VLÁKNA a TEXTIL

3

Volume 28.
September
2021

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

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 (3) 2021
Vlákna a textil (3) 2021

September 2021

Content

INFLUENCES OF THE OPERATING PARAMETERS OF EMBROIDERY STITCHES ON ELECTRICAL PROPERTIES OF THE CONDUCTIVE THREADS

Amal Abdullah Albishri[1], Emad El-Din Sayed Gohar[1] and Marwa Mohamed Tharwat[2]

[1]*Faculty of Human Sciences and Designs, Department of Fashion & Textile, King Abdul-Aziz University, Jeddah, Saudi Arabia*
[2]*Faculty of Engineering, Department Electrical and Computer Engineering, King Abdul-Aziz University, Jeddah, Saudi Arabia*
aaalbeshri@uj.edu.sa, egohar@kau.edu.sa, mmzahran1@kau.edu.sa

Abstract: *The conductive threads are very crucial and essential parts of smart textiles. However, there is still a lack of information in general about the operating parameters of embroidery with conductive threads and their influences on communication among electronic components in the e-textiles product. In this article, silver-coated conductive threads have been usage in the fabrication of 4 embroidered designs with two different stitch types (Tatami, Running) and two lengths for each stitch (4 mm, 6 mm). The electrical characteristics were measured and determined in the frequency domain from 100 kHz to 120 MHz. The impedance and resistivity of threads are determined also using the AC voltages at three different frequencies 100 kHz, 1 MHz and 10 MHz. The applied voltages were 0.0 -1.0 volts through thirty (30) steps. The most important results are summarized in the polarization of silver, which is contributing to the measured impedance values so that all stitch types with different lengths have the same behavior and trend. The designs of shapes by embroidered stitches are acting as perfect resistor at low frequencies while they are acting as perfect inductor at high frequencies. The 6 mm stitches length in all stitch types provides low resistance rather than 4 mm stitches against the common prediction. Therefore, these designs of embroidered shapes by certain stitches could be a good potential for antenna applications.*

Keywords: *conductive thread, e-textiles, wearable electronics, embroidery.*

1 INTRODUCTION

Textiles have been developed significantly in recent years than they were in the past, and it has a tendency to take advantage of advanced digital technologies. Therefore, the possible incorporation of electronics has rendered garments a new type of high-tech product [1]. The incorporation of technology into textile during production of smart garments is extremely important as this process involves the integration of two important components, namely textile and electronic units. The incorporation method depends on a desired function as each of many functions has unique requirements that must be met during the incorporation process. Accordingly, smart textile is a broad interdisciplinary field of research that combines design with textile techniques, electrical engineering, and information and communication technology in order to develop new products that meet specific aesthetic, functional and technical requirements [2] in an integrated manner. The incorporation of electronics into textiles has already opened the way for the production of garments with special capabilities which are used in the fields of defense, sports, medicine and health monitoring [3]. Such an innovation has become supportive of the functions that users aspire to, thus providing greater efficiency to perform the required tasks.

Currently, there are several distinct methods ensuring an effective functional link between textiles and electronics by incorporating conductive threads into fabrics, dyes, painting and embroidery. These methods and their end-use specific functions offer solutions to effectively use the materials with manufacture technology. The function of a textile is determined by the method used for the linking process [4]. This research deals with the technique of embroidery; a traditional method of incorporating threads into fabric, originally used for adding an aesthetic aspect [5] on all kinds of fabrics, given the high potential of embroidery, its rapid adaptation to new designs, and ability to continuously develop [6]. In addition, embroidery is applied on fabrics at the final manufacturing stage, and this can be an advantage because it makes initial manufacturing processes much easier [7, 8] and means for the mass production of electronic textiles [5, 9]. Thus, the ability of embroidery to incorporate electronics into traditional fabrics represents an opportunity to create new and versatile functions. This is applicable as the integration of multiple sensors and signal processing units to obtain interactive wearable textile systems, enabling the collection of large amounts of information, while providing greater security to the user [10].

Digital embroidery designs also allow the integration of electronic components [wires, switches, sensors or other electronics) into the surface of fabric, and through the use of conductive threads along with or without traditional threads to achieve the electrical conductivity advantage on textiles [11]. Thus, embroidery techniques using conductive threads on substrate fabrics have become a very attractive approach for fabricating textile-based circuits for smart wearables because of their circuit design freedom and ease of manufacture compared to other processes such as weaving, knitting and printing [8]. Automated embroidery has been one of the most widely used fabrication techniques in the field of smart textiles that contributes to the development of flexible and wearable electronics and is therefore referred to most often as electronic embroidery [2].

Electronic embroidery is one of the manufacturing techniques used in the field of smart textiles. In their pioneering work [12] Maggie Orth is responsible for the term e-embroidery, which describes the digital stitching of electro-conductive threads into textiles [13]. She used embroidery to create conductive electrodes for capacitive sensing, inspiring other works and thereby casting the seed for the prospective field of smart textiles [5]. Therefore, embroidered electronic systems are being increasingly researched, leading many researchers to examine the potentials and functional solutions offered by electronic embroidery, including physiological monitoring, due to the potential to place the base material in all directions instead of tailored fiber placement (TFP), including through availing direct contact between electrical sensors and the skin [14, 15], measuring temperature and the ECG signal, use of Electrocardiography (EKG) shirt with embroidered electrodes for measuring an electrocardiogram [16]; use of sensor for measuring an electromyogram [17].

Other researchers examined some medical cases, including the embroidered electrodes and their use in wearable surface electromyography (sEMG) [18]. Meanwhile, Linz et al. presented the first successful measurements with sensors. To obtain maximum unobtrusiveness with sensors for monitoring health parameters on the human body, they combined two technical solutions. First, contactless sensors for capacitive electromyography measurements were proposed. Secondly, the sensors were integrated into textile, so complete fusion with a wearable garment is enabled [19]. Roh et al. introduced the all-fabric intelligent temperature regulation system for smart clothing applications [20]. The techniques used in electronic embroidery to date can be identified in single-thread embroidery (ring stitches) which have been used mostly in body signal measurements. Two-thread embroidery (standard embroidery) which is a very versatile method for creating new technical materials that rely on precision and are repeatable. Intricate patterns can be achieved, such as circuit board stitching, pinch gesture recognition, strain and deformation sensors (resistive or capacitive sensors), moisture sensors (either capacitive or short- circuit based) [6, 9]. However, tailored fiber placement (TFP) places high tenacity fibers on a basic fabric to create preforms. TFP allows the exact placement of fiber and fiber - like materials onto a textile substrate. Electrically conductive yarns offer a variety of braiding possibilities [2, 9]. Each technique is used separately and the techniques can be combined according to the functional purpose.

In the field of communication and data transmission technology, automated embroidery using conductive threaded is considered a promising technique as antennas can be incorporated into garments [21-24]. With the continued increase in demand for smart wearable fabric systems, many studies have dealt with modeling embroidered contacts for electronics in textiles [25] as well as with employing embroidery inductors to increase the success of a textile-based circuit [26] and employing embroidery in a simple and easy manufacturing technique aimed at creating robust, reliable, pressure-sensitive sensors for concrete and wearable interfaces. The textile-based sensor technology is also an important component of textile industry, as it provides potential for incorporation into woven fabrics [27]. Other studies have examined the use of embroidered textile-based pressure sensors [5, 28-32]. The joining of conductive threads through embroidery was not limited to previous functions, but it included also the creation of an electronic chip board using conductive threads, incorporating framed-electronic components into fabric [33] and interaction-centered applications, such as pinch gesture recognition on textiles [34]. In general, there is lack of information about the operating parameters of embroidery with conductive threads and their influences on communication among electronic components in the e-textiles product. Some of these parameters are length of stiches, type of the stiches, type of conductive materials and conductive threads, electrical properties of those conductive threads and the communication of signals flow in the possible contacts of the conductive thread. In this article, a comparison study between two types of stitches made within different length and different conductive thread with a same conductive material as silver was made. The conductive thread and threads are very crucial and essential parts of the smart textiles. The variations in the application of silver-coated synthetic (polyamide, polyester and nylon) threads beside natural (cotton, silk and wool) threads in embroidery are very wide the electrical properties and characteristics must be well studied and known for each specific and proper application.

2 MATERIALS AND METHODS

The appropriate commercial conductive threads Amman silver tech-50 and Madeira HC12 have been selected for embroidery, also obtaining standard 100BY OEKO-TEX. We have been provided with standard threads by the company.

Table 1 Standard threads

Threads type		A (silver tech-50)	B (HC12)
Threads size [count] [35]	Tex no	62	62
	Linear density [dtex]	210*3	616*2
Threads diameter [35]	Optical diameter [mm]	0.36	0.39
Tensile properties of threads [36]	Breaking force [cN]	1930	2950
	Elongation at break [%]	20	22

The conductive threads A and B have been employed in fabrication of 4 embroidered designs with two different stitches types (Tatami, Running) and two lengths for each stitch type (4 mm, 6 mm). The basic textile of military camouflage was used for the Kingdom of Saudi Arabia and two layers of supportive textile were used for embroidery of Vaseline to reinforce the fabric on the back to prevent damage and tear in delicate materials and as a backing and reinforcing layer for embroidery. Based on the previous variables, the following design was proposed to implement embroidery samples in a way that suits the possibility of taking electrical measurements, as it requires preparing the design with a length of 1 meter and a spacing of 3 mm for the Running stitch and as for the samples of stitches (Tatami stitch) area of 5x5 cm and at an angle of 90°.

Embroidery samples were performed using an ELUCKY embroidery machine with an 11/75 needle to fit the thickness of the fabric. The morphological structure and texture of the conductive fibers spun to the thread were studied and measured in terms of dimensions and components the scanning electron microscope SEM, Quanta FEG 250, FEI and equipped with energy dispersion of X-ray spectroscopy technique EDX, Dutch company Quanta with field emission with an electric voltage of 5 kV to 30 kV. The Polarizing optical microscopy POM using Leica DM750P (Leica Microsystems, Switzerland) equipped with reflection Kit was used to investigate the texture of thread and their coating layer. The electrical properties of the conductive threads were measured and determined by the electrical characteristics using AC High Tester 3535 (Hioki, Japan) in frequency domain from 100 KHz to 120 MHz for high range of frequencies. While the lower range was measured by Ando AG-4311B LCR meter.

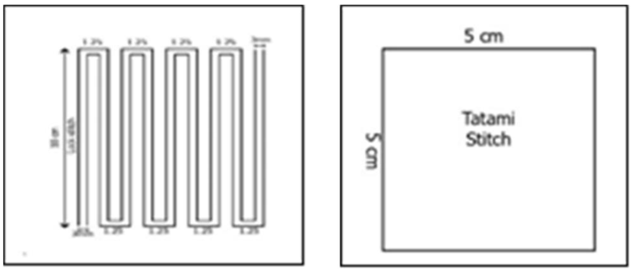


Figure 1 Design of embroidery samples

3 RESULTS AND DISCUSSION

3.1 Thickness of threads

There are discrepancies in the thickness for the two types of the conductive threads, where are determined from scanning electron microscope as well as polarizing optical microscope as stated in morphology sections. The thicknesses are shown in Table 2, because the thickness of those conductive threads is a vital parameter in the electrical properties determination.

Table 2 Thickness of threads by both SEM and POM techniques

Threads	Diameter [mm]	Radius [mm]
A	0.35±0.05	0.175±0.025
B	0.50±0.05	0.250±0.025

The following laboratory tests were conducted at the Saudi Standards, Metrology and Quality Organization (SASO) and to determine the specifications of the fabrics used and were as in Table 3.

Table 1 Standard of the fabrics used

Textile	Fiber composition [37]	Weave identification (construction) [38]	Fabric thickness [mm] [39]	Thread per unit length [40]		Fabric tensile strength [N] [41]		Mass per unit area [g/m^2] [42]
				warp	weft	warp	weft	
Basic textile	polyesters and viscose	plain weave 1/1	0.3	32/cm	32/cm	1032.8	822.2	201
Supportive textile	polyesters	non-woven	0.19			70.9*	63.4*	50

*marked testing included in accreditation scope in SASO

3.2 *Metal composition of the embroidery threads*

The conductive filaments were imaged with a scanning electron microscope technology at different levels of magnification up to 6000x. The fibers spun to the thread were studied and measured in terms of dimensions and components of it by X-ray energy dispersion spectroscopy technique attached to the scanning electron microscope made by the Dutch company Quanta with field emission with an electric voltage from 5 to 30 kV.

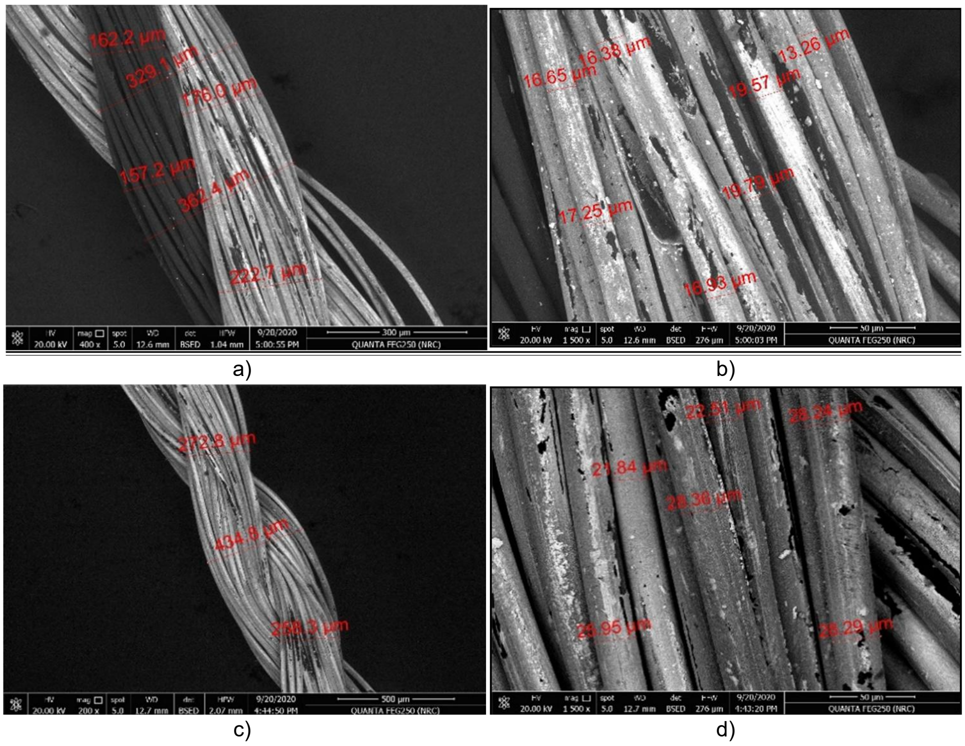
The Figure 3 shows an imaging of thread using a polarized optical microscope.

The X-ray energy dispersive spectroscopy of the threads is given in Figure 4.

Through the above, the basic components that make up the threads can be summarized in the Table 4.

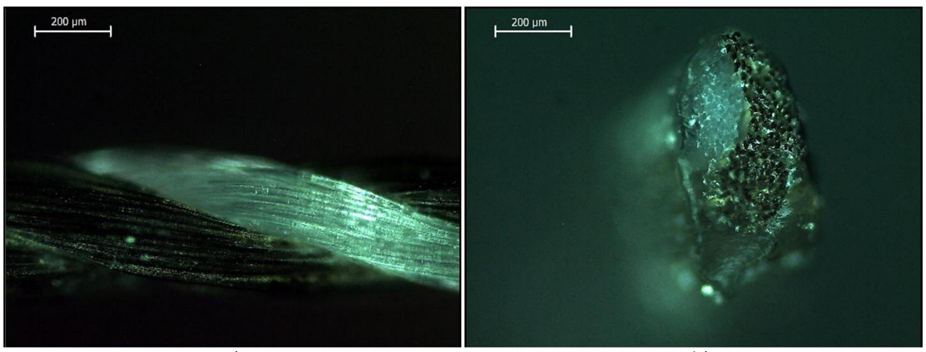
Table 2 the basic components for the threads

Conductive thread	Element [%]		
	C	O	Ag
A	50.22	33.08	16.69
B	29.10	17.58	53.31

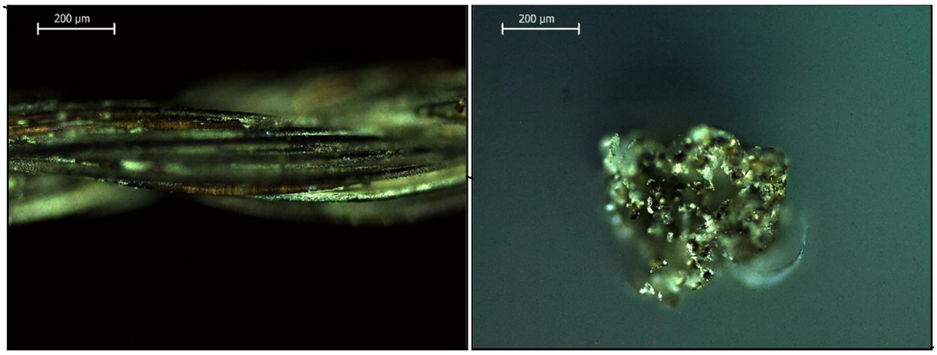


a) b) c) d)

Figure 2 Conductive filament imaging of A thread (a, b) and for B thread (c, d) at different magnifications (a - 400x; b, d - 1500x and c - 200x)

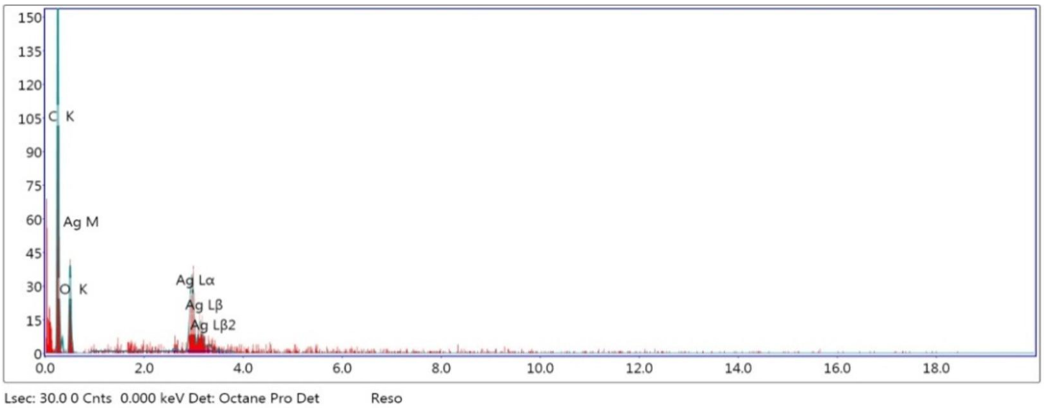


a) b)

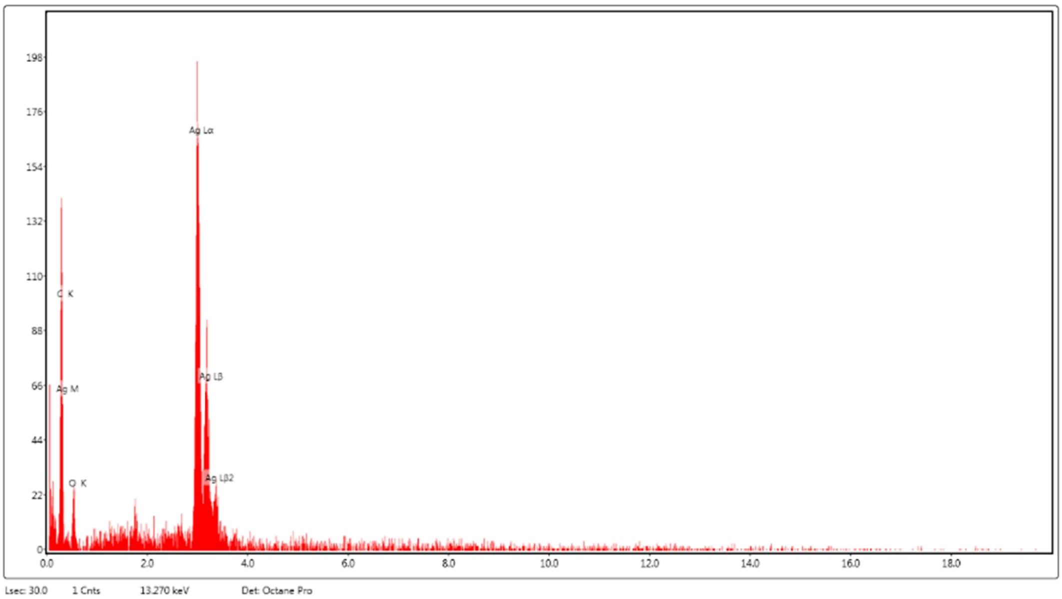


c) d)

Figure 3 The longitudinal section of the conductive A thread using a polarizing optical microscope with magnification 200x (a), the A thread cross-section (b); the longitudinal section of the conductive B thread (c) with magnification 200x and the B thread cross-section (d)



A thread



B thread

Figure 4 The X-ray energy dispersive spectroscopy of the threads

3.3 Electrical proprieties

There were having different DEN and other textile parameters as stated in their datasheet. The electrical characteristics were measured and determined using AC High Tester 3535 (Hioki, Japan) in frequency domain from 100 KHz to 120 MHz. This range was carefully selected for futuristic studies on antenna performance and efficiencies of those threads. Moreover, the efficacy of the embroidered conductive thread will be examined within different shapes, length, and designs. The impedance and resistivity of threads are determined also using the AC voltages at three different frequency 100 KHz, 1 MHz and 10 MHz.

The applied voltages are from 0.0-1.0 V through thirty (30) steps. The voltage should be small because the thread performance will be dealing with small voltages and signals from embedded electronics, sensors, and surrounding stimuli. Thus, the electrical test ought to consider these variations in the measurements of any electrical properties or parameters. These voltages were applied at 3 different frequencies: 100 KHz, 1.0 MHz and 10 MHz.

<u>*Electrical resistivity*</u> ρ [Ω.m] is known as specific electrical resistance or volume resistivity, which is an intrinsic property of matter. Electrical resistivity determines how strongly conductive thread resists or conducts electric current. Thus, low material resistivity means high conducting materials that allow electric current [42].

The A thread resistivity is a little bit lower than former conductive threads. Where, it was stable at 1.63 Ω.cm and 1.78 Ω.cm with 0.1 and 1.0 MHz respectively. Within 230% increase of resistivity, the A thread became 3.77 Ω·cm at 10 MHz for all applied voltages (see Fig.5-a).

In Fig.5-b), the resistivity of B conductive thread is stable at 2.27 Ω·cm and 2.22 Ω·cm with different voltages at 0.1 and 1.0 MHz respectively. While at 10 MHz the resistivity increased to 4.39 Ω.cm, but it was steady with all applied voltages.

<u>*Conductance G* [S]</u>

The reciprocal quantity of electrical resistance which is a measure opposition to the electric current flow for an object is the electrical conductance. Thus, electrical conductance is a measure for an electric current to pass through an object easily. According to Ohm's law, both current I and potential V are proportional to each other, the constant of this proportionality is resistance R or conductance G [43].

$$R = \frac{V}{I}\ , \qquad G = \frac{I}{V} = \frac{1}{R} \tag{1}$$

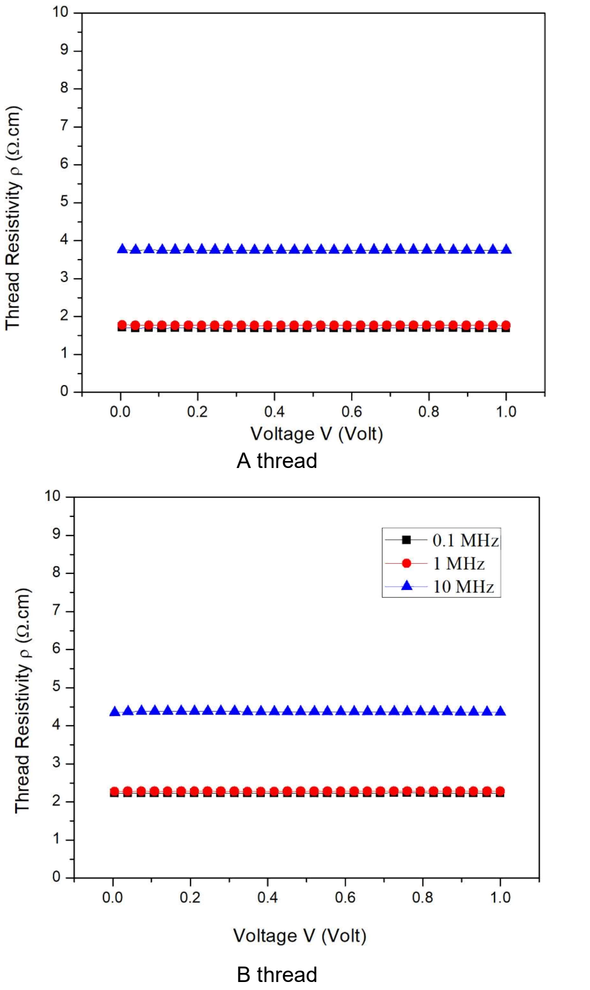


Figure 5 The electrical resistivity of threads measured with different voltages in range of 0.0-1.0 V at three different frequencies 100 KHz, 1.0 MHz and 10 MHz

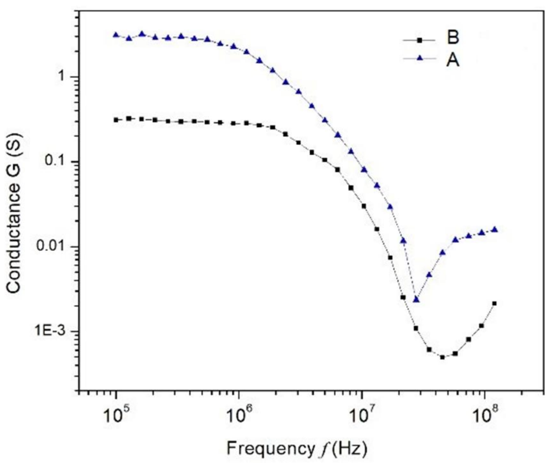


Figure 6 Log-Log scale graph of the thread electrical conductance G for all conductive threads against the frequencies

In Figure 6, the electrical conductance *G* is the highest for both A and B thread around 4 S. Several factors could affect electrical conductance such as the quality of coating, the thickness of conductive threads, length of threads and the composition of threads (as stated in morphology sections) [44-46]. It was worthy to be noted the conductance stability against frequencies is variant from each thread to another. A and B threads show the lowest stability until a few MHz, but having the highest electrical conductance values.

