava

Radlinskeho 9

812 37 Bratislava,

Slovakia