3.4 Electrical properties of embroidered textile

The embroidered textile consists of three layers for summer seasons using light material that designed to the militarily use. The embroidery has been performed using two extra supported textiles for embroidery. The electrical characteristics also have been determined for the textile without any embroidered stitches or conductive threads. In Figure 7, the impedance |*Z*| is typical of insulator material in range 15.5 MΩ at 150 Hz and decreased exponentially to 23.5 KΩ at 100 KHz. Then at high frequencies, the |*Z*| is reach to 177 Ω at 120 MHz. The phase angle is stable against all frequencies up to 100 MHz at -89° which is the characteristic of good small resistor accompanied with a capacitor. The reason for that is the textile in between parallel two electrodes acting as typical dielectric material. The real part of *Z** as the resistance *Rs* is decrease exponentially also as |*Z*| but starting from lower value at 1.15 MΩ at 150 Hz and continue in the decrease to 49 Ω at 120 MHz. the reactance *X* as imaginary part of *Z** is increased from -15.2 MΩ at 100 Hz and then increased to -170 Ω at 120 MHz in exponential way.

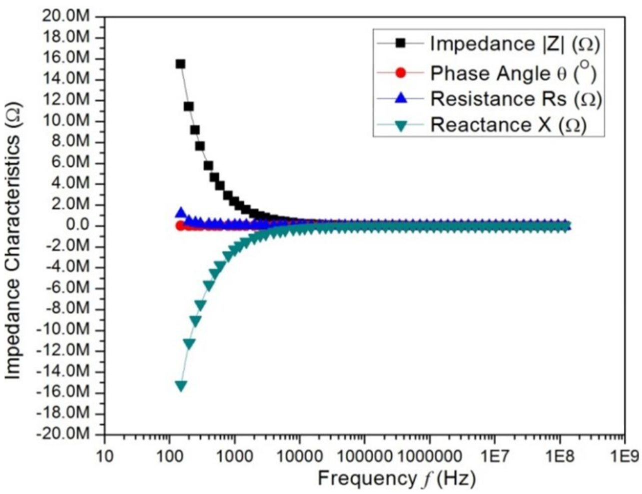


Figure 7 The semi-log scale plot of the impedance |*Z*| characteristics against the frequencies applied for embroidery on the blank textile without stitches

The Nyquist plot (or Nyquist Diagram) is a frequency response plot used in control engineering and signal processing. Nyquist plots are commonly used to assess the stability of a system with feedback. In Cartesian coordinates, the real part of the transfer function is plotted on the X axis, and the imaginary part is plotted on the Y axis. The frequency is swept as a parameter, resulting in a plot based on frequency. The Nyquist plot here is typical for insulator component as shown in Figure 8, which the Nyquist plot of blank textile declare the stability of the textile against the frequency which decrease from 1.2 MΩ to the lowest value 177 Ω of impedance at highest frequency 120 MHz.

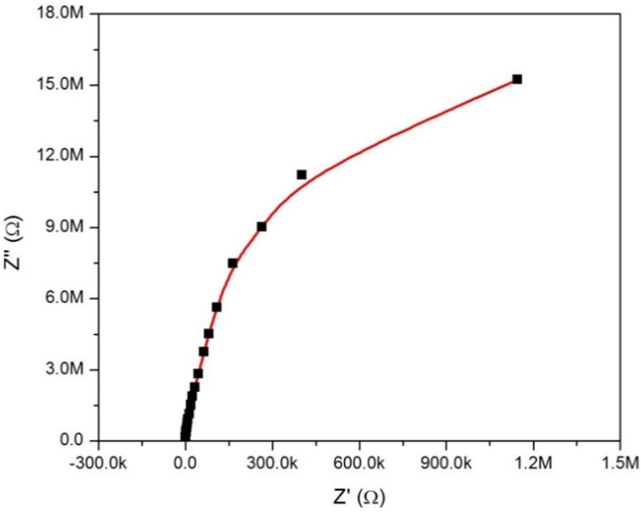


Figure 8 The Nyquist plot based on broad range of the frequencies for different embroidered stitches for E-clothes using Silver tech 50 conductive threads. The experimental real and imaginary values of the impedance of the conductive embroidered stitches in two different lengths

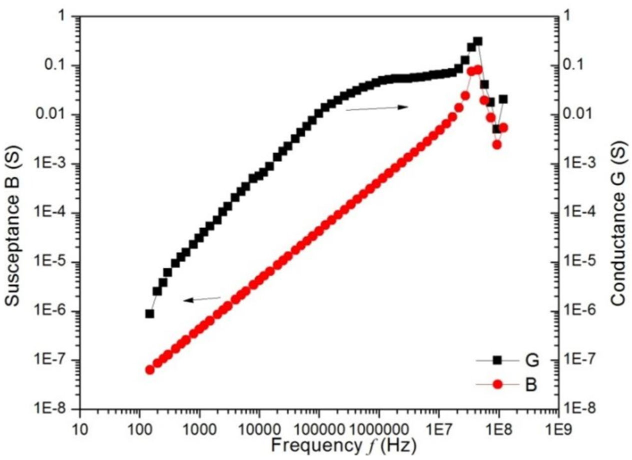


Figure 9 The conductance *G* and susceptance *B* against of the frequencies for E-clothes blank textile without any embroidered stitches. The experimental real G and imaginary B values of the admittance are co-presented

In Figure 9, the real and imaginary part of admittance |*Y*| values *G* and susceptance *B* are plotted against the applied frequencies from 100 Hz to 120 MHz. The current flow is not conducted in blank textile materials. The conductance *G* is very small which starts at 0.85 µS at 150 Hz and increase exponentially with increasing frequencies up to 0.065 S at 1 MHz then go into plateau for one decade of MHz from 0.8 MHz to 20 MHz. while the susceptance *B* is much smaller than conductance *G*. The susceptance *B* is increased from 62.5 mS at 150 Hz up to 0.014 S at 100 MHz as is shown in Figure 9.

3.5 Embroidery proprieties

The conductive threads A and B have been employed in fabrication of 4 embroidered designs with two different stitches types (Tatami, Running) and two length for each stitch (4 mm, 6 mm), (Table 5).

3.6 Alternative current AC measurements

The conductive thread A and B threads have been employed in fabrication of 4 embroidered designs with two different stitch types (Tatami, Running) and two length for each stitch (4 mm, 6 mm). The impedance against frequencies from 100 Hz-120 MHz is plotted in Log-Log scale that measured for two types of stitches with two different stitch lengths for each stitch type (4 mm and 6 mm).

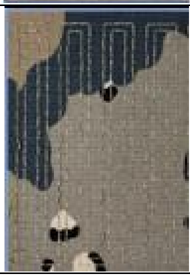
It is clearly seen from Figure 10a) that for A conductive thread, the impedance of Tatami stitches within length 6 mm has the lowest value at 0.6 Ω and stable from 100 Hz to 0.1 MHz but within 4 mm length to be 1.3 Ω in average for the same frequencies.

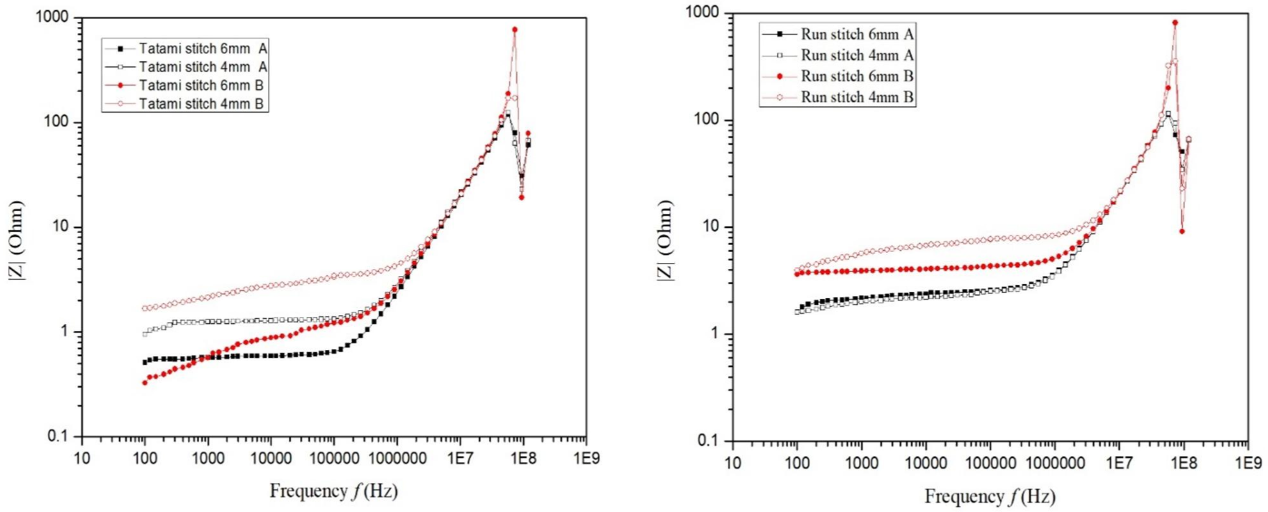
In the B conductive thread, the impedance of Tatami stitches within length 6 mm has the lowest value rather than the same type of stitch but within 4mm in low frequencies from 100 Hz to 1 MHz.

However, the impedance of Running stitch in a conductive thread one for its both length 4 mm and 6 mm are nearly the same and in a gradual increase from 1.6 Ω to 2.98 Ω. All impedance values are located between 0.6 Ω up to 4.3 Ω. Once, the impedance is crossing the frequency of 1 MHz, the polarization of silver is contributing again to the measurement, so that all stitches types with different length have the same behavior and trend, also the impedance becomes too high up to 120 Ω at high frequencies 100 MHz as it is shown in Figure 10b).

The same trend is observed also in the Running type stitches in B conductive thread of 6 mm stitch length against 4 mm stitch length also at low frequency. The Running stitch type of stitches has lower impedance than Tatami ones but is higher than Tatami stitches. All impedance values are located between 0.3 Ω up to 6.18 Ω. Once, the impedance is crossing the frequency of 10 MHz, the polarization of silver is contributing to the measurement so that all stitches types with different lengths have the same behavior and trend as is shown in Figure 10b).

Table 5 Embroidery stitches performance of the different on conductive threads

Type of stitches	**Running stitch**		**Tatami stitch**	
Length of stitch	**4 mm**	**6 mm**	**4 mm**	**6 mm**
A thread				
B thread				

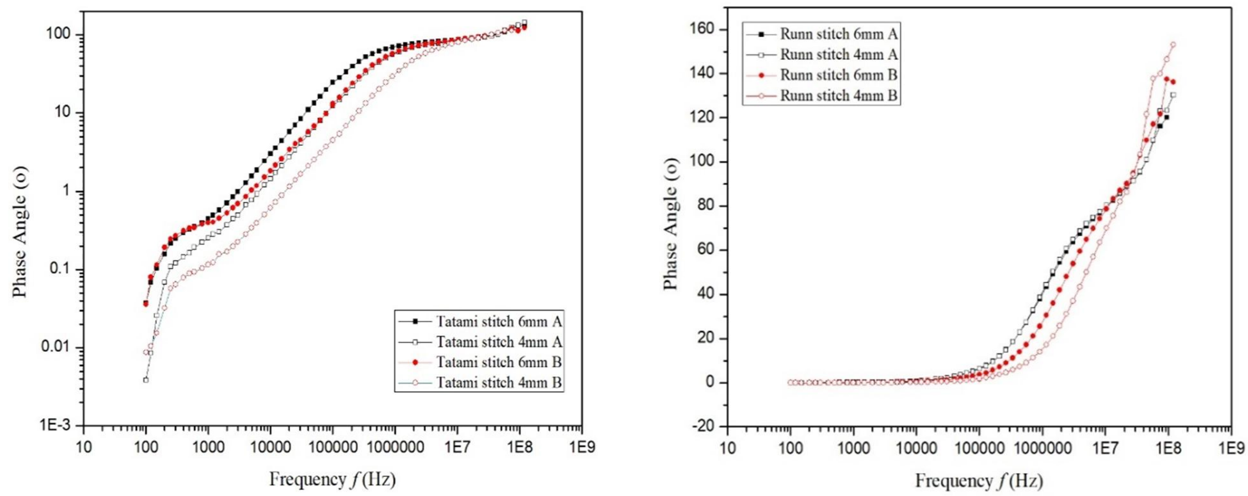


a) b)

Figure 10 The absolute value of impedance |*Z*| against the frequencies of different embroidered stitches for E-clothes

In A conductive thread, the phase angle is increased exponentially from very low values near to zero until 1 MHz, then the angle continues increasing into the plateau that started from 1-10 MHz with values near 90°. The same trend as in another B conductive thread is observed in the A conductive thread. However, the design's shapes by embroidered stitches are acting as a perfect resistor at low frequencies while they are acting as a perfect inductor. In A conductive thread Satin stitches within 6 mm length are showing the lowest phase angle. On contrary, the Tatami 6 mm stitches length is the highest phase angle at low frequencies. Phase angles in between Tatami 6 mm, other stitch types have typical trends also which Tatami 4 mm override, as well as both Running stitches of 4 mm and 6 mm, are override on each other. All stitch types override on each other at high frequencies 10-100 MHz**.**

The impedance phase angle for any component (in our case the embroidered stitches designs) is defined as the phase shift between the voltage across that component and current through that component. For a perfect resistor, the voltage drop and current are always in phase with each other, and so the impedance angle of a resistor is said to be 0°. For a perfect inductor, voltage drop always leads current by 90°, and so an inductor's impedance phase angle is said to be +90°. For a perfect capacitor, voltage drop always lags current by 90°, and so a capacitor's impedance phase angle is said to be -90°. Therefore, the impedances in AC behave analogously to resistances in DC circuits: they add in series, and they diminish in parallel.



a) b)

Figure 11 The absolute value of impedance phase angle against the frequencies of different embroidered stitches for E-clothes

In Figure11 the phase angle is increased exponentially from very low values near to zero until 100 KHz, then the angle continues increasing to the plateau that started at 1-10 MHz with values near 90°.

$$R = |Z| \cos \theta \quad (2)$$

$$X = |Z| \sin \theta \quad (3)$$

This means the design's shapes by embroidered stitches are acting as a perfect resistor at low frequencies while they are acting as a perfect inductor. Running stitches (B) within 4 mm length are showing the lowest phase angle. On contrary, in the B conductive thread the Tatami 6 mm stitches length is the highest phase angle at low frequencies but the same with Tatami in B thread 4 mm at high frequencies.

The same trend of 6 mm in B thread is observed, which is higher than 4 mm in B thread in all stitches. Thus, the 4 mm in B thread length is favorable for low phase shift designed embroidered stitches electronic component.

In Figure 12, the real value of resistance *Rs* is shown against the wide range of frequencies from 100 Hz up to 120 MHz. The *Rs* is real part of the impedance complex *Z** as the following:

$$Z^* = Z' + jZ'' = |Z|e^{j\theta} = R + jX \quad (4)$$

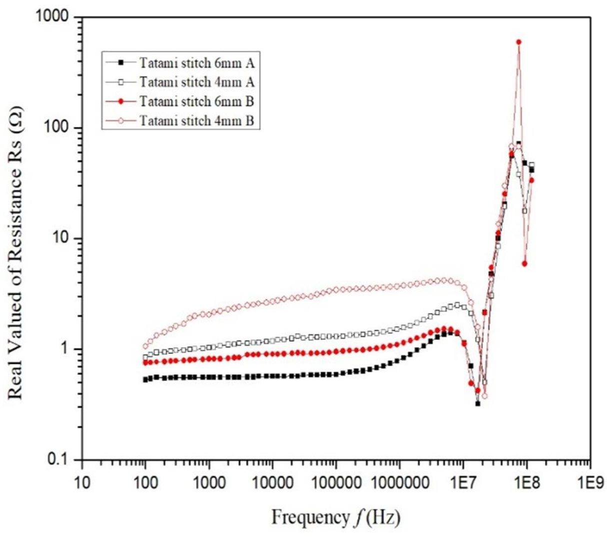
where: Z' is the real part of the complex impedance, which is represented by resistance value *R*. Similarly, the imaginary part Z'' is the amount of dissipated energy of the current signal in the circuit component. This term is always represented with $j = \sqrt{-1}$ imaginary symbol [47]. This imaginary part is valued by reactance X.

In Figure 12, the real value of resistance *Rs* is shown against the wide range of frequencies from 100 Hz up to 120 MHz.

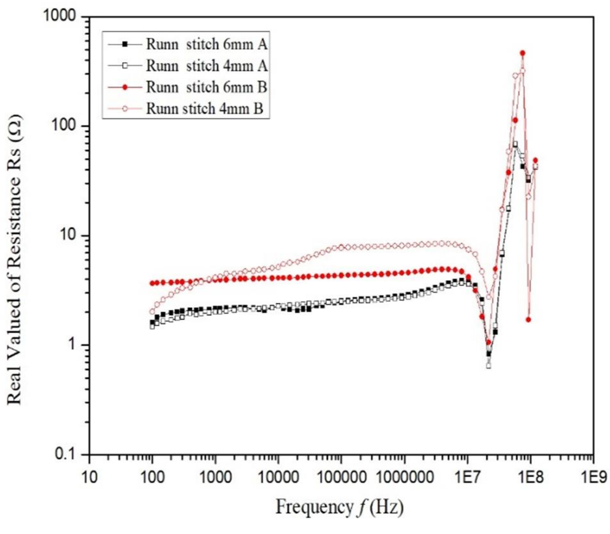
The *Rs* of 6 mm Tatami stitches in A conductive thread with length 6 mm is the lowest resistance and it is a half value of the 4 mm Tatami stitches. The 6 mm Tatami stitches in A conductive thread is similar to B conductive threads as well.

Also, the resistance of Tatami stitches in B conductive threads with length 6 mm is the lowest resistance and it is in the few-tenth other Tatami stitches with length 4 mm. The 6 mm stitches length in all stitches types provides low resistance rather than 4 mm stitches against the common prediction. This could be explained as the stress and strain due to the automatic machines of embroidery are less in 6mm if compared to these stresses accompanied with 4 mm stitches length.

The reactance *X* is the imaginary part of the impedance. It is the opposition of a circuit component to the current flow due to the inductance or capacitance of that component. Higher reactance leads to smaller currents at the same voltage applied. Although, reactance *X* is similar to electric resistance in this respect even if is measuring unit is "ohm" it also but differs in that reactance does not lead to dissipation of electrical energy as heat. Instead, energy is stored in the reactance and later returned to the circuit whereas a resistance continuously loses energy. Therefore, these designs of embroidered shapes by certain stitches could be a good potential for antenna applications. The reactance *X* is below 1 Ω until 1 MHz, while there is a continuous increase after 1 MHz to 100 Ω till 120 MHz, approximately as well as B conductive thread embroidery. The *X* is a typical trend without any significant differences in all types of stitches with their different stitch lengths (Figure 13).

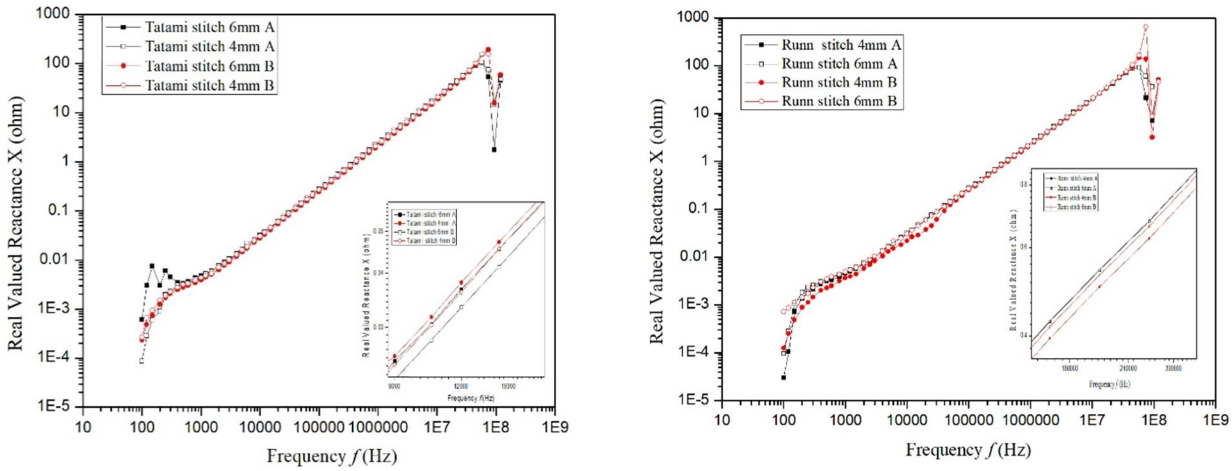


a)



b)

Figure 12 The real value of resistance *Rs* against the frequencies of different embroidered stitches for E-clothes



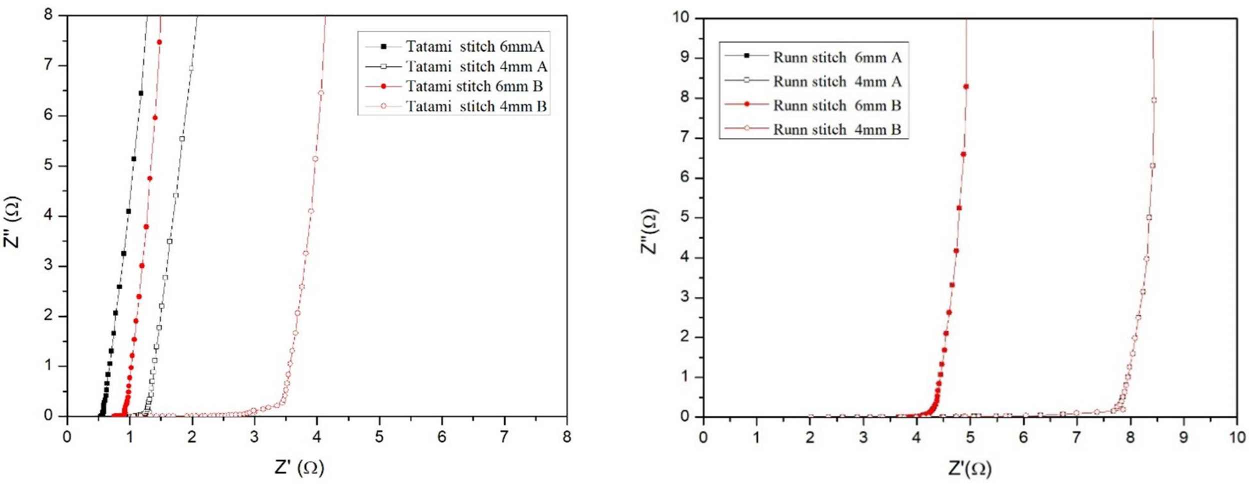
a) b)

Figure 13 The reactance *X* of the designed embroidered shapes by A conductive thread plotted in log-log scale against applied frequencies

However, a much close up to the reactance *X*, one can find that the Tatami 6 mm in A conductive thread is the lowest reactance but Tatami 4 mm is the highest reactance *X*. Both lengths of running stitches have the same values in A conductive thread, also, the reactance *X* of Running stitches 6 mm and 4 mm. One can find that the Tatami 6 mm in B conductive thread is the lowest reactance. Also, the reactance *X* of Running stitches of 4 mm is lower than the 6 mm.

The Nyquist plot (or Nyquist Diagram) is a frequency response plot used in control engineering and signal processing. Nyquist plots are commonly used to assess the stability of a system with feedback [48, 49]. In Cartesian coordinates, the real part of the transfer function is plotted on the X-axis, and the imaginary part is plotted on the Y-axis. The frequency is swept as a parameter, resulting in a plot based on frequency. The Nyquist plot here is typical for conductive component for all stitches types in both stitches lengths 4 mm and 6 mm. In Figure 14a), the Nyquist plot of A conductive thread is presented. The Tatami stitches length of 6 mm is showing the lowest value of impedance 0.5-0.65 Ω.

In B conductive thread, the Nyquist plot of Tatami stitches length of 6 mm is showing the lowest value of impedance overall the frequencies against the Running stitches 4 mm length in B conductive thread which shows the highest impedance and resistance (Figure 14b). Also, in Figure 14b), the Running stitches of A conductive thread of 4 mm and 6 mm lengths have high values of impedance from 3.5-4.0 Ω but very small reactance near zero across all low frequencies up to a few MHz.



a) b)

Figure 14 The Nyquist plot based on broad range of the frequencies for different embroidered stitches for E-clothes. The experimental real and imaginary values of the impedance of the conductive embroidered stitches in two different lengths are presented

On the other hand, the admittance $Y = 1/Z$ is reciprocal of the impedance *Z*, which is a measure of how easily a circuit or device will allow a current to flow. Likewise, the admittance *Y* is not only a measure of the ease with which a steady current can flow, but also the dynamic effects of the material's susceptance *B* to polarization. These dynamic effects of the material's susceptance are relating to the universal dielectric response, the power law scaling of a system's admittance with frequency under alternating current AC conditions. The complex admittance *Y** is consisted of the conductance *G* as a real part while the imaginary part is the susceptance *B* as the following:

$$Y = G + jB \tag{5}$$

where: *Y, G* and *B* are measured in Siemens [S].

In Figure 15a), the absolute admittance |*Y*| values are plotted against the applied frequencies from 100 Hz-120 MHz. The current flow is easily conduced in designed embroidered stitches by Tatami stitches in B conductive thread as the length parameter 6 mm very easy starting from 3 S to 0.8 S along with frequencies up to 800 kHz.

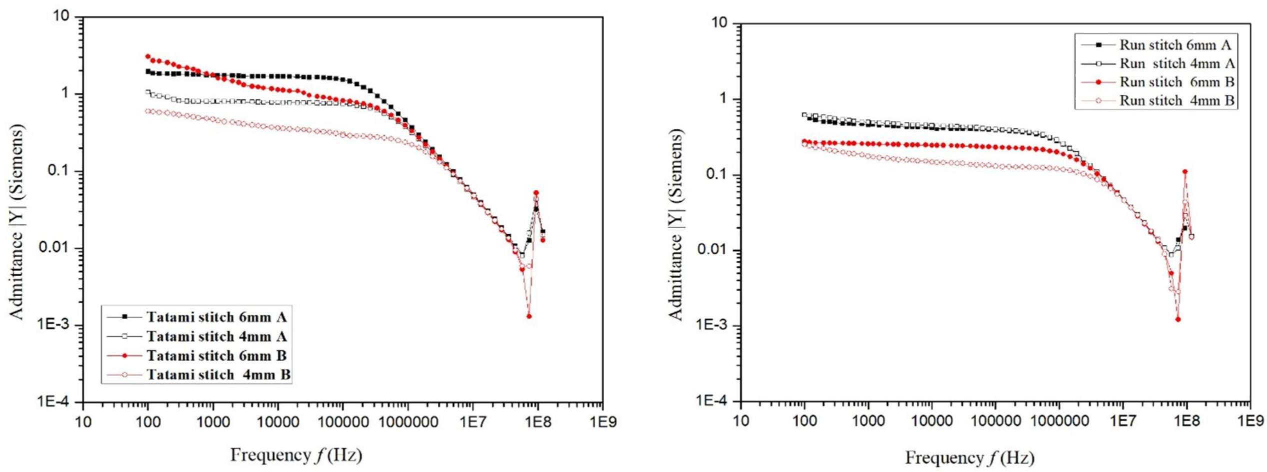
In Figure 15a), the absolute admittance |*Y*| values are plotted against the applied frequencies from 100 Hz - 120 MHz. The current flow is easily conducted in the designed embroidered stitches by Tatami stitches in A conductive thread within length parameter 6 mm as the highest value of the admittance as stable from 1.79-1.58 S in frequency range 100 Hz - 200 KHz, then the admittance decrease rapidly to 0.02 S at 100 MHz. On the opposite, for the same stitches type of Tatami but with stitches l; length 4 mm, the |*Y*| is the smallest value, and the opponent to current flow is much higher than other stitches. The |*Y*| is 0.46 S at 100 Hz and slightly declined to 0.207 S but at a much higher frequency (1 MHz) than other stitches types. Thus, the stability against the frequencies is increased on the count of the admittance value. Then, Satin stitches 4 mm have lower admittance than Tatami 6 mm. After that, the |*Y*| of Tatami 4 mm has continued the decrease and Running stitches in A conductive thread in both 4 mm and 6 mm are located at 0.46 S in Figure 15b). However, the stability of the admittance against the high frequency is in favor of the Running stitches rather than other types of stitches.

In final the lowest admittance lower than 0.3 S, the Running stitches in B conductive thread with both length 6 mm and then 4 mm Running stitches are ordered (Figure 15b).

Therefore, the real *G* and imaginary *B* component of the complex admittance *Y** is illustrated in the Figures 16 and 17. In the Figure 16, the conductance *G* is behaving as similar as the admittance but in different values and stability against the frequency up to 30 MHz.

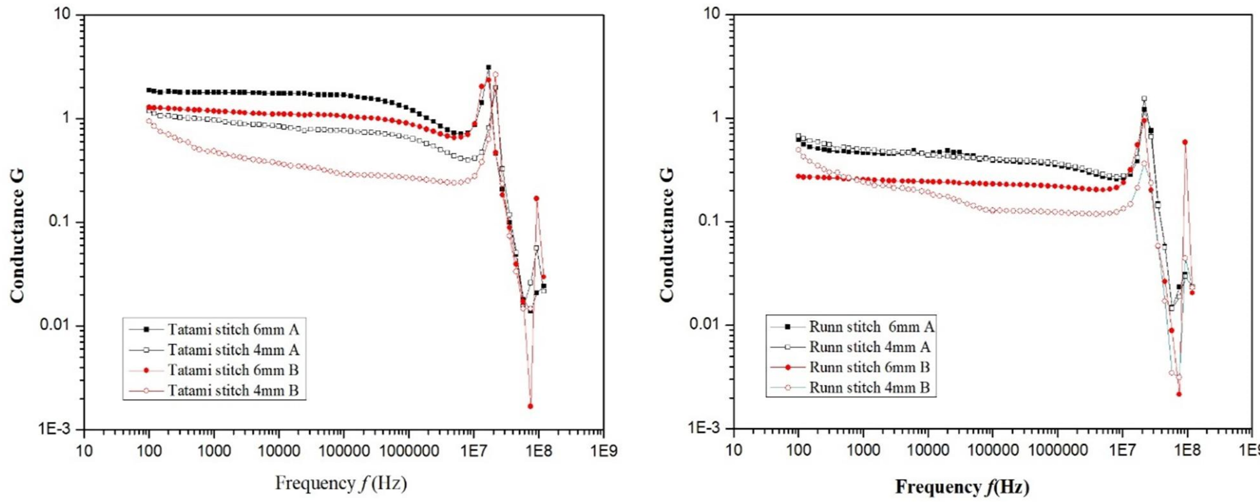
All conductance values of stitches types and lengths located in between 0.35-2.0 S approximately all over the measured frequency range. Then, the instability in the conductance after 30 MHz is due to the resonance of the silver metal that is coating the polymeric thread and filament as well as B conductive thread as the experimental limitations.

Whereas, in Figure 16., the imaginary part *B* which is representing the susceptance *B* of the materials (silvery conductive threads) in embroidered designed shapes by different types of stitches as Tatami, Satin and Running multiplied within two different lengths 4 mm and 6 mm. The susceptance *B* is related to the impedance *Z* and reactance *X* of the materials as shown before in equation (6).



a) b)

Figure 15 The log-log scale plot of the admittance *Y* against the frequencies for different embroidered stitches for E-clothes



a) b)

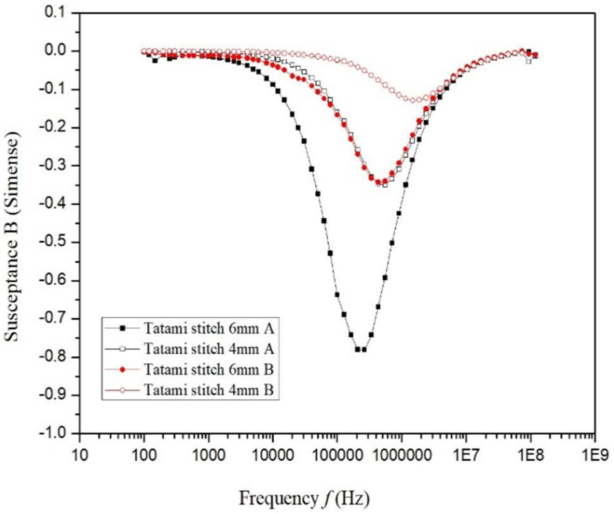
Figure 16 The log-log scale plot of the real part of admittance *Y* as the conductance *G* against the frequencies for different embroidered stitches for E-clothes

The susceptance *B* of this conductive thread has much higher values than B. This mean the energy stored in the stitches is much higher and it has followed the behavior and trend of both impedance |*Z*| and admittance |*Y*| against frequencies. In Figure 16, the Tatami 6 mm has susceptance *B* at -0.8 S at 265 KHz, Tatami 4 mm both have much close values of *B* at -0.44 S and -0.41 S at 438 KHz and 606 KHz, respectively. The Running stitches in 4 mm and 6 mm stitches have lower susceptance *B* as -0.175 S at 1.06 MHz. There for the real and imaginary component of the complex admittance is illustrated in the Figures 15 and 16. In the Figure 16, the conductance *G* is behaving as similar as the admittance but in different values and stability against the frequency up to 30 MHz. All conductance located in between 0.1-1 S approximately all over the measured frequency range. Then, the instability in the conductance after 30 MHz is due to the resonance of the silver metal that is coating the polymeric thread and filament to consist of the used conductive thread in the stitches as the experimental limitations. The imaginary part B which is representing the susceptance *B* of the materials (silvery conductive threads) in embroidered designed shapes by different types of stitches as Tatami, Satin and Running multiplied within two different lengths 4 mm and 6 mm. The susceptance *B* is related to the impedance *Z* and reactance *X* of the materials. Thus, the B can be deduced as the following:

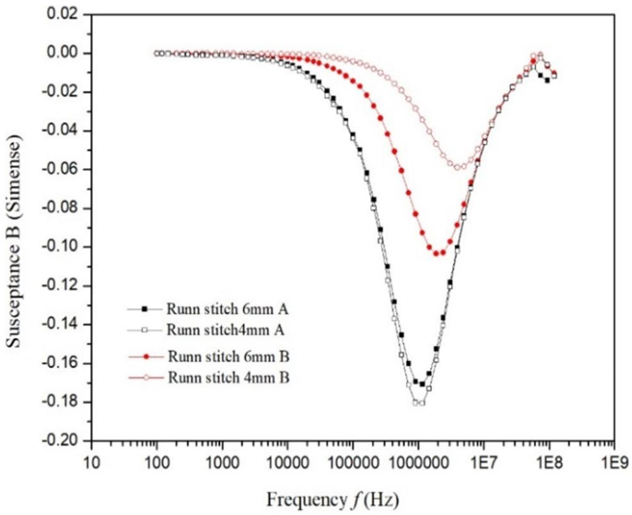
$$Y = G + jB = \frac{1}{Z} = \frac{1}{R + jX} = \\ = \left(\frac{R}{R^2 + X^2}\right) + j\left(\frac{-X}{R^2 + X^2}\right) \tag{6}$$

$$B = \frac{-X}{R^2 + X^2} = \frac{-X}{|Z|^2} \tag{7}$$

Therefore, the susceptance *B* is recalculated for all stitches types of Tatami and Running and they are represent in the Figure 16. There are clear differences among type of stitches as well as their lengths. The Tatami 6 mm stitches provided high conductance and low impedance. However, the susceptance *B* is very low near to zero at low frequencies until 4 KHz, then the amount of energy stored in the stitches decreased as seen in Figure 17. When AC passes through a component that contains a finite, nonzero susceptance, energy is alternately stored in, and released from, a magnetic field or an electric field. In the case of a magnetic field, the susceptance is inductive. In the case of an electric field, the susceptance is capacitive. Inductive susceptance is assigned negative imaginary number values, and capacitive susceptance is assigned positive imaginary number values. As the inductance of a component increases, its susceptance becomes smaller negatively (that is, it approaches zero from the negative side) in imaginary terms, assuming the frequency is held constant. As the frequency increases for a given value of inductance, the same thing happens. Therefore, in case of embroidered stitches all susceptance *B* values are negative and then the released energy would be inductive. The Tatami stitches with 6 mm length have stored much energy at high frequency 400 KHz as well as Satin 6 mm. However, energy but at higher frequency near to 1 MHz. the Tatami 4 mm is much less than pervious stitches but more shifted to higher frequency 1.5 MHz. Finally, running stitches store much lower energy but higher shift toward high frequencies 2 MHz and 6 MHz for Running 6 mm and Running 4 mm stitches.



a)



b)

Figure 17 The semi-log scale plot of the imaginary part of admittance *Y* as the susceptance B against the frequencies for different embroidered stitches for E-clothes

4 CONCLUSION

The conductive threads are very crucial and essential parts of smart textiles but there is a lack of information in general about the operating parameters of embroidery with conductive threads and their influences on communication among electronic components in the e-textiles product. In this article, silver-coated conductive threads have been employed in the fabrication of 4 embroidered designs with two different stitch types (Tatami, Running) and two lengths for each stitch (4 mm, 6 mm).

The influences of embroidery parameters and factors such as length of stitches as well as the type of stitches were investigated against the electrical properties of each design for each conductive thread usage.

Microstructure properties of conductive threads were characterized by energy-dispersive X-ray (EDX) and scanning electron microscopy (SEM). The embroidery process was done by the computerized embroidery machine. The effects of embroidery parameters such as different stitch type, stitch length and type of thread conductive were evaluated. The electrical characteristics also have been determined for the textile without any embroidered stitches of conductive threads.

The electrical characteristics were measured and determined in the frequency domain from 100 kHz-120 MHz. The impedance and resistivity of threads are determined also using the AC voltages at three different frequencies 100 kHz, 1 MHz and 10 MHz. The applied voltages are from 0.0-1.0 volts through thirty (30) steps.

The alternative current AC measurements were conducted for impedance, phase angle, and their corresponding parameters such as real-valued resistance, reactance, admittance, conductance, susceptance and Nyquist plot of ac impedance. Thus, results can be summarized as follows:

- The phase angle in textile is stable against all frequencies up to 100 MHz at -89° which is the characteristic of good small resistor accompanied with a capacitor. The reason for that is the textile in between parallel two electrodes acting as typical dielectric material.
- All impedance values are located between 0.3 Ω up to 6.18 Ω. Once, the impedance is crossing the frequency of 10 MHz, the polarization of silver is contributing to the measurement so that all stitches types with different lengths have the same behavior and trend.
- The phase angle is increased exponentially from very low values near to zero until 1 MHz, then the angle continues increasing into the plateau that started from 1-10 MHz with values near 90°. This mean the designs shapes by embroidered stitches are acting as perfect resistor at low frequencies while they are acting as perfect inductor at high frequencies.
- The 6 mm stitches length in all stitch types provides low resistance rather than 4 mm stitches against the common prediction. This could be explained as the stress and strain due to the automatic machines of embroidery are less in 6 mm if compared to these stresses accompanied with 4 mm stitches length.
- The reactance *X* is below 1 Ω until 1 MHz, while there is continuous increase after 1 MHz till 100 Ω at 120MHz, approximately. There are no big differences in X for all types of stitches with their different stitch lengths approximately as well as HC12 conductive thread embroidery.

The X is a typical trend without any significant differences in all types of stitches with their different stitch lengths. Therefore, these designs of embroidered shapes by certain stitches could be a good potential for antenna applications.

- The Nyquist plot here is typical for conductive component for all stitch types in both stitches' lengths 4 mm and 6 mm. The Nyquist plot of Tatami stitches of 6 mm length is showing the lowest value of impedance overall the frequencies against the lock stitches (B thread) 4 mm length which shows the highest impedance and resistance.
- The absolute admittance $|Y|$ values are plotted against the applied frequencies from 100 Hz-120 MHz. The current flow is easily conduced in designed embroidered stitches by Tatami stitches (A thread) as the length parameter 6 mm very easy starting from 3 S to 0.8 S along with frequencies up to 800 kHz. However, the stability of the admittance against the high frequency is in favor to the lock stitches than others stitch types.
- All conductance values of stitch types and lengths located in between 0.35-2.0 S approximately all over the measured frequency range. Then, the instability in the conductance after 30 MHz is due to the resonance of the silver metal that is coating the polymeric thread and filament conductive thread as the experimental limitations.
- The susceptance B of the A conductive thread has much higher values than B conductive thread. This means the energy stored in the stitches is much higher and it has followed the behavior and trend of both impedance $|Z|$ and admittance $|Y|$ against frequencies. The Tatami 6 mm (A thread) has susceptance B at -0.8 S at 265 KHz. Therefore, in the case of embroidered stitches all susceptance B values are negative and then the released energy would be inductive.
- Therefore, these findings are valuable for fabricating any of embroidered e-textiles such as high-performance circuits, antenna applications and other electrically conductive systems and devices. Additionally, these designs of embroidered shapes by certain stitches could be a good potential for antenna applications.

***Acknowledgement**: The authors would like to thank the Saudi Standards, Metrology and Quality Organization (SASO) for their valuable help in the textile measurements. The authors would also like to thank AMAAN and MADEIRA companies to bring them threads used in the research.*

5 REFERENCES

1. Ismar E., Behadir S.K., Kalaoglu F, Koncar V.: Futuristic clothes: electronic textiles and wearable technologies, Global Challenges 4(2), 2020, pp. 2056-6646, https://doi.org/10.1002/gch2.201900092
2. Mecnika V., Hoerr M., Krievins I., Jockenhoevel S., Gries T.: Technical embroidery for smart textiles, Materials Science. Textile and Clothing Technology 9, 2014, pp. 56-63, DOI: 10.7250/mstct.2014.009
3. Hughes-Riley T., Dias T., Cork C.: A historical review of the development of electronic textiles, Fibers 6(2), 2018, 34 p., https://doi.org/10.3390/fib6020034
4. Mecnika V., Scheulen K., Anderson C.F., et al.: Joining technologies for electronic textiles, chapter 7 in Electronic Textiles: Smart Fabrics and Wearable Technology, Dias T. (Ed.), Elsevier Science , 2015, p. 133-153, DOI: 10.1016/B978-0-08-100201-8.00008-4
5. Aigner R., Pointner A., Preindl T., et al.: Embroidered resistive pressure sensors: A novel approach for textile interfaces, Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, 2020, 13 p., https://doi.org/10.1145/3313831.3376305
6. ZSK, A guide to technical embroidery. 2020, ZSK, https://catalog.zsk.de/download/CARL-Autumn-2020.pdf
7. Linz T., Vieroth R., Dils C., et al.: Embroidered interconnections and encapsulation for electronics in textiles for wearable electronics applications, Advances in Science and Technology 60, 2008, pp. 85-94, https://doi.org/10.4028/www.scientific.net/AST.60.85
8. Roh J.-S.: Conductive Yarn Embroidered Circuits for System on Textiles, chapter in Wearable Technologies, 2018, pp. 161-175, http://dx.doi.org/10.5772/intechopen.76627
9. Eichhoff J., Hehl A., Jockenhoevel S., Gries T.: Textile fabrication technologies for embedding electronic functions into fibres, yarns and fabrics, chapter 7 in Multidisciplinary Know-How for Smart-Textiles Developers, Woodhead Publishing Series in Textiles, 2013, pp. 191-226, https://doi.org/10.1533/9780857093530.2.191
10. Trindade I.G., Machado da Silva J., Miguel R., et al.: Design and evaluation of novel textile wearable systems for the surveillance of vital signals, Sensors 16(10), 2016, 15 p., https://doi.org/10.3390/s16101573
11. McCann J.: The garment design process for smart clothing: from fibre selection through to product launch, chapter 4 in Smart clothes and Wearable Technology, Woodhead Publishing Series in Textiles 2009, pp. 70-94, https://doi.org/10.1533/9781845695668.1.70
12. Post E.R., Orth M., Russo P.R., et al.: E-broidery: Design and fabrication of textile-based computing, IBM Systems Journal 39(3.4), 2000, pp. 840-860, DOI: 10.1147/sj.393.0840
13. Taylor A.: Digital embroidery techniques for smart clothing, chapter 14 in Smart Clothes and Wearable Technology, Woodhead Publishing Series in Textiles, 2009, pp. 279-299, https://doi.org/10.1533/9781845695668.3.279

14. Rho S., Lim D., Yoo E., Hwang E.: The study on Seebeck effect of textile thermocouple manufactured by embroidery technique, Proceedings of the 19th World Textile Conference on Textiles at the Crossroads - AUTEX2019, Ghent, Belgium, 11-15 June 2019, pp. 1-3
15. Agcayazi T., Chatterjee K., Bozkurt A., Ghosh T.K.: Flexible interconnects for electronic textiles, Advanced Materials Technologies 3(10), 2018, art. No. 1700277, https://doi.org/10.1002/admt.201700277
16. Linz T., Kallmayer C., Aschenbrenner R., et al.: Fully untegrated EKG shirt based on embroidered electrical interconnections with conductive yarn and miniaturized flexible electronics, International Workshop on Wearable and Implantable Body Sensor Networks (BSN'06), IEEE, 2006, DOI: 10.1109/BSN.2006.26
17. Shafti A., Ribas Manero R.B., Borg A.M., et al.: Embroidered electromyography: A systematic design guide. IEEE Transactions on Neural Systems and Rehabilitation Engineering 25(9), 2016, pp. 1472-1480, DOI: 10.1109/TNSRE.2016.2633506
18. Lee S., Jamil B., Kim S., Choi Y.: Fabric vest socket with embroidered electrodes for control of myoelectric prosthesis, Sensors 20(4), 2020, pp. 1-17, https://doi.org/10.3390/s20041196
19. Linz T., Gourmelon L., Langereis G.: Contactless EMG sensors embroidered onto textile, Proceedings of the 4th International Workshop on Wearable and Implantable Body Sensor Networks (BSN 2007), IFMBE Proceedings 13. Springer, Berlin, Heidelberg, 2007, pp. 29-34, https://doi.org/10.1007/978-3-540-70994-7_5
20. Roh J.-S., Kim S.: All-fabric intelligent temperature regulation system for smart clothing applications, Journal of Intelligent Material Systems and Structures 27(9), 2016, pp. 1165-1175, https://doi.org/10.1177/1045389X15585901
21. Tsolis A., Whittow W.G., Alexandridis A.A., et al.: Embroidery and related manufacturing techniques for wearable antennas: challenges and opportunities, Electronics 3(2), 2014, pp. 314-338, https://doi.org/10.3390/electronics3020314
22. Zhang S.: Design advances of embroidered fabric antennas, Loughborough University, 2014,
23. Acti T., Chauraya A., Zhang S., et al.: Embroidered wire dipole antennas using novel copper yarns, IEEE Antennas and Wireless Propagation Letters 14, 2015, pp. 638-641, DOI: 10.1109/LAWP.2014.2371338
24. Ouyang Y., Chappell W.J.: High frequency properties of electro-textiles for wearable antenna applications, IEEE Transactions on Antennas and Propagation 56(2), 2008, pp. 381-389, DOI: 10.1109/TAP.2007.915435
25. Linz T., Simon E.P., Walter H.: Modeling embroidered contacts for electronics in textiles, The Journal of The Textile Institute 103(6), 2012, pp. 644-653, https://doi.org/10.1080/00405000.2011.597568
26. Roh J.-S., Chi Y.-S., Lee J.-H., et al.: Characterization of embroidered inductors, Smart Materials and Structures 19(11), 2010, 12 p., https://doi.org/10.1088/0964-1726/19/11/115020
27. Gehrke I., Tenner V., Lutz V., et al.: Smart textiles production: Overview of materials, sensor and production technologies for industrial smart textiles, MDPI Books, 2019, 204 p., https://doi.org/10.3390/books978-3-03897-498-7
28. Holleis P., Schmidt P., et al.: Evaluating capacitive touch input on clothes, in Proceedings of the 10th International Conference on Human Computer Interaction with Mobile Devices and Services, 2008, pp. 81-90, https://doi.org/10.1145/1409240.1409250
29. Kindermann P.: Embroidered touchpad sensors, Thesis, Computer Science Department, RWTH Aachen University, 2018, 35 p.
30. Ojuroye O.O., Torah R.N., Komolafe A.O., et al.: Embedded capacitive proximity and touch sensing flexible circuit system for electronic textile and wearable systems, IEEE Sensors Journal 19(16), 2019, pp. 6975-6985, DOI: 10.1109/JSEN.2019.2911561
31. Roh J.-S., Mann Y., Freed A., Wessel D.: Robust and reliable fabric, piezoresistive multitouch sensing surfaces for musical controllers, in Proceedings of the International Conference on New Interfaces for Musical Expression, 30 May - 1 June 2011, Oslo, Norway, pp. 393-398
32. Roh, J.-S.: Textile touch sensors for wearable and ubiquitous interfaces, Textile Research Journal 84(7), 2014, pp. 739-750, https://doi.org/10.1177/0040517513503733
33. Ismar E., Tao X., Rault F, et al.: Towards embroidered circuit board from conductive yarns for E-textiles, IEEE Access 8, 2020, pp. 155329-155336, https://doi.org/10.1109/ACCESS.2020.3018759
34. Gilliland S., Komor N., Starner T., Zeagler C.: The textile interface swatchbook: Creating graphical user interface-like widgets with conductive embroidery, in International Symposium on Wearable Computers (ISWC) 2010, IEEE, 2010, pp. 1-8, https://doi.org/10.1109/ISWC.2010.5665876
35. SASO-ISO-2062:2009. Standard specification for determination of single-end breaking force and elongation at break using constant rate of extension (CRE) tester. Textiles - Yarns from packages. Retrieved from: https://wasif.saso.gov.sa/Pages/User/SearchResults.aspx?searchkey=2062
36. SASO-ISO-2060:1994. Standard specification for determination of linear density (mass per unit length) by the skein method. Textiles - Yarn from packages. Retrieved from: https://wasif.saso.gov.sa/Pages/User/SearchResults.aspx?searchkey=2060
37. SASO-ISO-7211-1:1984. Standard specification for Part 1: Methods for the presentation of a weave diagram and plans for drafting, denting and lifting. Woven fabrics - Construction - Methods of analysis. Retrieved from: https://wasif.saso.gov.sa/Pages/User/SearchResults.aspx?searchkey=7211
38. SASO-ISO-2286-3:1998. Standard specification for Determination of roll characteristics – Part 3: Method for determination of thickness. Rubber- or plastics-coated fabrics. Retrieved from:

https://wasif.saso.gov.sa/Pages/User/SearchResults.aspx?searchkey=2286

39. SASO-GSO-1269:2006. Standard specification for determination of number of threads in woven fabrics. Retrieved from: https://wasif.saso.gov.sa/Pages/User/StandardInfo.aspx?ref=xc354345XS53x4_28237x6yty34554sfswet

40. SASO-ISO-13934-1:2013. Standard specification for determination of maximum force and elongation at maximum force using the strip method. Textiles -- Tensile properties of fabrics. Retrieved from: https://wasif.saso.gov.sa/Pages/User/SearchResults.aspx?searchkey=13934

41. SASO-ISO-3801:1977. Standard specification for determination of mass per unit length and mass per unit area. Textiles - Woven fabrics. Retrieved from https://wasif.saso.gov.sa/Pages/User/SearchResults.aspx?searchkey=3801

42. Bogatin E.: Signal Integrity: Simplified, 1st ed., Prentice Hall Professional, 2003, 587 p., ISBN: 0130669466

43. Halliday D., Resnick R., Walker J.: Fundamentals of Physics, 10th ed., John Wiley & Sons, 2013, 1448 p., ISBN: 978-1-118-23072-5

44. Swielam E., Eltopshy S., Sobhy S.K., et al.: Impact of the fabrication parameters on the performance of embroidered E-clothes, Egyptian Journal of Chemistry 62(1), 2019, pp. 109-117, DOI: 10.21608/ejchem.2018.4555.1399

45. Nassar A., Taha A.S., Labeeb A., Gouda E.S.A.: Structure and properties of the Al-Sn-Cu bearing alloy under different cold rolling conditions, Journal of Materials Science and Engineering B 5(7-8), 2015, pp. 298-304, https://doi.org/10.17265/2161-6221/2015.7-8.007

46. Labeeb A.M., Sobhy S.K., Eltopshy S.M., et al.: Embroidery on textiles as a smart solution for wearable applications, International Design Journal 9(2), 2019, pp. 53-58, DOI: 10.21608/idj.2019.83296

47. Batoo K.M., Kumar S., Lee C.G., Alimuddin: Study of ac impedance spectroscopy of Al doped MnFe2−2xAl2xO4, Journal of Alloys and Compounds 480(2), 2009, pp. 596-602, https://doi.org/10.1016/j.jallcom.2009.01.137

48. Negroiu R., Svasta P., Ionescu C., Vasile A.: Investigation of supercapacitor's impedance based on spectroscopic measurements, in 1st PCNS Passive Components Networking Days, Brno, Czech Republic, 12-15th Sept. 2017

49. Abbasi A., Hosseini S., Somwangthanaroj A., et al.: Poly (2, 6-dimethyl-1, 4-phenylene oxide)-based hydroxide exchange separator membranes for zinc–air battery, International Journal of Molecular Sciences 20(15), 2019, pp. 1-17, https://doi.org/10.3390/ijms20153678

AIR PERMEABILITY AND STRUCTURAL PARAMETERS OF SINGLE JERSEY KNITTED FABRIC

Marie Havlová

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

Abstract: *The main aim of our study is to investigate the influence of the basic structural parameters on the air permeability value of single jersey weft knitted fabric. A specific experimental set of knitted fabrics was used for this purpose – the yarns of two materials (viscose and polyester) and two yarn counts (20 tex and 29.5 tex) were used, each of these four yarns was used to manufacture a set of single jersey knitted fabric samples of several different densities. Altogether 22 different knitted samples were prepared and used for investigation the basic relationships between air permeability and the structural parameters of the knitted fabrics. Primary and secondary structural parameters such as area of unit cell, thickness, planar weight or porosity were investigated. Porosity was calculated according to three different theoretical models. Our results showed that as the thickness and planar weight of the knitted fabric increase, its air permeability decreases. As the porosity of the knitted fabric increases, its air permeability increases, with the value of air permeability responding most sensitively to the porosity expressed as a proportion of the open area of the knitted fabric. The results also showed that the relationship between air permeability and porosity as well as the relationship between air permeability and planar weight are not completely linear. Linear relationship was found between the air permeability of the knitted fabric and the ratio of its porosity and its planar weight.*

Keywords: *air permeability, knitted fabric, structural parameters, porosity, planar weight.*

1 INTRODUCTION

Due to the method of construction, textile materials in general are a porous structure. Therefore, a large part of their total volume is airspace. This porous character determines all physical properties of textile materials. The size of the pores in textile as well as their shape, arrangement and distribution are one of the crucial characteristics for a number of fabric properties including comfort parameters. One of them is the ability of the fabric to transmit air.

Air permeability is one of the fundamental textile properties and it is an important factor in the comfort of a fabric [1, 10], together with the water vapour permeability and thermal insulation properties as well as the tactile characteristics of the fabric. All these comfort properties are very closely related to the porosity of the fabric. A number of authors have researched the relationship between the structure and comfort parameters of the textile fabrics [1-3, 5, 6]. The property usually given by the description of the structure of the fabric is just the porosity. The pore dimension and distribution are functions of the geometric structure of the fabric. Understanding the relationships between the structural parameters and physical properties of the textile materials is very important for the ability to simulate and design these properties before the fabric is made. It is necessary to focus on knitted fabrics, because they provide excellent comfort qualities and have preferred in many types of clothing. They are increasingly used in clothing production. Today, many knitted fabrics are made that imitate the original traditional woven fabrics – such as denim, corduroy, tweed, bouclé, brocade etc. Air permeability is very important for these fabrics because it allows to ventilate the space under the garment. Some authors have investigated the relationship between the structural parameters (primary or secondary) of a knitted fabric and its comfort parameters, including air permeability. For example, Ogulata [1] conducted an experimental study in order to develop a theoretical model to predict air permeability values for plain knitted fabric and used D'Arcy's formulation for expressing the relationship between the air permeability of knitted fabrics and fabric structure parameters. In this paper, the porosity ε_V based on the proportion of volumes was used and the pore was considered to have a circular cross section. The set of 18 knitted samples was made for this experiment and for these samples the near linear relationship between predicted and experimental values of air permeability was shown. Coruh [2] investigated the influence of different loop lengths and different fibre blend ratios of single jersey knitted fabrics on the mechanical and comfort properties and found that an increase in the loop length increases the air permeability, while an increase in the thickness of knits decreases the air permeability. Twelve variants of fabrics were prepared from cotton, viscose and polyester blend yarns. Wilbik-Halgas [3] examined relationship between air permeability and water vapour permeability using a set of double-layered knitted fabrics. The surface porosity was measured by image analysis method. Their results showed that air permeability is a function of the thickness and porosity of the knitted fabric. Benltoufa [4] ranks air permeability among the methods of porosity determination together with image analysis method and geometry modelling and concluded that the most suitable and easiest method to determine porosity is the geometrical model based on the proportion of volumes ε_V. Bivainyte [5] concluded that the air permeability of double-layered knitted fabrics with different patterns can be predicted by the area linear filling rate. 16 variants of knits were used for this experiment and porosity value ε_A was calculated on the base of proportion of areas. The conclusion was that if the knitted fabrics are made with the same pattern the air permeability depends on the loop length. Maheswaran [6] investigated the properties of plain jersey knitted fabrics produced from blended yarns. 18 samples were obtained for this experiment. It was found that main factors influencing the air permeability of knitted fabrics are fabric thickness and yarn hairiness. Other authors try to describe in detail the geometry of the loop in the knitted fabric - for example Suh [7], Munden [8] or Peirce [9]. However, these models are complex and requires many parameters to characterise the loop shape geometry and in addition, they usually also require a number of simplifying assumptions. Benltoufa [4] compared porosity values calculated using Suh's geometrical model and using much simpler model of porosity based on the proportion of volumes ε_V below and for 60 samples of knitted fabrics obtained very similar results.

The aim of our study is not to find a generally valid model for predicting the air permeability value of a knitted fabric, but to examine the influence of basic and in practice easily detectable structural parameters such as thickness, planar weight or density of the knitted fabric on the value of its air permeability and also to compare the relationships between air permeability and porosity values calculated according to three different theoretical models. A specific experimental set of knitted fabrics with defined structural parameters is to be used for this purpose.

2 RESEARCH METODOLOGY

2.1 Air permeability

Air permeability *AP* [m/s] of textile materials is generally understood as the ability of fabric to transmit air. Permeability measurement is carried out according to the standard ISO 9237 and air permeability is expressed as the speed of air flowing through the sample of fabric given (under defined measurement conditions – clamping area 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.

2.2 Structural parameters of plain jersey weft knitted fabrics

Analogous to woven fabrics [10, 11], the basic structure of the knitted fabric may be described as follows: the method of yarn interlacing, yarn diameter or the linear mass of this yarn, wale spacing and course spacing, the thickness of the fabric or its surface mass. The fabric structure parameters can be divided into primary and secondary parameters. Primary parameters of fabric structure are dependent variables, where the choice of one parameter influences the effect of the others. All others fabric structure parameters depend on primary parameters. These are secondary parameters [12].

The jersey based plain structure is the simplest, but at the same time the most used structure of the weft knitted fabric. Dimensional characteristics of unit cell of this fabric are illustrated in Figure 1:

- wale spacing W [m] (or loop width); the number of wales per meter w [1/m], while W=1/w,
- course spacing C [m] (or loop height); the number of courses per meter c [1/m], while C=1/c,
- yarn diameter d [m],
- loop length l [m].

The primary structural parameters are yarn diameter, plain jersey structure, wale spacing and course spacing. However, it is very important to note that the wale spacing W [m] is defined by the knitting machine gauge and course spacing C [m] is changed by the sinking depth [13]. So for samples knitted on one machine: in the first phase we change the course spacing. Removing the knitted fabric from the machine is followed by relaxation, after which the length of the loop is the same, but wale spacing and course spacing change nonlinearly [14].

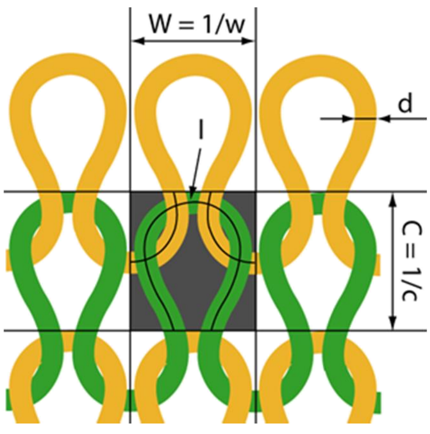


Figure 1 Scheme of unit cell of a plain knitted fabric

Very important parameter of a knitted structure is the loop length *l* [m]. The loop length is usually mentioned as the primary knitted structure parameter [8, 13], which is changed by the machine used and its settings. The loop length can be determined experimentally. However, if the value of loop length is calculated theoretically, it would be more logical to consider this parameter as a secondary structural parameter, because it is calculated from the primary structural parameters. For example, the geometrical model by Dalidovic [15] calculates the loop length as a function of yarn diameter, wale spacing and course spacing:

$$l = \frac{\pi}{2} \times W + \pi \times d + 2C \tag{1}$$

This model is one of the most used due to its simplicity. The yarn diameter *d* [m] can be determined experimentally or calculated as:

$$d = \sqrt{\frac{4T}{10^{-6}\pi \times \mu \times \rho_F}} \tag{2}$$

where: ρ_F [kg/m^3] is the density of fibres, T [tex] is the count of yarn and μ [-] is the packing density of yarn [16]. In this case, a free yarn diameter is involved. It means considerable simplification, because the yarn cross section is deformed at the interlacing points in the textile structure.

The two-dimensional Figure 1 does not show the thickness of the fabric t [m]. The thickness of the knitted fabric, as its secondary structural parameter, is results of its primary structural parameters and can be easily determined experimentally. According to some authors [2, 3, 6], the thickness of a knitted fabric is one of the most important parameters for its air permeability. Finally, the planar weight of the knitted fabric W_T [kg/m^2] is a secondary structural parameter, which is also the result of its primary structural parameters. The planar weight (or surface mass) is the weight per unit area of the fabric and can be easily determined experimentally. Based on the structural parameters above, a porosity of the knitted fabric can be calculated. There exist generally three basic techniques for characterization of idealized fabric porosity [17]:

- Porosity based on the proportion of densities ε_D [-] is computed from the equation:

$$\varepsilon_D = 1 - \frac{\rho_T}{\rho_F} \tag{3}$$

where: ρ_F [kg/m^3] is the density of fibres and ρ_T [kg/m^3] is the volumetric density of the fabric defined by the relation:

$$\rho_T = \frac{W_T}{t} \tag{4}$$

where: W_T [kg/m^2] is the planar weight and t [m] is the thickness of the fabric. Then density based porosity can be calculated as:

$$\varepsilon_D = 1 - \frac{W_T}{(\rho_F \times t)} \tag{5}$$

Dias [18] refers this method as the experimental evaluation of porosity. This method is simplest and applicable for all fabrics regardless of their construction.

- Porosity based on the proportion of areas ε_A is defined as [5]:

$$\varepsilon_A = 1 - \frac{A_Y}{A_T} \tag{6}$$

where A_Y [m^2] is the area of projection of the yarn in unit cell of the knitted structure:

$$A_Y = d \times l - 4d^2 \tag{7}$$

and A_T [m^2] is the total area of projection of this unit cell:

$$A_T = C \times W \tag{8}$$

Then the porosity ε_A can be calculated as:

$$\varepsilon_A = 1 - \frac{d \times l - 4d^2}{C \times W} \tag{9}$$

- Porosity based on the proportion of volumes ε_V is defined as [1, 4]:

$$\varepsilon_V = 1 - \frac{V_Y}{V_T} \tag{10}$$

where: V_Y [m^3] is the yarn volume in unit cell of the fabric calculated as:

$$V_Y = \left(\frac{\pi d^2}{4}\right) \times l \tag{11}$$

and V_T [m^3] is the total volume of unit cell of the fabric:

$$V_T = C \times W \times t \tag{12}$$

Then the porosity ε_V can be calculated as:

$$\varepsilon_V = 1 - \frac{\pi d^2 \times l}{4C \times W \times t} \tag{13}$$

All discussed structural parameters are summarised in affinity diagram on Figure 2.

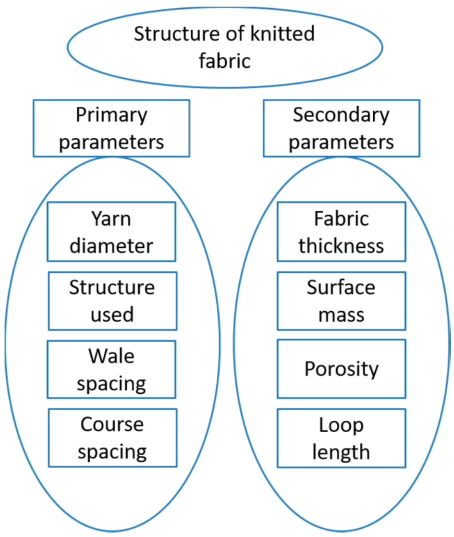


Figure 2 Affinity diagram of basic structural parameters of a knitted fabric

3 MATERIALS AND EXPERIMENT

Knitted fabrics of single jersey structure were used for the experiment. The samples were specially made for the research purpose on a small-diameter circular knitting machine – Rius-Protex (Spain) from polyester and viscose ring-spun yarns, which have always been of two linear densities 20 tex and 29.5 tex. Samples of the fabrics with different densities were knitted from each yarn – altogether 22 different knitted samples were prepared (Figure 3 and Table 1). Figure 4 shows images of knitted fabric made of viscose yarn 29.5 tex.

Table 1 Knitted fabrics structural parameters

sample	W_T [kg/m²]	*t* [mm]	A_T [mm²]	ε_D [-]	ε_A [-]	ε_V [-]
VI_20	0.084	0.44	0.98	0.870	0.431	0.797
	0.099	0.45	0.74	0.852	0.349	0.772
	0.105	0.46	0.66	0.846	0.315	0.762
	0.117	0.47	0.56	0.832	0.258	0.742
	0.134	0.48	0.42	0.809	0.151	0.697
PL_20	0.085	0.43	0.92	0.858	0.447	0.812
	0.100	0.46	0.70	0.843	0.366	0.793
	0.119	0.49	0.52	0.824	0.269	0.769
	0.133	0.52	0.47	0.814	0.240	0.770
VI_29.5	0.108	0.47	1.20	0.844	0.506	0.770
	0.115	0.48	1.08	0.838	0.374	0.761
	0.126	0.49	0.97	0.825	0.340	0.749
	0.138	0.52	0.77	0.821	0.264	0.731
	0.149	0.54	0.68	0.812	0.219	0.718
	0.165	0.55	0.58	0.797	0.164	0.701
	0.181	0.57	0.51	0.784	0.110	0.686
	0.201	0.58	0.45	0.765	0.058	0.669
PL_29.5	0.120	0.54	0.98	0.851	0.319	0.759
	0.147	0.56	0.67	0.810	0.191	0.709
	0.172	0.56	0.58	0.779	0.135	0.685
	0.185	0.58	0.52	0.771	0.094	0.677
	0.187	0.58	0.50	0.769	0.075	0.670

Primary and secondary structural parameters of all knitted fabric samples were determined with laboratory tests. The planar weight of the fabrics W_T was measured according to Standard EN 12127 and the thickness of the fabrics *t* according to Standard EN ISO 5084. The number of courses per mm *c* and wales per mm *w* was measured according to Standard EN 14971.

The loop length *l* was calculated according to (1), with the yarn diameter value *d* calculated according to (2). The porosity values ε_D, ε_A and ε_V were calculated according to (5), (9) and (13). The parameters of the knitted fabrics are summarized in Table 1.

The air permeability of the fabrics *AP* [m/s] was measured according to Standard EN ISO 9237 using a Textest FX 3300 air permeability tester. The measurements were performed with a constant pressure difference of 50 Pa and 20 cm² test area.

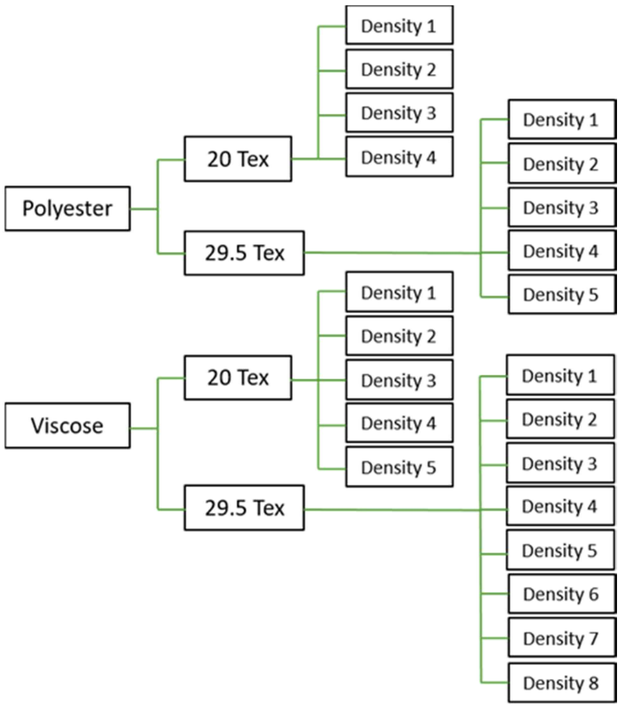


Figure 3 Knitted samples preparation diagram

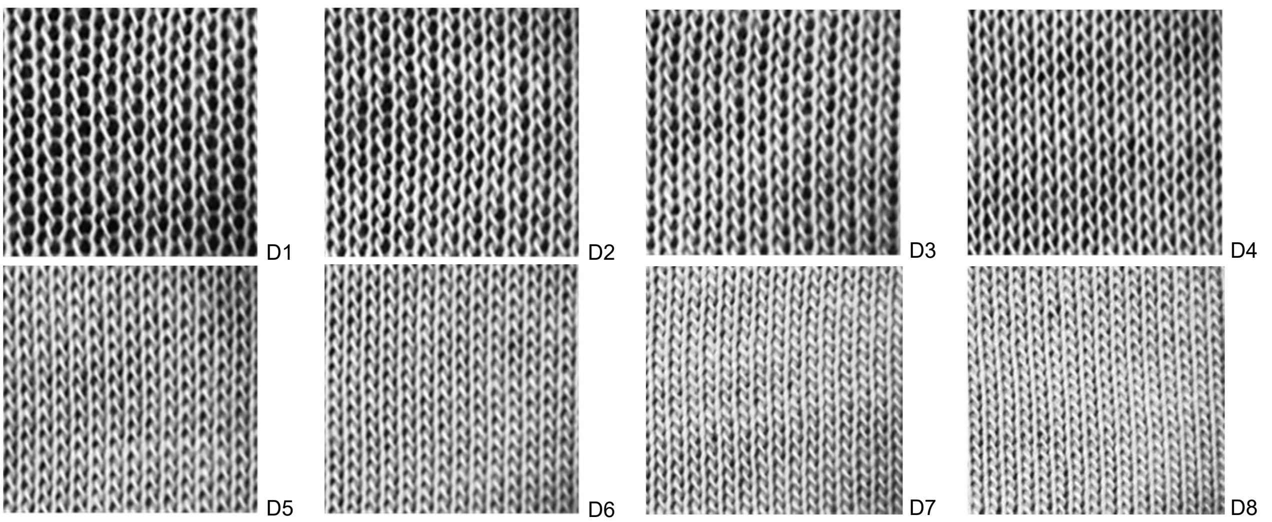


Figure 4 Microscopic views of the knitted fabric samples Viscose_29.5 tex with different densities (D)

4 RESULTS AND DISCUSSION

According to some authors [2, 3, 6], the thickness of the knitted fabric is an important structural parameter for the value of its air permeability. Figure 5 and the correlation coefficients in Table 2 show that when the knitted fabric samples are made from the same yarn, the data show a strong negative linear dependence (e.g. VI_29.5: R=-0.98). If the thickness of the fabric increases, then its air permeability decreases. However, the correlation coefficient is lower when the knitted fabric samples are made of different yarns (R=-0.81). In this case the linear relationship is not so strong.

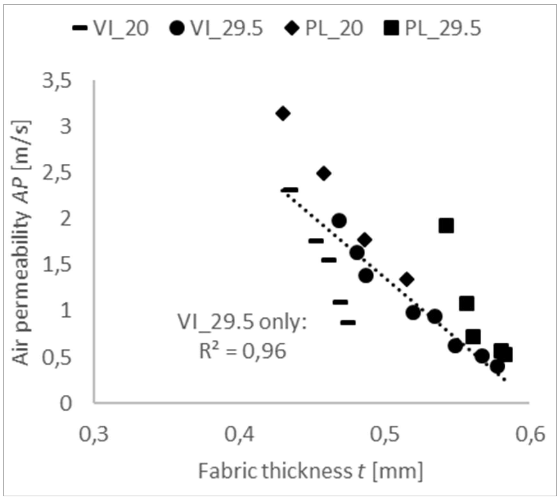


Figure 5 Relationship between thickness and air permeability of knitted fabrics

Table 2 Correlation coefficients for relationships between air permeability and selected structural parameters of knitted fabrics

	t [mm]	W_T [kg/m^2]	A_T [mm^2]	ε_D [-]	ε_A [-]	ε_V [-]
All data	-0.81	-0.90	0.64	0.88	0.92	0.94
VI_29.5	-0.98	-0.95	0.996	0.94	0.97	0.97

Another important structural parameter of the knitted fabric is the loop length. This parameter also affects the value of air permeability of knitted fabric [1, 2, 5]. Since in our paper the loop length is calculated theoretically according to (1) as a function f (W, C, d), the dependence of the air permeability of the knitted fabric on the area of its unit cell A_T calculated according to (8) is shown in Figure 6.

Figure 6 and Table 2 show that if the knitted fabric samples are made from the same yarn (material and yarn count), the dependence is strongly linear (e.g. VI_29.5: R=0.996). This must be so, because the area of unit cell A_T in this is exactly the parameter of the knitted fabric that changes. Only in this case it is possible to evaluate that if the area of the pore cell of the knitted fabric increases, its air permeability also increases. Figure 6 also shows that for sets of knitted fabrics made of different yarns, the parameters a and b of the linear dependence in the form $y=a*x+b$ change. Thus, the slope of the line and the displacement of the line on the y-axis are different.

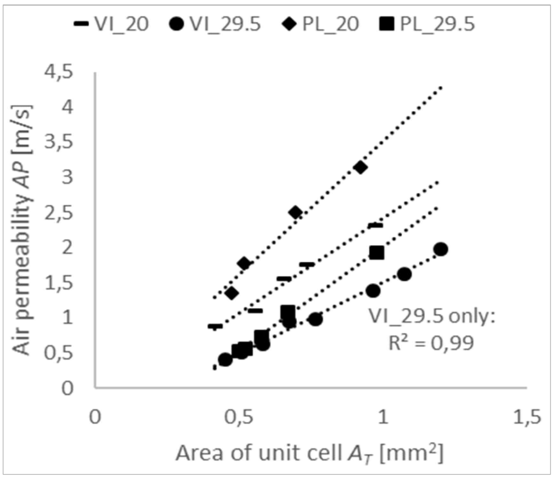


Figure 6 Relationship between area of unit cell and air permeability of knitted fabrics

The planar weight of the knitted fabric is a parameter that is easily measurable and in practice is usually known for a fabric given. Table 2 shows that the relationship between the planar weight and the air permeability of the knitted fabric shows a strong negative linear dependence, even if it is a set of all knitted fabrics – made of different yarns (R=-0.90). This means that as the planar weight of the knitted fabric increases, its air permeability decreases. However, from Figure 7, the data correspond better to nonlinear dependence than the linear one. That is, the air permeability of the knitted fabric decreases nonlinearly depending on its planar weight.

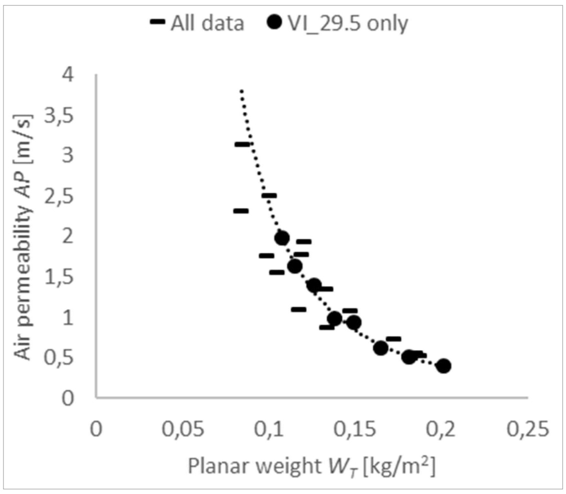


Figure 7 Relationship between planar weight and air permeability of knitted fabrics

In the case of knitted fabrics with a higher planar weight, a relatively large change in planar weight will cause only small change in air permeability. Conversely, in the case of knitted fabrics with a lower planar weight, a relatively small change in the planar weight can cause a large change in the air permeability value – the sensitivity of air permeability to planar weight varies. This means that it is necessary to find another structural parameter that will be significant for the air permeability value of the knitted fabric.

Figure 8 shows relationships between air permeability of the knitted fabric and its porosity values calculated according to 3 different models - (5), (9) and (13): ε_D = f (W_T, t, ρ_F), ε_A = f (C, W, d), ε_V = f (C, W, d, t).

From Table 2 it is evident that all three relationships show a strong positive linear dependence. If the knitted fabric samples are made of the same yarn, the correlation coefficients range in 0.94-0.97. If the knitted fabric samples are made of different yarns, the correlation coefficients range in 0.88-0.94. However, Figure 8 shows that air permeability value responds most sensitively to the porosity based on the proportion of areas ε_A.

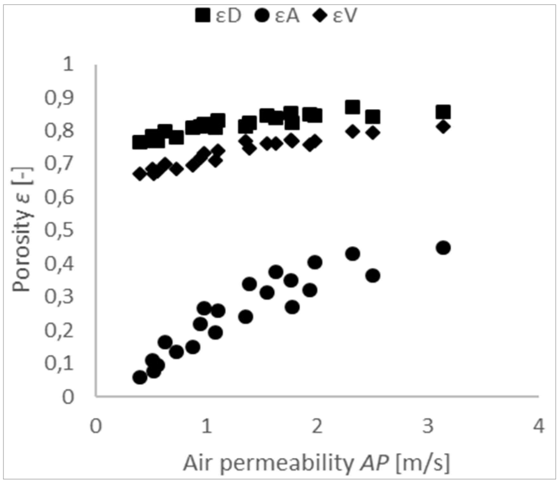


Figure 8 Relationship between air permeability and porosity of knitted fabrics

Figure 9 shows the relationship between porosity ε_A and air permeability of knitted fabrics only. It is evident that this dependence is not completely linear. If the porosity ε_A of the fabric increases, the air permeability value also increases. However, in the case of knitted fabrics with lower porosity, a relatively large change in the porosity value will cause a small change in the air permeability, and conversely, in the case of knitted fabrics with higher porosity, a relatively small change in the porosity will cause a large change in the air permeability value. Therefore, the sensitivity of the air permeability value to the porosity value of the fabric varies.

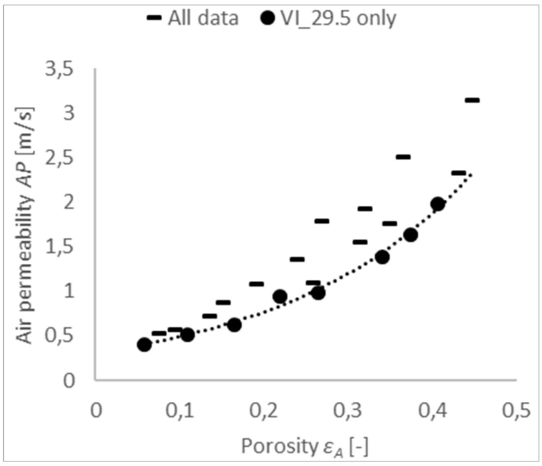


Figure 9 Relationship between porosity ε_A and air permeability of knitted fabrics

Therefore, if the air permeability value increases depending on the porosity ε_A and decreases depending on the planar weight W_T, the air permeability value should depend on the ratio ε_A/W_T. Figure 10 shows a strong positive linear dependence between air permeability values and values of the ratio ε_A/W_T in the case when the knitted fabric samples are made from yarns of the same material.

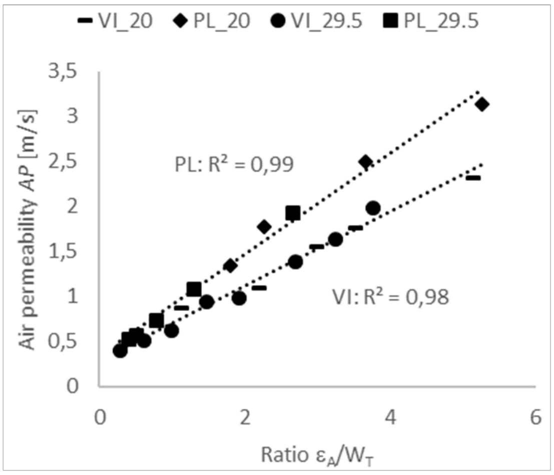


Figure 10 Relationship between ε_A/W_T ratio and air permeability of knitted fabrics

5 CONCLUSSIONS

Four sets of knitted samples were used for the experiment. In one set of samples only one primary structural parameter - density of knitted fabric - was changed, while the other primary structural parameters - material, yarn count, structure - remained unchanged.

The change in the primary structural parameter was reflected in the changes in the secondary structural parameters - thickness, planar weight and porosity of fabrics.

According to experimental results:

- The air permeability of knitted fabric decreases when its thickness increases. In the case of fabrics made of the same yarn, the relationship shows the strong negative linear dependence with the correlation coefficient value R=-0.98. In the case that the fabrics are made of different yarns, the correlation coefficient value decreases (R=-0.81).
- The air permeability of knitted fabric increases when its area of unit cell increases. However, only in the case of fabrics made of the same yarn, the relationship shows strong linear dependence. The slope of the line and the displacement of the line on the y-axis are different for sets of fabrics made of different yarns. Therefore, the values of *a* and *b* parameters of the linear dependence in the form *y=a*x+b* are probably to be dependent on the structural parameters of yarns (material, yarn count, yarn diameter, …). However, a larger set of experimental knitted fabrics will need to be used to investigate such dependencies.
- The air permeability of knitted fabric decreases nonlinearly when its planar weight increases. The relationship shows that the significance of the planar weight of the knitted fabric for its air permeability varies and is relatively higher for knitted fabrics with lower planar weight value.
- The air permeability of knitted fabric increases nonlinearly when its porosity increases. The relationship shows that the significance of the porosity of the knitted fabric for its air permeability varies and is relatively higher for knitted fabrics with higher porosity value. The air permeability value responds most sensitively to the porosity, which is calculated as the proportion of the open area of the knitted fabric.
- Our data also showed that the air permeability value of the knitted fabric increases linearly when the proportion of its porosity and planar weight increases. This applies if the knitted fabrics are made of the same material (polyester or viscose).

The aim of our study was not to find a generally valid model for predicting the air permeability value of a knitted fabric. Due to the narrow spectrum of experimental fabrics used, the results cannot be generalized. However, on the contrary, thanks to the precisely defined structural parameters of the knitted fabric samples used, it was possible to investigate the elementary relationships between these structural parameters and the air permeability value. Consequently, our study can serve as a basis for exploring a wider range of common clothing knits.

***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).*

6 REFERENCES

1. Ogulata R.T., Mavruz S.: Investigation of porosity and air permeability values of plain knitted fabrics, Fibres & Textiles in Eastern Europe 18(5), 2010, pp. 71-75
2. Coruh E.: Optimization of comfort properties of single jersey knitted fabrics, Fibres & Textiles in Eastern Europe 4(112), 2015, pp. 66-72, DOI: 10.5604/12303666.1152728
3. 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
4. Benltoufa S., Fayala F., Cheikhrouhou M., Ben Nasrallah S.: Porosity determination of Jersey structure, Autex Research Journal 7(1), 2007, pp. 63-69, http://www.autexrj.org/No1-2007/0209.pdf
5. 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
6. Maheswaran R., Srinivasan V., Muralikrishnan A.: Prediction and experimental investigation of knitted fabric thickness and its influence on single jersey fabric properties, Fibres & Textiles in Eastern Europe 28(3), 2020, pp. 38-43, DOI: 10.5604/01.3001.0013.901
7. Suh M.W.: A study of the shrinkage of plain knitted cotton fabric, based on the structural changes of the loop geometry due to yarn swelling and deswelling, Textile Research Journal 37(5), 1967, pp. 417-431, https://doi.org/10.1177/004051756703700513
8. Munden D.L.: The geometry and dimensional properties of plain-knit fabrics, Journal of the Textile Institute Transactions 50(7), 1959, pp. 448-471, https://doi.org/10.1080/19447025908659923
9. Peirce F.T.: Geometrical principles applicable to the design of functional fabrics, Textile Research Journal 17(3), 1947, pp.123-147, https://doi.org/10.1177/004051754701700301
10. 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 resistence and thermal resistence, Fibres & Textiles in Eastern Europe 25(5), 2017, pp. 79-86, DOI: 10.5604/01.3001.0010.4632
11. 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
12. 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

13. Pavko-Cuden A., Hladnik A., Sluga F.: Loop length of plain single weft knitted structure with elastane, Journal of Engineered Fibers and Fabrics 8(2), 2013, pp. 110-120
14. 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
15. Dalidovic A.S.: Knitting Theory Basics (Osnovy teorii vjazanija), Light Industry, Moscow 1971, 432 p. (in Russian)
16. Neckář B., Vyšanská M.: Simulation of fibrous structures and yarns. Simulation in textile technology – Theory and applications, Woodhead publishing. 2012, DOI: 10.1533/9780857097088.222
17. 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
18. Dias T., Delkumburewatte G.B.: Changing porosity of knitted structures by changing tightness, Fibers and Polymers 9(1), 2008, pp. 76-79, DOI:10.1007/s12221-008-0012-6

THE RELATION BETWEEN SIGNS OF GARMENTS AND FASHION MARKETING STRATEGY, A LITERATURE REVIEW

Luisa-Fernanda Hernández-Gallego[1] and Manuela Escobar-Sierra[2]

[1]Faculty of Production and Design, Pascual Bravo University Institution, Calle 73#73A-226, Building 13 Office 308
[2]Faculty of Economic and Administrative Sciences, University of Medellin, Carrera 87 N° 30-65 Building 12 Office 101
luisa.hgallego@gmail.com, manuelaescobar@gmail.com

Abstract: *Marketing practitioners misunderstand how consumers purchase and wear clothes. For academics, this lack of knowledge is a consequence of disregarding the symbolic aspect of garments and represents the main reason for the marketing inefficiencies. Those ideas lead us to wonder how signs of garment related to fashion marketing strategy. We follow a sequential mixed-method. First, we develop a bibliometric analysis, then we use those results to our content analysis, and the result is our discussion status. Afterward, we present our theoretical lenses, which we build following a qualitative approach. Also, we propose a conceptual model to fulfill the lack of knowledge about symbolic aspects in garment through a conceptual relation between signs of garment and fashion marketing strategy. Finally, our literature review shows that symbolic aspects help to create value for clients. For this reason, we recommend for future marketing research develop empirical verification of our structural model.*

Keywords: *Sign, garment, strategy, marketing, fashion, literature review.*

1 INTRODUCTION

Marketing discipline helps to overcome context challenges [1], generating well-being and influencing customer behaviour [2, 3]. Mainly, we center our study on the fashion industry. This industry has endured for many years [4], and we notice that marketing in the fashion industry supplies basic needs, such as communication, selling and increasing profit. Also, marketing strengthens the relationships between brands and consumers [5]. Marketing uses tools in fashion such as triune brain [6], marketing mix [7, 8] and corporal language [9]. Those devices increase marketing inefficiencies because there is a lack of knowledge in the depth of fashion consumers' symbolic needs, leading to a lack of well-being in the fashion context [10, 11].

Likewise, we review the usual devices used by marketing practitioners to reduce inefficiencies and increase well-being. One of those devices is the new P in the marketing mix [12]. For example, the practitioners include participation to incorporate the consumer in the brand decisions [13-15]. Apart from marketing mix devices, practitioners invented a rebranding divide to improve efficiency [16, 17]. However, that device results damage brand reputation. Furthermore, due to the practitioner's lack of knowledge about consumer needs[18-20] the marketing devices are useless in fashion. In this sense, one option is to use the constructs or concepts of marketing to perform an accurate segmentation, taking the fashion characterization of consumers as a referent.

Thus, practitioner's unsolved issues affect shareholders margins. For instance, in 2019, shareholders lost 42 million USD in announcements because consumers block publicity. This phenomenon is one of the visible impacts of the failed marketing strategies[21, 22]. Another example is capitalization; the shareholders manifest a loss of 74% of their investments due to the lack of knowledge in consumer needs or preferences [23]. Therefore, marketing experts say that it is necessary to invest in market research to know the consumer and reduce margin lost [24, 25].

Additionally, scholars recommend reviewing subject matters around get to know consumer's needs preferences and motivations. They mention symbols as a dimension of persons that affects the purchase behavior of consumers. Moreover, academics emphasize current topics such as symbolic communication, sign consumption, and value. For example, the researchers mention the study of garments as a representation of brand status to improve brand identity as a cause of symbolic communication [26, 28, 30]. Also, they analyze sign consumption because signs of garments satisfies consumer needs [28, 29, 32-35]. Another scholars proposal is value delivery, and they say that the image, identity, and personality of brands provide value to consumers [28, 34, 35].

We recognize the importance of signs of garments in fashion marketing and the gaps in knowledge in the marketing discipline; therefore, we present our work as follows. Initially, we introduce a general context of fashion marketing. Second, we identify the theoretical gap related to marketing inefficiencies. At this point, we take as a reference the practitioners, shareholders and scholars. After that, we present our search question. The third part is our theoretical framework. We present a description based on the authors' proposal about sign, garment and marketing. Once we presented our theoretical gap. The fourth part is where we describe our methodological design. In our methodological design, we present two stages. In the first one, we construct state of the art through a mixed-method approach. Consequently, in the second stage, we present our theoretical lenses through a qualitative approach. Afterward, in the fifth part, we present our conceptual model that is our result of the relation between signs of garments and fashion marketing strategy. Finally, we discuss our findings with other authors, and we conclude by highlighting our limitations. Additionally, we suggest future research inquiries.

2 THEORETICAL FRAMEWORK

For our theoretical framework, we review the author's proposal about the sign, garment, and marketing. Then we try to connect the terms based on the authors approach.

2.1 Sign

Saussure (1945) [37] introduces the sign term, and he says that a sign is a concept used to communicate attributes. After Saussure came Peirce (1974) [38], and he proposes that a sign refers to an object real or imaginable. Those authors were the pioneers at sign study, later came others, such as Morris (2005) [39]; he says that the sign help to understand the world. Lamillar (2001) [40] revealed that humans use signs to understand words. Moreover, the sign has many interpretations. One of those is Eco (1994) [41] approach, and he believes that signs allow persons to interact with others. And Sandoval & Canales (2015) [42] explains that signs help us to communicate thoughts. In the following, we choose Saussure (1945) [37] and Peirce (1974) [38] definitions because they highlight the elements of the sign e.g., concept, object, interpretant and representamen. For instance, Saussure helps us to understand the sign through attributes. To complement the sign, Peirce shows us the sign structures through triadic relations. The Peirce sign structure includes (1) the object, (2) the representamen and (3) the interpretant. In particular, in Peirce structure (1), the object satisfies human or symbolic needs [43]. And (2) the representamen and (3) the interpretant are materialized in people. The persons representing the sign's elements understand the attributes, and they have a particular behavior [44]. Thus, we return to the proposed constructs of Saussure and Peirce, which are the concept, object, interpretant and representamen.

2.2 Garment

Our second concept is the garment, and we approach this concept symbolically and communicatively, not in the functional aspect. In this sense, the scholars propose to review its meanings. For example, the researchers define garment as an expression of social habits and traditions [45]. At the same time, the garment is part of people's social life and gives them the power to rep resent a social status in a particular context [46]. Moreover, in the economic logic, the garment reflects social values [47] because it is a product and an artifact created by persons to satisfy human and symbolic needs [32].

As an object of design, the garment constitutes by (1) garment universe, (2) consumer profile and (3) fashion context. In our case, we select the casual wear universe because it presents flexible, comfortable and versatile clothes [48]. Consequently, we focus on a neo-traditional consumer profile [44, 49] articulated in the fashion universe and represents sensitive persons. And our fashion context is the Pret a Porter [32, 50], which works as an interactive platform and basic creation system.

2.3 Marketing

Our final concept is marketing that works to establish relationships between brands and consumers [51]. The marketing goal is to influence the purchase and behavior of clients [52, 53]. For example, the marketing creates experiences for consumers generating bonds and returning value to brands [53, 54]. We find in the literature that the marketing process accomplishes its goal through marketing mix to establish relationships among brands and consumers [44, 45, 55].

Consequently, marketing support itself in areas such as (1) marketing mix, (2) consumer and (3) fashion context, to establish relationships between garment brands and consumers, generating value for the stakeholders. In our research we focus on (1) the marketing mix, which aims to integrate the product, place, promotion, and price, executing the strategies and catching the value of consumers [56]. Those actors are essential because they purchase and wear clothes, and marketing mix strategies influence their experiences [44]. Thus, we center our research on the fashion context, specifically in the Pret a Porter context. We identify that the fashion business needs an articulation with marketing to offer products, establish relationships and create value for fashion consumers [55].

In our representation, we wanted to show the concepts and their common elements. One of those elements is persons that we present as a representamen and interpretant in the sign, as users in the garment, and consumers in marketing [38, 44, 49, 51]. Also, the object is in the sign as the object itself, in the garment is the clothes, and in the marketing appears as a product [38, 43, 51].

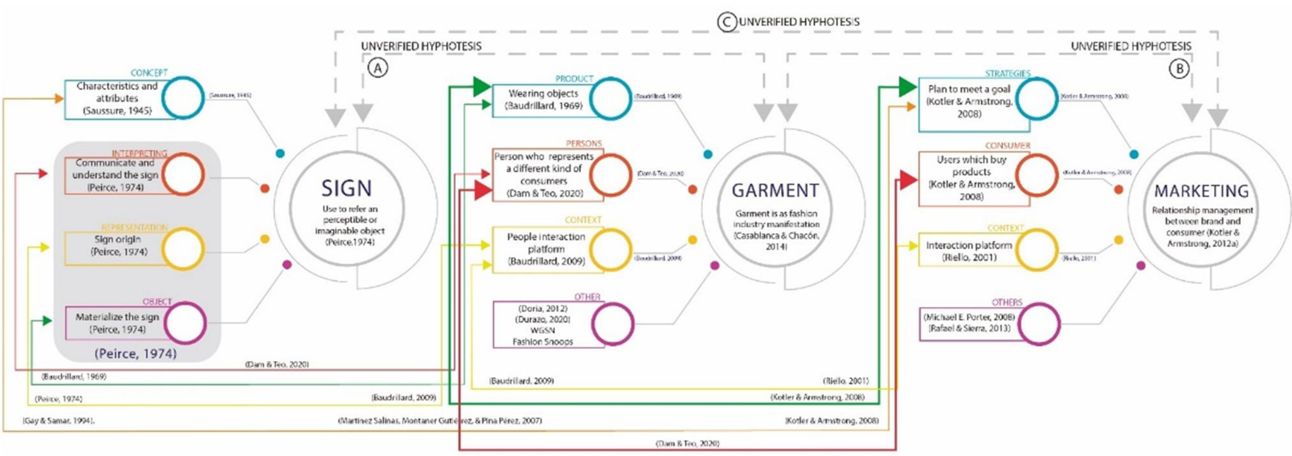


Figure 1 Primary connection between sign, garment and marketing (source: Hernández-Gallego & Escobar-Sierra)

The other element is the context, that in marketing is P of place, in the garment is the Pret a Porter, and the representamen in the sign [32, 38, 45]. Thus, besides our empirical connection of terms, we need to establish deep connections to develop our structural model.

3 METHODOLOGY

The methodology followed a sequential mixed-method approach [57] for the art status that began with a bibliometric analysis to know the number of publications about signs of garment in marketing strategy. The search criteria we use citation pearl growing and in the resulting data used VosViewer® software to map the connections between terms. This software shows us the occurrence and concurrence of terms in the selected database. Those results feed our content analysis, which is our qualitative approach. Then we follow a checklist to review the main theories of our theme. And all the results of our analysis feed in our structural model where we try to relate signs of garment and fashion marketing strategy.

3.1 State of the art methodology

For this phase, we follow a mixed-method approach [57]. Thus, we start with the bibliometric analysis where we use citation pearl growing, and we search in the Scopus database. Then we use the VosViewer® software to identify the occurrence and concurrence of terms.

Later we use the Prisma technique to filter the documents [58], and we use Atlas.Ti® software to evaluate the main texts and develop a hermeneutic coding.

Our methodology design tries to cover all the points of view in a mixed method. For our research, we use the Scopus database, VOSViewer® and Atlas.Ti® software to structure our data.

3.2 Election of theoretical lenses methodology

The theoretical lens methodology constitutes the second phase of our methodology, and we apply a qualitative approach. Then, we conduct a content analysis based on a checklist of the main theories of our theme [59]. For the theoretical lenses, we choose the theories related to the sign, garment, and marketing concepts giving us the scope of our structural model.

Table 1 Methodology design for the election of theoretical lenses (source: Hernández-Gallego & Escobar-Sierra)

Criteria	Qualitative approach
Role of the theory	Inductive
Research strategy	Causal-comparative [60]
Sample	Psychological and behavioral theories Management theories Humanities theories
Unit of analysis	Theories
Variables	Scope and implications over the sign, garment and marketing relation
Data analysis	Content analysis

Table 2 Methodology design for the construction of state of the art (source: Hernández-Gallego & Escobar-Sierra)

Criteria	Quantitative approach	Qualitative approach
Role of the theory	Deductive	Inductive
Research strategy	Simulation	Discourse analysis
Unit of analysis	Word cooccurrence	Content of concepts
Sample	3.281 records of Scopus	
Variables	Occurrence, concurrence and the relation between words	Concepts and relations
Data analysis	Bibliometric analysis using VOSViewer® software (version 1.6.11)	Content analysis using Atlas.Ti® software (version 7.5.4)

4 RESULTS

Our results present the discussion of the state of the art, the content analysis, the theoretical lenses election, and our structural model.

4.1 Results of the state of the art

Our results of state of art are divide into two. First, we develop the quantitative approach to feed the qualitative approach. We use bibliometric analysis to measure the number of publications [61], and we construct a search equation [62]. Then we run our search equation in the Scopus database. We process data in the VosViewer® software to extract the occurrence level among concepts with the information that we collect from Scopus. Then we use these results to develop our content analysis, where we use the Prisma tool to gather the documents we will use in our content analysis [58]. Once we obtain the documents, we process them in Atlas.Ti® software where we apply a hermeneutic coding to identify the academic proposal about our concepts.

Finally, we present our primary structural model where we relate our concepts.

4.1.1 Bibliometric analysis results

Consequently, we construct our search equation. This equation includes terms such as a sign, market, and business, key word use by the academic community.

$$\begin{gathered}(\text{"sign" or" mark" or "symbo} * \text{" or "signa} * \text{"})\\ \text{and ("marke} * \text{" or "merchand} * \text{" or "busine} * \text{")}\\ \text{and ("cloth" or "garme" or "costum} * \text{" or " fashio}\\ * \text{" or "dres} * \text{")}\end{gathered} \tag{1}$$

In addition, we run the search equation and find 3281 literature records. We process those records on VosViewer® software and obtain the general knowledge map. This map shows the terms concerning signs of garment in fashion marketing strategy. Also, this map presents to us a cluster related to the medical field, so we dismissed that cluster. And we focus on the cluster that relates terms of our concern.

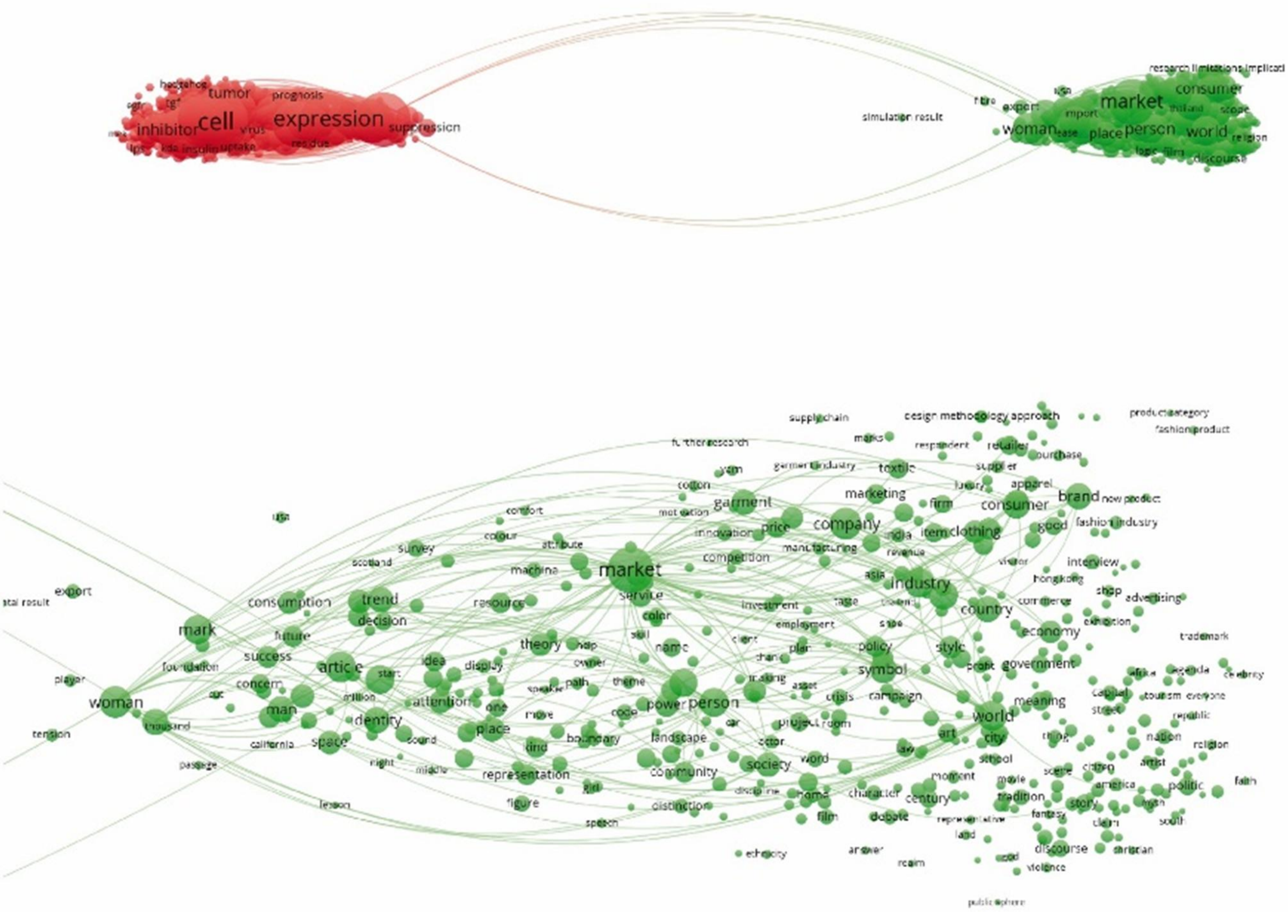


Figure 2 Knowledge map for signs, garments, and marketing (source: Hernández-Gallego & Escobar-Sierra)

As we said, our general map register two clusters, we dismissed the first one. On the contrary, the second cluster presents terms such as symbol, market, and industry. Once we review those VosViewer® results, we group the terms, and we define five sub-groups that we named sign, marketing, garment, context and persons. To illustrate we present Table .

Table 3 Group of terms identify on the second cluster (source: Hernández-Gallego & Escobar-Sierra)

Concept	Occurrence
MARKETING (name as 01 in Figure 3)	
Market	465
Industry	196
Consumer	162
Brand	151
PERSONS (name as 04 in Figure 3)	
Woman	215
Person	190
Man	152
SIGN (name as 02 in Figure 3)	
Image	183
Symbol	158
Identity	155
History	153
CONTEXT (name as 05 in Figure 3)	
World	198
Country	152
GARMENT (name as 03 in Figure 3)	
Trend	146
Garment	143

Consequently, we analyze the information about the clusters and our sub-groups. First, we have marketing, a commercial sector to satisfy consumer needs through enterprises [63, 64], and has its own terms such as Industry, consumer and brand. The second sub-group is the sign, and we understood it as a representation that uses symbols to communicate ideas with terms such as symbol, identity, and history [65-67]. The third sub-group is the garment to exchange values to satisfy the representation needs of persons, and its related terms are the trend, garment, or clothing [55, 68]. The fourth sub-group is persons, and we can associate them as users or consumers, and its terms are woman and man [44, 69]. Finally, our last sub-group is context, and we identified that it is an interactive platform delimited by human construction [45, 55, 70], with terms as world and country. To illustrate our interpretation, we present our preliminary relation between the sub-groups.

According to our bibliometric findings, our preliminary version of our conceptual model presents the context as a frame to the other terms that enable them to interact [32]. Then we find the persons who are a common term among the concepts and helps them to function [8, 38, 44]. Consequently, we present the marketing, the sign, and the garment in the center to represent our main concern.

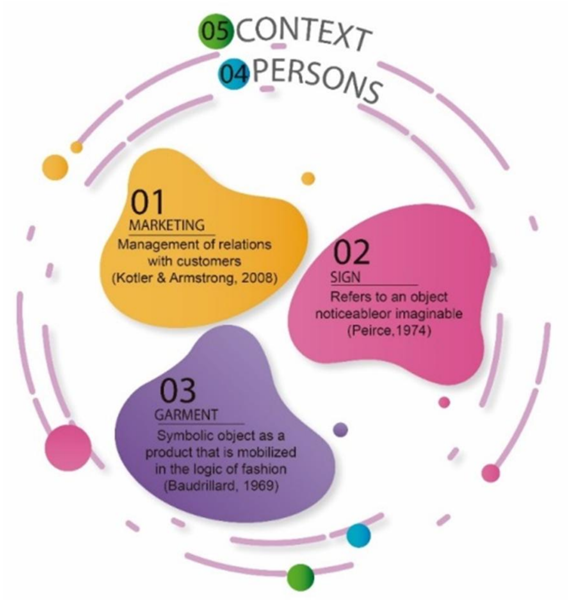


Figure 3 Preliminary version of our conceptual model according to our bibliometric findings (source: Hernández-Gallego & Escobar-Sierra)

4.1.2 *Content analysis results*

Our content analysis has a preparation phase, where we use the Prisma tool to filter documents [58]. This technique helps us to remove the duplicated records. Then we use the snowball technique to feed our main records acquire 87 documents. Moreover, we process the documents in Atlas. Ti® software, where we codify the text using our sub-groups as codes, such as marketing, persons, sign, garment, and context. Then we calculate the C-Coefficient to identify the strength of their correlations [71]. At this point, we clarify that the cero is associated with a null correlation, and the one represents a perfect correlation, as we show in Table .

Hence, we found that C-Coefficient has its own measure scale for correlations. For example, the correlations measure between 0.0 and +0.10 are weak correlations. The +0.10 and +0.25 are positive correlations, and the number near one represents a perfect correlation. Knowing these metrics, we can understand that (1) Consumption-Marketing, (2) Icon-Marketing, (3) Icon-Symbol, (4) Marketing-Product, (5) Fashion-Marketing, and (6) Fashion-Product, has a perfect correlation. On the other hand, we discover that Atlas.TI® software shows a yellow point in the C-Coefficient when the relationship cannot be measure and exceeds the software standard.

Table 4 C-coefficient of hermeneutic coding of central literature about signs, garments and marketing (source: Hernández-Gallego & Escobar-Sierra)

	CONSUM	ICON	IDENTI	MERCA	MOD	PRODUCT	SIGN	SIMBO	VEST
CONSUM		10 - 0,01	n/a	12 - 0,01	42 - 0,02	n/a	10 - 0,01	n/a	n/a
ICON	10 - 0,01		3 - 0,00	13 - 0,01	1 - 0,00	n/a	196 - 0,49	2 - 0,01	34 - 0,02
IDENTI	n/a	3 - 0,00		1 - 0,00	1 - 0,00	1 - 0,00	4 - 0,00	n/a	5 - 0,00
MERCA	12 - 0,01	13 - 0,01	1 - 0,00		38 - 0,02	147 - 0,10	14 - 0,01	1 - 0,00	3 - 0,00
MOD	42 - 0,02	1 - 0,00	1 - 0,00	38 - 0,02		56 - 0,03	2 - 0,00	n/a	11 - 0,00
PRODUCT	n/a	n/a	1 - 0,00	147 - 0,10	56 - 0,03		5 - 0,01	n/a	1 - 0,00
SIGN	10 - 0,01	196 - 0,49	4 - 0,00	14 - 0,01	2 - 0,00	5 - 0,01		1 - 0,00	5 - 0,00
SIMBO	n/a	2 - 0,01	n/a	1 - 0,00	n/a	n/a	1 - 0,00		n/a
VEST	n/a	34 - 0,02	5 - 0,00	3 - 0,00	11 - 0,00	1 - 0,00	5 - 0,00	n/a	

Sign

According to the authors, we know that signs have the power to design effects on people. For example, we can use signs to establish status relations between persons [72-74]. In this sense, scholars say that people establish social relations to communicate ideas or create groups [75]. Those relations lead us to understand the sign as a way to exchange ideas and consolidate social identities [76]. The authors determine that every communicative or social process where people exchange ideas needs icons [77, 78]. Indeed, we can reaffirm that process because we need icons and symbols to relate with others, and this makes us create images as a representation of ourselves [79].

Garment

The garment experts center their attention on customers because they play a role in a specific context [80]. The garment provides the customer process of adaptation because it helps to communicate ideas, signs, and intentions [81]. In other words, social interaction conditions customer's purchases, driving them to wear clothes depending on their role and context [82]. On the other hand, the customers' needs become an opportunity for the fashion industry because it transforms social interaction and consumers' role in archetypes to represent their style ideas [83, 84]. In this process, the fashion industry controls the purchase process regulating consumer practices using fast changes resulting in new symbolic content [85, 86].

Marketing

The scholars highlight the significant investments in strategies and tactics that do not produce radical impacts in the marketing field [87]. In this context, the academics say that the most implemented strategies are the P of price and product with their respective tactics to get close to new customers [84]. In other words, scholars suggest involving customers in industry decisions. And, one of the options that we found is to improve communication tactics in the P of promotion. This helps to persuade making decisions of the client [84, 88].

Persons

Scholars define the persons who develop different roles. For example, in the fashion industry, personas are sensitive users because they exchange ideas through garments [89]. In other words, persons wear clothes to reflect a cultural archetype. Similarly, we found that the person is the center of all economic activity in the marketing discipline. At this point, marketing and fashion came together through persons. For this reason, scholars suggest understanding consumers as a content generator because they have the power to communicate memorable experiences of the fashion brands [74, 90, 91].

Context

According to scholars, there are different conceptions about context. The first perception is the context as an artificial space where we can condition the purchase of products [92-94]. In the same way, that artificial space may stimulate economic practices, and we can provide this practice as an experience. Alternatively, other scholars say that the context is a symbolic space where persons interact with each other. In this sense, the context simulates symbolic benefits such as status or material benefits as a priority. For example, the persons in the symbolic context can relate with other persons and interact with different stimuli [94]. Thus, we use the scholars' proposal to feed our first preliminary version of the conceptual model and present the secondary version that will lead us to accomplish our structural model.

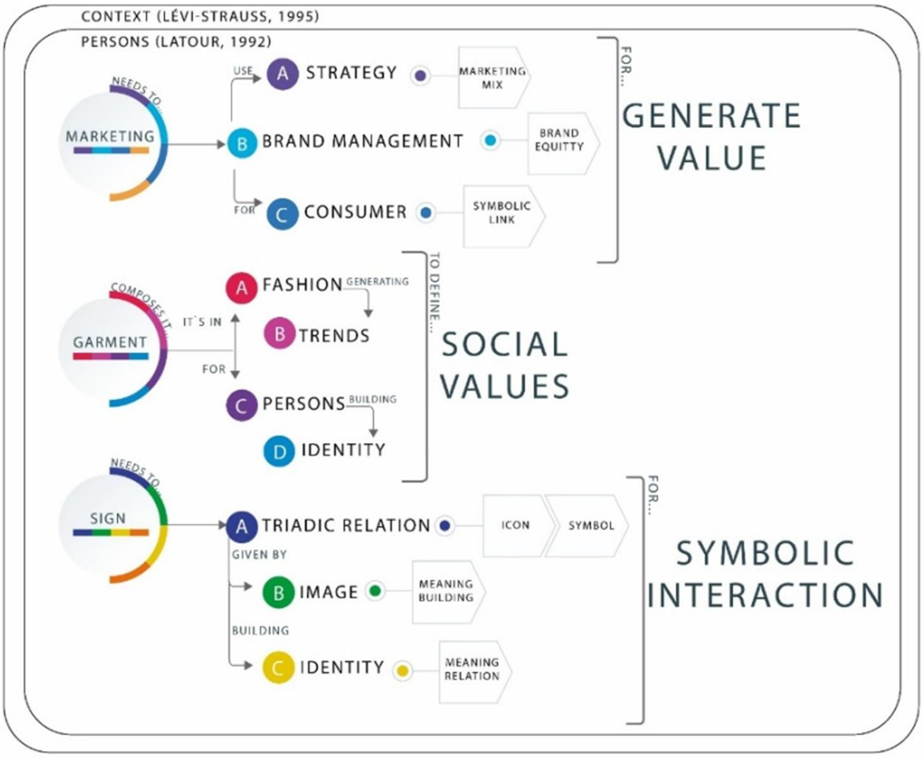


Figure 4 Secondary version of our conceptual model according to our content analysis findings (source: Hernández-Gallego & Escobar-Sierra)

The secondary version of our conceptual model is the result of our bibliometric and content analysis. We feed this model with the academics proposal, and we see that context and persons remain as frames to marketing, garment and sign.

Our first construct is marketing, make use of brand management through brand equity [1, 95, 96] and strategies to generate a symbolic link with consumers [97]. That process generates value [8].

Our second construct is the garment and is a manifestation of symbolic production that uses fashion as a dynamic device [98]. Consequently, fashion generates trends, and that product and values flow dynamize social standards [99, 100]. Moreover, the garment process is for users [44, 83] because they can build identity through the garment. That process results in social values.

Finally, the sign as an idea presented by a visible or imaginable object is composed of a triadic relation proposed by Peirce [38], the image and identity. The sign needs the triadic relation given by the image to build identity, and that process generate symbolic interaction [101]. To summarise, we will feed our secondary version of our conceptual model using the theoretical lenses results.

4.2 Theoretical lenses results

According to our methodology, we conduct a content analysis to choose our theoretical lenses. We review the scope and implication of the humanities, psychology, behavior and management theories to apply them in our research scope. First, we present our checklist, and then we choose the theories for our research.

Table 5 theoretical lenses checklist (source: Hernández-Gallego & Escobar-Sierra)

Theory	Premise
Knowledge management	The knowledge as a competitive advantage [102]
Psychosocial theory	Persons as active beings search to adapt to an environment. More than passive persons, they are slaves of impulses [103]
Psychoanalysis	Psychoanalysis tries to explain the capabilities in the function of the psyche [104]
Autoplastic adaptation	The autoplastic adaptation refers to a subject trying to change the situation, which means the external context [105]
Critical studies of social institutions	The critical studies of social institutions study the power, and the relevance to analyzed it as something that works in a chain [106]
Science and action	Science and action center their attention on how human being design their actions in tough situations [107]
Psychological climate of freedom	It studies the relation between client and therapist as a fundamental element [52]

Theory	Premise
Structuring theory	Structuring theory studies social systems creation and reproduction based on the analysis of the structure and the involved agents [108]
Experimental and cognitive psychology	It analyzes how the minds process knowledge [109]
The social construction of reality	The social construction of reality determines society as a human construction [110]
Political doctrine	Political doctrine study the concept of the state reason [111]
Sociological method	The sociological method explains that the social facts exist before the human and for that are external to him [112]
Critical theory	The critical theory center their attention on illustration dialectic, negative dialectic, and indissolubility of something [113]
Cognitive psychology	Cognitive psychology refers that the mind could be damage in the autistic kid in an independent way of the other aspects of the intelligence [114]
Network actor theory	Network actor theory defines a net as an only entity [115]
Theory of human development	The goal of human beings is to have a biological and psychological balance, freeing tensions [116]
General schema theory	The scheme term is used to call cognitive patterns of information, including different relations between knowledge elements [117]
Critical theory	A variable of critical theory is based on the public space notion [118]
Psychoanalytic theory and practice	Psychoanalytic theory study the superation of maternity fixation [119]
Theory of social action	It refers to an adequate description of the motivation and the causes of social action (attitude concept) [120]
Project zero	Project zero try to understanding and improving the cognitive process of thinking in a superior order [121]
Personal development	It studies the enhancements of the personality which refer to the superation of the early stages of childhood [122]
Theory of principles and parameters	Propose generative grammar to put the syntaxis in the middle of linguistics research [123] [124]
Critical theory	The goal of critical theory is to give a main role to the human activity [125]
Constructivist learning theory	It studies the thinking as a genetic base through sociocultural stimuli because think is configured for the information that a person receives [126]
Brain damage in cognitive skills	Brain damage in cognitive skills tries to define that psychological trauma is a protective mechanism and is not an organic defect [127]
Language and thought	It refers to the identity between the significance of language and the thoughts, understanding the thoughts [128]
Institutional economics	The institutional economics promoted the reform of labor legislation, especially about health and safety conditions in the workplace [129]
Neurosis	The identity of neurotic people is divided between the real self and the ideal self [130]
Radical empirical phenomenology	The ethnomethodology is based on the assumption that all human beings have a practical sense which practical rationality that they use in everyday life [131]
Psychosynthesis	It means the process of growth and integration of elements that previously separated in the human being. Leading to the harmonization of an integrated personality that is called conscious self [132]
Logotherapy	Logotherapy focus on the somatic or physical, the mental, and the spiritual dimensions [133]
Linking model	The linking model study the organizational environment [134]
Synapse	It refers to the synaptic hypothesis to describe the interactions between reflexes [135]
Morphology	The morphology study the dendritic spines on neurons [136]
Theory X, Theory Y	Theory X: says that the worker is pessimistic, static, rigid, and with an innate aversion to work, avoiding it if possible. Theory Y: propose that people like to take risks and the answers are not always the same in similar circumstances. [137]
Critical theory	it works on reflection, from reflexivity, and self-reflexivity [138]
Unified positivism	It describes human interaction as a contact phenomenon [139]
Dialectics	It proposes to neutralize the problems of Kantian ethics, but without abandoning the moral normativism of universalist pretension [140]
Episodic memory	The episodic memory determines that the memory is constructed [141]
Conditional response	The conditional response study the brain links and the response to an stimuli [142]
Limited rationality	People try to seek minimal satisfaction. That is, they try to achieve certain levels of success [143]
theory of recognition	It studies how articulate the descriptive dimension of a theory of recognition with the prescriptive description of a moral theory [144]
Needs (domination)	The needs theory focus on the fictitious needs, and the real ones [145]
Interpersonal relations theory	Man is a psychosomatic-social unit that rejects any psychological position that pretends to analyze him in fragments [146]
Theory of communicative action	It is based on the idea of a complete transformation of the critique of knowledge into a critique of society [147]
Criticism of Cartesian dualism	It offers the analogy of philosophy as if it were cartography [148]
General system theory	In classical economics, society was considered a sum of subjects as social atoms [149]
Dynamic capabilities	The introduction of dynamism achieve an adaptive coherence with the changing environment [150]
Myth and ceremony in the structure of organizations	In modern societies, the myths generate a formal organization given by the identity and legitimacy of work [151]
Chaos theory	Chaos is the science of the organization until an even more powerful lens appears over reality to overcome it [152].

Theory	Premise
Public administration	Practice and public administration ideas are shaped by political, economic, social, and cultural institutions and values [153]
Human behavior	Human behavior studies the effectiveness, human, and organizational development for continuity and survival [154]
Contingency theory	It is based on the belief that there is no single way to design and manage an organization [155]
Human relations	It is a realistic interpretation of democracy and management effort over the authority of the worker[156]
Theory of resources and capabilities	This theory considers the internal analysis of the organization [157]
Behavior theory	Studies the incidence of thoughts, feelings, and behaviors of people also contribute to the development of Gestalt psychology [158]
The human condition	The human condition is characterized by identifying the values of the market because man has transformed himself into a consumer good [159]
Selective atention theory	It is about the ability of an organism to focus its mind on a particular stimulus or task, despite the presence of other environmental stimuli [160]
Competitiveness	It studies the competitiveness from the point of view of the value chain, the five forces model, and competitive advantage [161][162]
Science of semiotics	It refers to a sign that materialized through an object communicates [38]
The fashion system	The fashion system refers to the structures of the garment from a symbolic aspect [163]
Representation	The representation study the mental model and the reality trough the acting, iconic, and symbolic modes [164]
Symbolic interactionism	The individual understands what kind of behavior is expected, and appropriate in different social situations [165]
Symbolic interactionism	Symbolic interactionism is within the interpretative paradigm. It analyzes the meaning of social action from the perspective of the participants [166]
Institutionalist theory	This theory focuses on the structure that gives a different status to each member of the society [167]
Theory of social practice	The theory of social practice refers to the activity as a constituent aspect of the social world [101]
Network actor theory	The Latour perspective center the attention on the actor as a person or object involved in a process [168]
Structural anthropology	The structural anthropology study the rules and structure of social communication as an unconscious process and drives oppositely to the sociological explanation [169]

The checklist allows us to understand that every construct has its own theory. For example, Lewin's theory [158] understands people's cognition in the marketing frame. Bruner's proposal [164] explains the sign as a symbolic system and Bourdieu's approach [170] analyzes the garment as social life object. Consequently, we found that Institutional Theory cohesions our constructs. We analyze this theory under Veblen`s view [167] because he proposes a social validation and exchange intention by persons. The institutional theory allows us to connect the marketing, the sign, and the garment, in a specific context with specific consumers. To feed Institutionalist theory, we choose Peirce's semiotic science to refer to the sign structure. Also, the symbolic interactionism of Simmel & Wolff 's to us refers to the immaterial power of garments. Finally, the selective attention of Broadbent to focus on consumer stimuli. We present this connection in Figure.

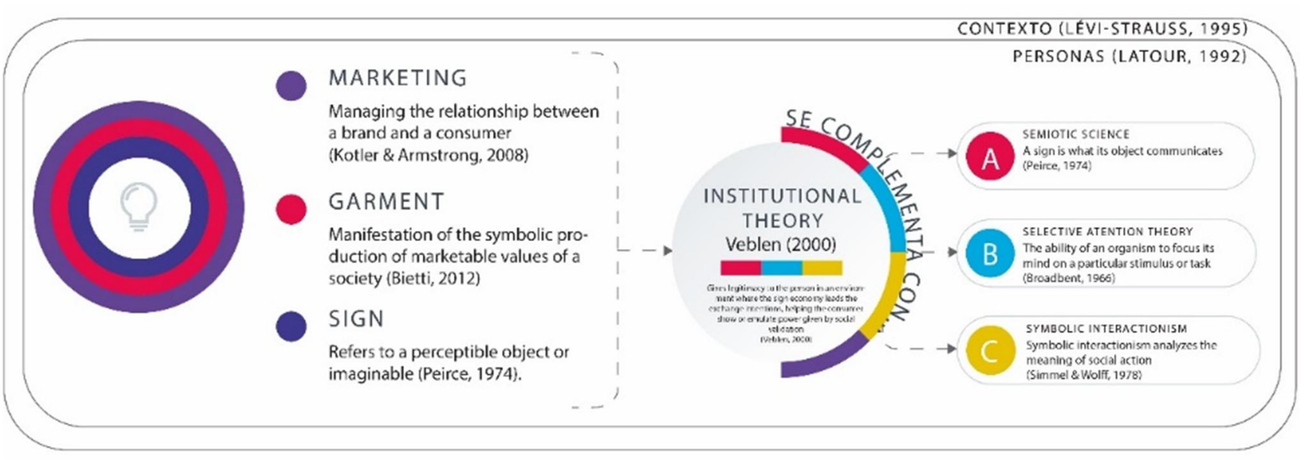


Figure 5 Theoretical lenses results (source: Hernández-Gallego & Escobar-Sierra)

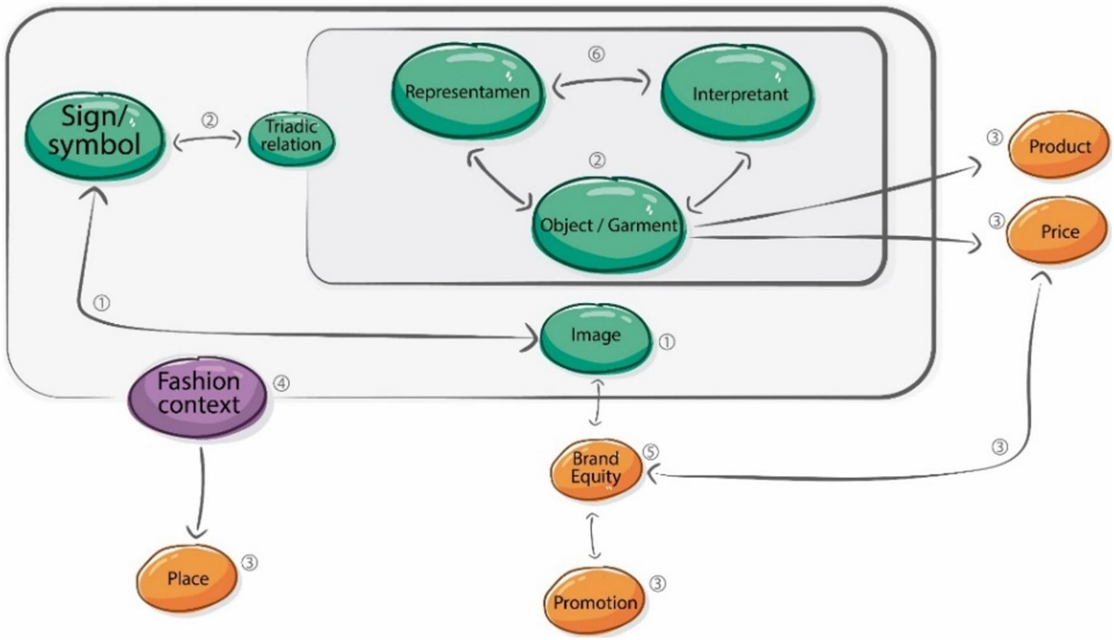


Figure 6 Conceptual model for the relation between signs of garments and fashion marketing strategy (source: Hernández-Gallego & Escobar-Sierra)

4.3 Structural model for the relation between signs of garments and fashion marketing strategy

Our main result is our structural model to establish the relationships between signs of garment and fashion marketing strategy [171]. We named the Conceptual model for the relation between signs of garments and fashion marketing strategy. In the future, we pretend to transform our structural model into a measurement model [172]. It is important to understand that the concepts presented in circles refer to latent variables. In addition, we put numbers to identify the conceptual background of our model (Figure 6).

The number one refers to our latent variable of the sign, and we supported on the Saussure's proposal [37] where the sign is a concept that communicates ideas through attributes. The number 2 refers to the triadic relation of the sign, and we sustain in Peirce's science semiotic [38]. The representamen and the interpretant refer to persons and context, and the object represents the garment. For number 3, we present the marketing concepts, which Kotler & Amstrong's validate [8]. Those latent variables connect with the garment as a product offered. And, they relate to the sign as attributes directed to consumers. The number 4 is our fashion context it means our interactive platform where the marketing provides their products and persons transform those objects in symbolic meaning [32, 100]. With number 5, we show brand equity to reveal symbols and brand archetypes that belong to marketing and provide images in the sign variable [95, 96]. Finally, in number 6, we want to highlight the power of the representamen and the interpretant as persons in the sign structure [44]. Those constructs enable the communicational process. As a closure, we want to emphasize that our structural model is the main result of our methodological process presented before and, we discover that marketing lays the foundation to generate interaction between persons, garments, signs, and context with our research. Moreover, in our structural model, we can see that marketing, sign and garment relate in symbolic and material dimensions.

5 DISCUSSION WITH OTHER AUTHORS

In our discussion with other authors, we analyze their proposals to contrast with our results about reducing marketing inefficiencies and generating well-being among consumers. In this sense, when authors refer that garment represents status for persons is correct [26-32]. In other words, the garment solves the representation needs in persons through brand identity [33-35]. However, we do not see how brands accomplish representation needs in persons in the scholars' proposal. On the contrary, the structural model presents the links, and we can infer the vias to solve symbolic needs and reduce marketing inefficiencies. Another aspect addressed by academics is luxury, and they found that consumers validate this concept. However, academics avoid the study of signs because there may not be a relationship at first sight. In the luxury example, we think it is vital to understand the signs because they affect different dimensions of the consumer. The signs can materialize in objects, but the object itself is not a sign [33-35]. One of the consequences of the consumer's validation is giving symbolic value to brands. Consequently, the academics explain the value, and they approach it through strategies. They mention that some strategies, such as brand equity, image, and personality, can create and return value [28]. This approach to value needs to get in deep because the brand identity and image by themselves will not generate or return value. In other words, the value is a symbolic aspect of client relationships with brands, and we believe that it is important to improve the relationship through symbolic messages. In this sense, it is necessary to identify which strategies are the most shocking and give visual and symbolic content to consumers to receive and return value [28, 34, 35].

6 CONCLUSIONS, RECOMMENDATIONS AND LIMITATIONS

We accomplish to relate signs of garments to the fashion marketing strategy when we detected the common constructs such as brand equity, marketing mix and the sign structure. Our results help us say that if we want to create value for clients, we need to include signs in our proposal to generate brand loyalty. The symbolic gap that we found may help the transdisciplinary exercise between designers and marketing practitioners to approach the context and business needs through the symbolic aspects. For example, designers could improve the project method using signs, and marketers accomplishing their goal using symbolic communication to clients. Therefore, applying the signs correctly creates bonds between consumers and brands. In this sense, we recognize that persons live in the signs dynamic. For that reason, if we apply symbolic aspects to brands, we should reduce marketing inefficiencies. Alternatively, we found the current need to improve tools, theoretical knowledge, and strategies to apply the constructs of marketing, fashion and signs.

On the other hand, we identify that practitioners and theoreticians face trouble when choosing any strategy. In this sense, they are not clear about which marketing strategy use to create value. To reduce inefficiencies and choose strategies in fashion, we present signs as a solution in the fashion industry because they help us know the client's motivation to buy and wear garments. Therefore, to know the importance of signs, we develop a structural model based on a literature review, and we accomplish to relate signs with fashion marketing strategy. Consequently, our structural model shows different dimensions to establish relationships between sensitive fashion customers with brands through signs.

In addition, we affirm that our methodological process allows us to put philosophical constructs into practice in a systematic way. In this sense, we bring conceptual bases where we accomplish to connect opposite constructs. However, we suggest for future research evolve the structural model to a measurement model to settle the concepts. Moreover, we recommend an empirical verification of our model in the fashion context. We recognize that our work has an analytical scope and gives advance in the construction of knowledge. Finally, we think it is important an empirical verification in each research to generalize the theory.

7 REFERENCES

1. Domínguez P.R.: Introduction to Business Management (Introducción a la Gestión Empresarial), 2011 (in Spanish)
2. Smith A: The Wealth of Nations, La riqueza de las naciones. Reino Unido, 2016, (in Spanish)
3. Aya Pastrana N., Somerville C., Suggs L.S.: The gender responsiveness of social marketing interventions focused on neglected tropical diseases, Glob. Health Action 13(1), 2020, doi: 10.1080/16549716.2019.1711335
4. Lorenzo A.D.: Fashion notes from prehistory to modern times (Apuntes de moda desde la Prehistoria hasta época moderna), Indumenta: Revista del Museo del Traje, 2007, pp. 77-86 (in Spanish)
5. Neme Chaves S.R., Rodríguez-González L.: Symbolic Consumption: A Sociocultural Perspective in Understanding Consumer Behavior (Consumo simbólico: una perspeCtiva sociocultural en la Comprensión del Comportamiento del Consumidor), Rev. iberoamericna piscología Cienc. y Tecnol. 6(2), 2013, pp. 27-33 (in Spanish)
6. Hunt S.D.: Marketing Theory, no. c. M.E. Sharpe, 2010
7. Cárcel F., Roldán C.: Basic principles of Knowledge Management and its application to the industrial company in its tactical activities of maintenance and operational exploitation: A qualitative study (Principios básicos de la Gestión del Conocimiento y su aplicación a la empresa industrial en sus actividades tácticas de mantenimiento y explotación operativa : Un estudio cualitativo), Intang. Cap. 9(1), 2013, pp. 91-125, doi: 10.3926/ic.341 (in Spanish)
8. Kotler P., Amstrong G.: Fundamentals of Marketing (Fundamentos de Marketing) 2008.(in Spanish)
9. Ekman P.: Telling lies: Clues to deceit in the marketplace, 1992
10. Chawla Y., Kowalska-Pyzalska A., Silveira P.D.: Marketing and communications channels for diffusion of electricity smart meters in Portugal, Telemat. Informatics 50(March), 2020, p. 101385, doi: 10.1016/j.tele.2020.101385
11. del Olmo Arriaga J.L., Paricio Esteban M.P., Sánchez Valle M.: Marketing and communication of fashion, luxury and lifestyle (Marketing y Comunicación de moda, lujo y lifestyle), 2018, pp. 301-303, (in Spanish)
12. Conexión esan: The 8 Ps of the marketing mix of intangible products (Las 8 P del marketing mix de productos intangibles), Marketing, 2020, https://www.esan.edu.pe/apuntes-empresariales/2020/01/las-8-p-del-marketing-mix-de-productos-intangibles/ (in Spanish)
13. Criteo: Marketing in the fashion sector: How to master the 3 most important trends of 2019 (Marketing en el sector moda: Cómo dominar las 3 tendencias más importantes del 2019), Marketing, 2019. https://www.criteo.com/es/insights/top-ropa-estrategias-marketing/ (in Spanish)

14. Sistemex: 5 solutions for companies with marketing problems, (5 soluciones para empresas con problemas de mercadotecnia), marketing Digital, 2020 https://sistemex.com/blog/marketing-digital/5-soluciones-para-empresas-con-problemas-de-mercadotecnia/ (in Spanish)
15. Ruiz I.: 10 Common Marketing challenges or problems for companies, (10 Retos o problemas habituales de Marketing para las empresas), Mailrelay By CPC, 2018, https://blog.mailrelay.com/es/2018/10/23/problemas-habituales-de-marketing# (in Spanish)
16. Paul R.: Symbolic interactionism (El Interaccionismo Simbólico), no. 1902, 1979, p. 10, http://cmap.javeriana.edu.co/servlet/SBReadResourceServlet?rid=1K6XH9QJQ-1HB851T-2M6 (in Spanish)
17. Durán A:R.: Aspects that you must understand in any branding and rebranding process (Aspectos que debes comprender en todo proceso de branding y rebranding), Mercadotecnia, 2020, https://www.merca20.com/aspetos-que-debes-comprender-en-todo-proceso-de-branding-y-rebranding/ (in Spanish)
18. Asesores de Pymes: Why does a global marketing strategy fail? (¿Por qué falla una estrategia de marketing global?), Internacionalización, 2015, https://asesoresdepymes.com/por-que-falla-una-estrategia-de-marketing-global/ (in Spanish)
19. La República: Semiology or semiotics in marketing (Semiología o semiótica en el mercadeo), Opinión, 2015, https://www.larepublica.co/opinion/analistas/semiologia-o-semiotica-en-el-mercadeo-2253821 (in Spanish)
20. Burgoa L.G.A.: Hidden marketing problems (small but big impact changes) (Problemas de marketing ocultos (cambios pequeños pero de gran impacto)), Perspectivas 27, 2011, pp. 91-111, (in Spanish)
21. Montes A.: Online marketing grows and the challenges to maintain it too (El mercadeo en línea crece y los retos para mantenerlo también), Semana, 2019, https://www.semana.com/tecnologia/articulo/retos-del-marketing-digital-en-colombia/603314 (in Spanish)
22. Kourtellis N.: The advertising ecosystem: what is the cost of user online privacy? (El ecosistema de la publicidad: ¿cuál es el coste de la privacidad en línea del usuario?), Blogthinkbig.com, 2018, https://blogthinkbig.com/ecosistema-publicidad-coste-privacidad (in Spanish)
23. Olson M., van Brever D., Verry S.: When Growth Stalls, Harv. Bus. Rev., March 2008, pp. 50-61
24. Kolsky E.: Engagement for a changing world, February 2014, p. 12
25. Custumer Focus: 50 important statistics about Customer Experience (50 estadísticas importantes sobre la Experiencia del Cliente), Customer Experience, 2015, http://www.customerfocus.es/50-estadisticas-importantes-experiencia-del-cliente-parte-i/ (in Spanish)
26. Edwards T.: Living dolls? The role of clothing and fashion in 'sexualisation, Sexualities 23(5-6), 2020, pp. 702-716, doi: 10.1177/1363460718757951
27. Collett M., Cluver B., Chen H.L.: Consumer Perceptions the Limited Lifespan of Fast Fashion Apparel, Res. J. Text. Appar. 17(2), 2013, pp. 61-68, doi: 10.1108/RJTA-17-02-2013-B009
28. Kim J.E., Lloyd S., Adebeshin K., Kang J.Y.M.: Decoding fashion advertising symbolism in masstige and luxury brands, J. Fash. Mark. Manag. 23(2), 2019, pp. 277-295, doi: 10.1108/JFMM-04-2018-0047
29. Millan E., Wright L.T.: Gender effects on consumers' symbolic and hedonic preferences and actual clothing consumption in the Czech Republic, Int. J. Consum. Stud. 42(5), 2018, pp. 478-488, doi: 10.1111/ijcs.12447
30. Cho S., Aflatoony L., Morris K., Uriyo A.: Development of garment design strategies for women with visual impairments, Int. J. Fash. Des. Technol. Educ. 13(2), 2020, pp. 181-189, doi: 10.1080/17543266.2020.1761461
31. Candy F.J.: The fabric of society: An investigation of the emotional and sensory experience of wearing denim clothing, Sociol. Res. Online 10(1), 2005, doi: 10.5153/sro.965
32. Baudrillard J.: Consumer society (La sociedad de consumo), Primera ed. Madrid: SILO XXI, 2009 (in Spanish)
33. Darmody A., Zwick D.: Manipulate to empower: Hyper-relevance and the contradictions of marketing in the age of surveillance capitalism, Big Data Soc. 7(1), 2020, doi: 10.1177/2053951720904112
34. Koivisto E., Mattila P.: Extending the luxury experience to social media - User-Generated Content co-creation in a branded event, J. Bus. Res. 117(October), 2020, pp. 570-578, doi: 10.1016/j.jbusres.2018.10.030
35. Tofighi M., Grohmann B., Bodur H.O.: Ethical attribute and brand concept congruity enhances brand evaluations, Eur. J. Mark. 54(1), 2020, pp. 79-108, doi: 10.1108/EJM-02-2018-0104
36. Latter C., Phau I., Marchegiani C.: The roles of consumers need for uniqueness and status consumption in haute couture luxury brands, J. Glob. Fash. Mark. 1(4), 2012,, pp. 206-214, doi: 10.1080/20932685.2010.10593072
37. De Saussure F.: General Linguistics Course (Curso de Lingüistica general), Buenos Aires, 1945 (in Spanish)
38. Peirce C.S.: The science of semiotics (La Ciencia de la Semiótica), Colección, 1974 (in Spanish)
39. Morris C.: Theory of signs fundaments (Fundamentos de la teoría de los signos) 70, 2005, (in Spanish)
40. Lamillar F.J.S.: General Theory of Signs and Meaning (Teoría General de los Signos y del Significado), Nepomuceno, 2001, pp. 41-58, http://personal.us.es/salguero/Publicaciones/TeoSign.pdf (in Spanish)
41. Eco U.: Sign (Signo), Letra e, 1994 (in Spanish)
42. Sandoval S.L.M., Canales B.L.V.: The sign and its theoretical approaches in the development of the science of semiotics (El signo y sus aproximaciones teóricas en el desarrollo de la ciencia de la semiótica), Razón y Palabra no. 91, 2015 (in Spanish)
43. Baudrillard J.: The system of objects (El sistema de los objetos), Ciudad de México: Letra e, 1969 (in Spanish)
44. Dam R.F., Teo Y.S.: Personas - A Simple Introduction, Interaction Design Fpundation, 2020, https://www.interaction-design.org/literature/article/personas-why-and-how-you-should-use-them
45. Riello G.: Brief history of fashion (Breve historia de la moda) vol. 24, Barcelona, 2001 (in Spanish)
46. Goux J.-J.: The price of frivolous things (El precio de las cosas frívolas), Des. 17(17), 2011, pp. 15-23 (in Spanish)
47. Jiménez Gómez J.: Fashion and social class in the age of consumption (La moda y la clase social en la era del consumo), Departamento de Sociología, 2008, pp. 1-166, papers2://publication/uuid/A5C1CE0C-2888-45B4-A38F-9839F4F9E0C7 (in Spanish)

48. Makryniotis T.: Fashion and Costume Design in Electronic Entertainment - Bridging the Gap between Character and Fashion Design, Fash. Pract. 10(1), 2018, pp. 99-118, doi: 10.1080/17569370.2017.1412595
49. Inexmoda: The new vision of the fashion consumer (La nueva visión del consumidor de moda) p. 49, 2015 (in Spanish)
50. Riviére M.: Fashion Dictionary (Diccionario de la moda), 2nd ed., Barcelona: Penguin Random House, 2014 (in Spanish)
51. Kotler P., Armstrong G.: Fundamentals of Marketing (Fundamentos de Marketing) 8th ed., Mexico D.F: Pearson Educación, 2008 (in Spanish)
52. Rogers C.R.: Client-centered therapy 49(4), 1952
53. Kim T., Sung Y., Ho Moon J.: Effects of Brand Anthropomorphism on Consumer-Brand Relationships on Social Networking Site Fan Page: The Mediating Role of Social Presence, Telemat. Informatics 51(January), 2020, p. 101406, doi: 10.1016/j.tele.2020.101406
54. Cardenas S.: Sensory Marketing: Influence of the senses on the behavior and decision making of clothing store customers (Marketing Sensorial: Influencia De Los Sentidos En El Comportamiento Y Toma De Decisiones De Los Clientes De Tiendas De Ropa), 53(9), 2015, pp. 1689-1699, doi: 10.1017/CBO9781107415324.004 (in Spanish)
55. Lipovetsky G.: The empire of the ephemeral (El imperio de lo efímero), 1st ed., 136(1), Barcelona, 1990 (in Spanish)
56. Kotler P., Armstrong G.: Marketing, México D. F, 2012
57. Mingers J.: Combining IS Research Methods: Towards a Pluralist Methodology, Inf. Syst. Res. 12(3), 2001, pp. 240-259, doi: 10.1287/isre.12.3.240.9709
58. Moher D., Liberati A., Tetzlaff J, Altman D.G., Grp P.: Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement, Phys. Ther. 89(9), 2009, pp. 873-880, doi: 10.1371/journal.pmed.1000097
59. Cavanagh S.: Content analysis: concepts, methods and applications, Nurse Res. 4(3), 1997, pp. 5-16, doi: 10.7748/nr.4.3.5.s2
60. Mills G.E., Gay L.R.: Educational Research: Competencies for Analysis and Applications, 11th ed., Kendallville: Pearson, 2016
61. Durieux V., Gevenois P.A.: Bibliometric indicators: quality measurements of scientific publication., Radiology. 255(2), 2010, pp. 342-51, doi: 10.1148/radiol.09090626
62. [62] Schlosser R.W., Wendt O., Bhavnani S., Nail-Chiwetalu B.: Use of information-seeking strategies for developing systematic reviews and engaging in evidence-based practice: The application of traditional and comprehensive Pearl Growing. A review, Int. J. Lang. Commun. Disord. 41(5), 2006, pp. 567-582, doi: 10.1080/13682820600742190
63. Buthelezi T., Mtani T., Mncube L.: The extent of market concentration in South Africa’s product markets, J. Antitrust Enforc. 7(3), 2019, pp. 352-364, doi: 10.1093/jaenfo/jnz014
64. Korica M., Bazin Y.: Fashion and Organization Studies: Exploring conceptual paradoxes and empirical opportunities, Organ. Stud. 40(10), 2019, pp. 1481-1497, doi: 10.1177/0170840619831059
65. Almela A.C.: Beyond the icon (Más allá del ícono), in Congreso Internacional de Semiótica, 2018, pp. 1-13 (in Spanish)
66. Baudrillard J.: The symbolic exchange and death (El intercambio simbólico y la muerte), 1980 (in Spanish)
67. Moreno A.M.: Elements of semiotics in brand design as a complex sign (Elementos de semiótica en el diseño de marca como signo complejo), Comun. y Cult. 2(1), 2014, pp. 38-46, (in Spanish)
68. Vänskä A.: How to do humans with fashion: Towards a posthuman critique of fashion, Int. J. Fash. Stud. 5(1), 2018, pp. 15-31, doi: 10.1386/infs.5.1.15_1
69. Mora J.F.: Philosophy Dictionary (Diccionario de Filosofia) 29(3), 2012 (in Spanish)
70. Muñoz Pérez E.: Transcendence, world and freedom in the environment of Being and Time by Martín Heidegger (Trascendencia, mundo y libertad en el entorno de Ser y Tiempo de Martín Heidegger), Veritas 32(32), 2015, pp. 95-110, doi: 10.4067/s0718-92732015000100005 (in Spanish)
71. Oviedo H.C., Campo-Arias A.: Approach to the use of Cronbach's alpha coefficient (Aproximación al uso del coeficiente alfa de Cronbach), Rev. Colomb. Psiquiatr. 45(1), 2016, pp. 19-25, http://www.redalyc.org/pdf/806/80634409.pdf%0Ahttp://www.redalyc.org/pdf/806/80650839004.pdf (in Spanish)
72. Cancelliere E.: Pandora: Myth And Icon For A Royal Party (Pandora: Mito E Icono Para Una Fiesta Real), Anu. calderoniano 3(3), 2010, pp. 67-86, doi: 10.31819/9783954879908-004 (in Spanish)
73. Strathern M.: The self in self decoration, Oceania 38(4), 1984, pp. 302-318, doi: 10.2307/40332210
74. Bellezza S., Gino F., Keinan A.: The Red Sneakers Effect: Inferring Status and Competence from Signals of Nonconformity, J. Consum. Res. 41(1), 2014, pp. 35-54, doi: 10.1086/674870
75. Rodríguez Ferrándiz R.: Icon and television (Icono y televisión), Signa Rev. la Asoc. Española Semiótica no. 9, 2000, pp. 551-566, (in Spanish)
76. García J.D.M.: The symbolic homo sapiens. Discourses of Patriarchal Mythology in Western Culture (El homo sapiens simbólico. Los discursos de la mitología patriarcal en la cultura occidental), Feminismo/s 20(2), 2012, pp. 81-105, (in Spanish) doi: http://dx.doi.org/10.14198/fem.2012.20.05
77. Law D., Wong C., Yip J.: How does visual merchandising affect consumer affective response?: An intimate apparel experience, Eur. J. Mark. 46(1), 2012, pp. 112-133, doi: 10.1108/03090561211189266
78. Díaz P., Quintas N., Muñiz C.: Media Bodies versus Real Bodies (Cuerpos Mediáticos versus Cuerpos Reales), Icono 14(8), 2010, pp. 244-256, doi: https://doi.org/10.7195/ri14.v8i3.237 (in Spanish)
79. SanMiguel P., Sábada T.: Analysis of the first studies on personal leadership and the dissemination of fashion trends (1950-2000) (Análisis de los primeros estudios sobre el liderazgo personal y la difusión de tendencias de moda (1950-2000)), RIHC. Rev. Int. Hist. la Comun. no. 10, 2018, pp. 99-121, doi: 10.12795/rihc.2018.i10.06 (in Spanish)
80. Debord G.: The society of the spectacle (La sociedad del espectáculo), 2003 (in Spanish)
81. Blumer H.: Fashion: from class differentiation to collective selection, Sociol. Q., 1931, pp. 275-291, doi: 10.1111/j.1533-8525.1969.tb01292.x
82. Zuluaga P.: Theoretical contextualization of protection mechanisms in the world of Colombian fashion (Contextualización teórica de los mecanismos de protección en el mundo de la moda colombiana), Panorama 7(12), 2013, pp. 97-121, (in Spanish)
83. Hansen K.T.: The World in Dress: Anthropological Perspectives on Clothing, Fashion, and Culture, Annu.

Rev. Anthropol. 33(1), 2004, pp. 369-392, doi: 10.1146/annurev.anthro.33.070203.143805

84. Kuksov D.: Brand value in social interaction, Manage. Sci. 53(10), 2007, pp. 1634-1644, doi: 10.1287/mnsc.1070.0720
85. Fuentes Ortega J., Muñoz F., Quiroga Romero E.: First approach to the possibilities of application of Giles Lipovetsky's theory of fashion to the history of Psychology (Primer acercamiento a las posibilidades de aplicación de la teoría de la moda de Giles Lipovetsky a la historia de la Psicología), Rev. Hist. Psicol. 28(2), 2007, pp. 275-280 (in Spanish)
86. Barreiro A.M.: Towards a new fashion system: the zara model (Hacia un nuevo sistema de la mda: El modelo zara), Rev. Int. Sociol. 66(51), 2008, pp. 105-122, doi: https://doi.org/10.3989/ris.2008.i51.111 (in Spanish)
87. Scott A.J.: Competitive dynamics of Southern California's clothing industry: The widening global connection and its local ramifications, Urban Stud. 39(8), 2002, pp. 1287-1306, doi: 10.1080/00420980220142646
88. Corneo G., Jeanne O.: A theory of fashion based on segmented communication, Univ. Bonn, no. January 1995, pp. 1-21, 1994, http://www.researchgate.net/publication/4923619_A_Theory_of_Fashion_Based_on_Segmented_Communication/file/5046351cc2b8556de1.pdf
89. Arbaiza Rodriguez F., Huertas García S.: Advertising communication in the fashion industry: branded content, the case of fashion films (Comunicación publicitaria en la industria de la moda: branded content, el caso de los fashion films), Rev. Comun. 17(1), 2018, pp. 9-33, doi: 10.26441/RC17.1-2018-A1 (in Spanish)
90. Meena N K., Yang J., ZacharisE.: Optimisation framework for the design and operation of open-market urban and remote community microgrids, Appl. Energy 252(May), 2019, p. 113399, doi: 10.1016/j.apenergy.2019.113399
91. Liao Z., Cheung M.T.: Internet-based e-shopping and consumer sttitudes: an empirical astudy, Inf. Manag. 39(4), 2002, pp. 283-295, doi: 10.1016/S0378-7206(01)00097-0
92. Brewer M.B.: The Social Self: On being the same and different at the same time, Soc. Psychol. (9th Ed. 17(5), 2014, pp. 475-482, doi: 10.1177/0146167291175001
93. Larner W., Molloy M., Goodrum A.: Globalization, cultural economy, and not-so-global cities: The New Zealand designer fashion industry, Environ. Plan. D Soc. Sp. 25(3), 2007, pp. 381-400, doi: 10.1068/d1103
94. Pesendorfer W.: Design Innovation and Fashion Cycles, Am. Econ. Rev. 85(4), 1995, pp. 771-792, doi: 10.2307/2118231
95. Aaker D., et al.: Brand management, Gestión de marcas, 6^{th} ed., Boston: Harvard Business Review, 2000 (in Spanish)
96. Frutiger A.: Signs, symbols, marks, signals (Signos, símbolos, marcas, señales), Barcelona, 2005 (in Spanish)
97. Sánchez-Contador Uría A.: Identity through fashion (La identidad a través de la moda), Rev. Humanidades, no. 29, 2016, pp. 133-152, (in Spanish), doi: http://dx.doi.org/10.5944/rdh.29.2016.17220
98. Bietti F.: The cultural clothing industry, towards a fashion phenomenology (La industria cultural del vestir, hacia una fenomenología de la moda), VII Jornadas de Sociología de la Universidad Nacional de La Plata. p. 14, 2012, https://www.aacademica.org/000-097/585.pdf (in Spanish)
99. Venkatesh A., Joy A., Sherry J.F., Deschenes J.: The aesthetics of luxury fashion, body and identify formation, J. Consum. Psychol.. 20(4), 2010, pp. 459-470, doi: 10.1016/j.jcps.2010.06.011
100. Suzuki T., Best J.: The emergence of trendsetters for fashions and fads: Kogaru in 1990s Japan, Sociol. Q. 44(1), 2003, pp. 61-79+i, doi: 10.1525/tsq.2003.44.1.61
101. Bourdieu P.: Sociology and Culture, Sociologia y Cultura 22(4), 1980 (in Spanish)
102. Martensson M.: A critical review of knowledge management as a management tool, J. Knowl. Manag. 4(3), 2000, pp. 204-2016, doi: 10.5465/AMR.1999.1580444
103. Erikson E.H.: Identity, New York: Norton & Company, 1994
104. Ferenczi S.: Theory and Technique of psycho-analysis 2(2432) New York: Boni and Liveright Publishers, 1927
105. Alexander F.: The Interface Between the Psychodynamic and Behavioral Therapies 137(12), New York: Plenum Medical Book Company, 1980
106. Foucault M.: Watch out and punish (Vigilar y castigar), Buenos Aires: Siglo veintiuno editores, 1976 (in Spanish)
107. Argyris Ch.: Reasons and rationalizations, Oxford, 2004
108. Giddens A.: The constitution of society: Outline of the theory of structuration: Elements of the theory of structuration, Basil Blackwell Ltd, 2004
109. Bartlett F.: Thinking as experimental social study 13(2), 1959
110. Berger P.L., Luckmann T.: The social construction of reality (La construcción social de la realidad), Buenos Aires, 2003 (in Spanish)
111. Maquiavelo N.: The Prince (El Principe), 1999 (in Spanish)
112. Durkheim E.: Sociology and Philosophy, New York: Cohen and West Ltd, 2012
113. Adorno T.W.: Epistemology and Social Sciences (Epistemología y ciencias sociales), Madrid: Ediciones Cátedra, S. A, 2001 (in Spanish)
114. Rivière A.: The subject of cognitive psychology (El sujeto de la psicología cognitiva), Barcelona: Alianza Editorial, 1987 (in Spanish)
115. Callon M.: Why virtualism paves the way to political impotence 2(1), The Max Planck Institute for the Study of Societies in Cologne, 2001
116. Buhler C.: The child and his family 53(9), New York: Routledge, 2012
117. Rumelhart D.E.: Cognitive Science, Orlando: Academic Press, 2008
118. Negt O., Luge A.: Public Sphere and Experience 85, Minnesota: University of Minnesota Press, 1993
119. Rank O.: Myth of the birth of the hero, J. Nerv. Ment. Dis. 41(2), 1914, pp. 110-117, doi: 10.1097/00005053-191402000-00005
120. Parsons T.: The structure of social action (La estructura de la acción social), Madrid: Ediciones Guadarrama, 1961 (in Spanish)
121. Perkins D.: Educating for a changing world (Educar para un mundo cambiante), Innovación Educativa, 2015, p. 245, www.cedro.org (in Spanish)
122. Klein M.: Love, guilt and reparation (Amor, culpa y reparación), Barcelona: Paidós, 1974 (in Spanish)
123. Chomsky N.: Syntactic Structures, Berlin: Mouton de Gruyter, 2002
124. Chomsky N.: Language and Mind, Massachusetts: Cambridge, 2006

125. Horkheimer M.: Critique of instrumental reason (Crítica de la razón instrumental) 7, Buenos Aires, 1973 (in Spanish)
126. Piaget J.: Balancing Cognitive Structures Central Developmental Problem (La equilibración de las estructuras cognitivas Problema central del desarrollo), 5th ed., Siglo veintiuno editores, 1998 (in Spanish)
127. Goldstein K.: The organism, a holistic approach to biology, New York: Zone Books, 1995
128. Wittgenstein L.: Tractatus logico-philosophicus, Londres: Routledge, 2001
129. Commons J.R.: Legal foundations of capitalism 2(5), Toronto: The Macmillan Company, 1924
130. Horney K.: The Therapeutic Process 53(9), Yale University Press, 2013
131. Garfinkel H.: Ethnomethodology studies (Estudios de etnometodología), Barcelona: Anthropos Editorial, 2006 (in Spanish)
132. Assagioli R.: Psychosynthesis, New York: Esalen, 1974
133. Frankl V.: Psychoanalysis and existentialism (Psicoanálisis y existencialismo), Mexico D.F: Fondo de Cultura Económica, 1978 (in Spanish)
134. Zaleznik A., Likert R.: The Human Organization: Its Management and Value 21(4), San Francisco: McGraw Hill, 1968
135. Sherrington C.S.: Man on his Nature, New York: Cambridge University Press, 2009
136. y Cajal S.R.: Recollections of My Life 53(9), The MIT Press, 2013
137. Mcgregor D.M.: Theory X and Theory Y (La Teoria X Y La Teoria Y), The Human Side of Enterprise, 1986, pp. 134-144 (in Spanish)
138. Schweppenhäuser H.: Language, literature and art (Sprache, Literatur und Kunst), J.B Metzlet, 2015 (in German)
139. Staats A.W.: Current issues in theoretical psychology 25(2), New York: Elsevier, 1991
140. Wellmer A.: The persistence of modernity, Polity Press, 1991
141. Neisser U.: Cognitive Psychology, 2014
142. Pavlov I.P.: The conditioned reflexes. Lessons on the role of the great hemispheres (Los reflejos condicionados. Lecciones sobre la función de los grandes hemisferios), Madrid: Ediciones Morata, 1929 (in Spanish)
143. Simon H.A.: Administrative behavior (El comportamiento Administrativo), Madrid: Aguilar S.A., 1971 (in Spanish)
144. Honneth A.: The Struggle for Recognition: The Moral Grammar of Social Conflicts, Massachusetts: The MIT Press, 1996
145. Marcuse H.: Culture and society (Cultura y sociedad) 6(8), 1968 (in Spanish)
146. Sullivan H.S.: The (Inter)personal theory of psychiatry, New York: Tavistock, 2017
147. Habermas J.: Religion and rationality: Essays on reason, God, and modernity, Massachusetts, 2002
148. Ryle G.: The concept of mind. Londres: Hutchin Son's University Library, 1984
149. von Bertalanffy L.: An outline of general system theory, Br. J. Philos. Sci. 10(2), 1950, pp. 103-123
150. Garzón Castrillón M.A.: Dynamic Capabilities Model (Modelo De Capacidades Dinámicas), Dimens. Empres. 13(1), 2015, p. 111, doi: 10.15665/rde.v13i1.341 (in Spanish)
151. Meyer J.W., Rowan B.: Institutionalized Organizations: Formal structure as mith and ceremony, in The new institutionalism in organizational anlysis, 1977, pp. 21-23
152. Fitzgerald L.A.: Chaos: The lens that transcends, J. Organ. Chang. Manag. 15(4), 2002, pp. 339-358, doi: 10.1108/09534810210433665
153. Shafritz J.M., Hyde A.C.: Classics of public administration (Clásicos de la administración pública) 53(9). 2013 (in Spanish)
154. Cobo Olivero C.E.: Human behavior (El comportamiento humano), Cuad. Adm. 19(29), 2011, p. 113, doi: 10.25100/cdea.v19i29.126 (in Spanish)
155. Kulkarni V.: Contingency Theory Notes, Int. Encycl. ofOrganizational Commun., 2011, doi: 10.1002/9781118955567.wbieoc041
156. O'Connor E.S.: The politics of management thought: A case study of the Harvard Business School and the Human Relations School, Acad. Manag. Rev. 24(1), 1999, pp. 117-131, doi: 10.5465/AMR.1999.1580444
157. Hernández J.S., Mirón S.I.: The Theory of Resources and Capabilities: A Current Focus on Business Strategy (La teoría de los recursos y las capacidades: un enfoque actual en la estrategia empresarial), An. Estud. económicos y Empres. no. 15, 2002, pp. 63-89, (in Spanish)
158. Lewin K.: Principles of Topological Psychology 7(1), 1938
159. Fromm E.: The anatomy of human destructiveness, New York: Holt, Rineha Rt and Winston, 1973
160. Broadbent D.E.: Perception and communication 8(6), Londres: Pergamon, 1966
161. Porter M.E.: From Corporate Advantage to Competitive Strategy, Harv. Bus. Rev., no. May-June, 1987, pp. 1-22, doi: 10.1007/978-1-349-20317-8_17
162. Porter M.E.: Competitive Strategy: Techniques for Analyzing Industries and Competitors, New York: The Free Press, 2017
163. Barthes R.: The Fashion System (El Sistema de la moda), Barcelona: Editorial Gustavo Gili S.A., 1978 (in Spanish)
164. Bruner J.S.: Acts of meaning, Massachusetts: Cambridge University Press, 1990
165. Mead G.H.: The genesis of the self and social control (La génesis del self y el control social), Reis, no. 55, 1991, p. 165, doi: 10.2307/40183545 (in Spanish)
166. Simmel G., Wolff K.: The Sociology of Georg Simmel 13(1), Glencoe: The Free Press, 1978
167. Veblen T.: Theory of the Leisure Class (Teoría de la Clase Ociosa), 2000 (in Spanish)
168. Latour B.: Science in Action (Ciencia en Acción), Barcelona, 1992 (in Spanish)
169. Lévi-Strauss C.: Structural Anthropology (Antropología Estructural), 1995 (in Spanish)
170. Bourdieu P.: The social sense of taste (El sentido social del gusto), Buenos Aires, 2010 (in Spanish)
171. Verdugo M.Á., Crespo M., Badía M., Benito A., Baz M.B.O.: Methodology in research on disability. Introduction to the use of structural equations (Metodología en la investigación sobre discapacidad. Introducción al uso de las ecuaciones estructurales), 2008 (in Spanish)
172. Baah C., et al.: Examining the correlations between stakeholder pressures, green production practices, firm reputation, environmental and financial performance: Evidence from manufacturing SMEs, Sustain. Prod. Consum. 27, 2021, pp. 100-114, doi: 10.1016/j.spc.2020.10.015

RIB KNITTED FABRICS WITH TUCK STITCHES: STRUCTURE AND PROPERTIES

Olena Kyzymchuk[1], Olha Stefashyna[1], Liudmyla Melnyk[1], Oleksandr Holovnia[2], Svitlana Arabuli[1] and Daryna Levytska[1]

[1]*Kyiv National University of Technologies & Design, N.-Danchenko Street 2, Kyiv, 01011, Ukraine*
[2]*Lviv National Academy of Arts, Kubiiovycha Street 38, Lviv, 79011, Ukraine*
arabuli.si@knutd.edu.ua; oleksandr.holovnya@gmail.com

Abstract: *Knitted fabrics with tuck stitches are widely used in the manufacturing of knitwear, hats, scarves, etc. due to the variety of patterned effects that can be obtained. It should be noted that the structure and properties of the knitted fabric will depend on the number of tuck stitches in the structure. The goal of this work is to develop a few types of knitted fabrics with different content of tuck stitches and to analyze the effect of tuck stitches on the structural characteristics and deformation properties of the fabric. Two sets of fabrics were produced on a 10-gauge flat-bed knitting machine from 32x2 tex half wool yarn. They are differed by basic interlooping and the number of tuck stitches in the repeat. Dependencies of the structural parameters as well as deformation properties on the number of tuck stitches in the interlooping repeat were set up. They should be taking into account when designing new products from these and similar fabrics.*

Keywords: *rib knitted fabric, tuck stitch, deformation component, full deformation, shrinkage, structure.*

1 INTRODUCTION

Today, the problem of expanding the knitwear range [1] is a topical issue for the vast majority of knitting companies [2]. This problem can be solved in several ways [3]: first, by improving the knitwear design solutions; secondly, to make fuller use of the existing technological potential of knitting machines [4]. Modern knitting equipment allows to create a wide range of interlooping and gets a variety of pattern effects, and electronic needle selection systems contribute to an almost unlimited increase in the pattern repeat size, both in height and width.

According to the variety of patterned effects that can be obtained: lace [4], embossed [6], racked [7], tinted; tuck stitch is occupied one of the first places. Tuck stitches offer many decorative possibilities; they can be used to produce openwork effects, make surface texture effects and improve ladder resistance [7]. Tuck stitches are stitches in which certain loops are drawn through the loops of a previous course and through open loops [9]. Scilicet a tuck stitch is composed of two elements held loop and tuck loop [10]. These loops differ by size and yarn configuration [11]. The tuck stitch may have few tuck loops [4]. Successive tucks on the same needle are placed on top of each other at the back of the head of the held loop and each, in turn, assumes a straighter and more horizontal appearance. Under normal conditions, up to four successive tucks can be accumulated before tension causes yarn rupture or needle damage [4, 10]. The limit is affected by machine design, gauge, yarn count and elasticity, yarn tension and take down tension. From the other side, tucking may occur few adjacent needles [12]. The head of the tuck loop will float freely across these adjacent needles. Dependent upon structural fineness, tucking over six adjacent needles is usually the maximum unit [10].

The uniqueness of the loops` structure of the tuck knit is significantly reflected in the shape, size and disposition of both elements of the tuck stitches as well as conventional loops. So, there are four types of loops in the half cardigan structure (Figure 1): held loop 1 and tuck loop 4 usually at the front side; conventional loops 2 and 3 at the backside [13]. Loop 2 is tightened due to dragging the yarn into held loop 1. Loop 3 has got round shape due to the redistribution of the yarn from the tuck loop 4 and due to the elastic properties of the threads themselves [9].

The properties of knitted fabric are mostly determined by the properties of the basic interlooping (plain, rib or interlock) at the same time changing them. Thus, a single fabric with tuck stitches has a greater thickness, weight [14] and porosity compared to a single jersey [15]. When the tuck stitches give the miss stitch effect in fabric, the weight ant thickness is lower than expected [16]. From the investigation single jersey fabric with tuck loop incorporated with knit loop in wales direction [17] it was found that with the increase of tuck loop percentage in wales direction fabric width and areal density increases. But increasing number of tuck loop does not show any linear relationship with shrinkage and spirality. The fabrics such as lacoste structure having more pores and larger pores show the higher resistance against pilling. Tendency to generate lesser pills will enhance aesthetic property of tuck fabric. Visual investigation shows that tuck stitch was the most beautiful and decorative stitch [15]. The knitted fabric with tuck stitches is less stretchable and has better shape retention than the basic structure. The stretch property walewise is limited due to held loops at the same time the stretch property coursewise is limited due to tuck loops oriented in the stretching direction. Generally, with an increase in the number of tuck stitches the width of the fabric grows and the slackness of the structure increases [18].

In another study [19], the effect of tuck loop on fabric width in grey and finished state, shrinkage, spirality and areal density were investigated when yarn count, stitch length, machine gauge, machine diameter, dyeing and finishing procedures were same. From the investigation it was found that with the increase of tuck loop percentage in wales direction fabric width and areal density increases. But increasing number of tuck loop does not show any linear relationship with shrinkage and spirality.

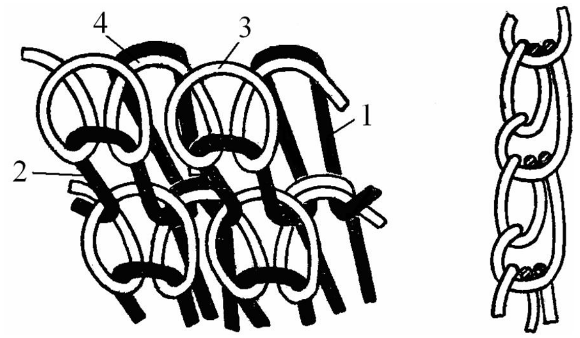


Figure 1 Half cardigan structure

With regard to rib knitted fabric, such common interlooping as a full cardigan and half cardigan are the objects of the vast majority of studies [11-13, 20]. All loops at one or both sides of such fabrics are tuck stitches. It was established that the elongation of half-cardigan is the greatest in wale direction and the elongation of full-cardigan is the greatest in course direction [12]. As a result of the study effects of knit structure on the properties of winter outerwear [20], it was established that the tuck stitch fabrics have the lowest resistance to abrasion. The full cardigan fabric has the lowest resistance to pilling. Half cardigan fabrics have weaker bursting strength performance. At the same time, they are the most permeable to air.

In the other study [21], it was found that the tuck stitches within the structure of composite reinforcement did not have a contributive effect on the tensile and compressive behaviors. But as the tensile and compressive strength values in course and wale directions were much closer to each other for the full cardigan derivative composites than the 1+1 rib composites, the full cardigan derivative composites can still be preferred. The authors conclude that different weft knitted structures which are composed of tuck stitches should be studied. There is also information on the effect of the tuck index on the properties of rib 1+1 knitted fabric [22]. It was concluded that the width, thickness and air permeability successively increase with increasing of tucking course and the length gradually decreases. For drape property, single needle tuck stitch with three tucking courses is biggest and its change presents parabolic curve. In the study [23], the influence of the number of tuck loops in the repeat of the combined interlooping formed by alternation of rib 1+1 and half-cardigan courses in different ratios on the fabric properties was investigated. The increasing the number of tuck stitches in the repeat leads to an increase in the thickness and, accordingly, the surface density. The values for half cardigan are 25% higher than for rib 1+1.The increasing the number of tuck loops in the repeat leads, as well, to a decrease in the difference in the stretchability in different directions. The full deformation of half cardigan is almost the same both course-wise and walewise and it is 140 ÷ 150%.

Therefore, there is a lack of information on the effect of tuck stitches on the properties of rib knitted fabric, when the tuck loops are not formed on each needle of the needle bar. The purpose of this work is to study the rib knitted fabrics with tuck stitches according to repeat and to establish the effect of the tuck stitch number on the properties of developed knitted fabrics.

2 MATERIALS AND METHODS

Rib knitted fabric with tuck loops formed according to the repeat on the needles of one needle bed is the object of this study. All knitted fabrics are manufactured on a 10-gauge flat-bed knitting machine from 32x2 tex half wool (50% wool and 50% polyacrylonitrile fibers) yarn. The tuck stitch is formed by standard method for weft knitting: by holding the old loop and then accumulating new loop in the needle hook. New loop becomes a tuck loop as it and the held loop are knocked-over together at later knitting cycle [10].

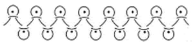
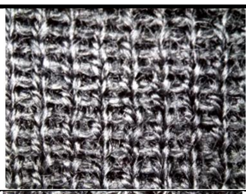
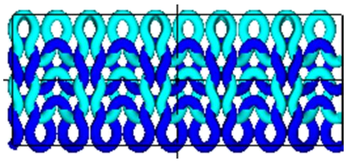
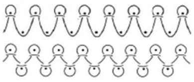
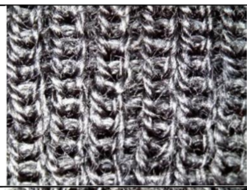
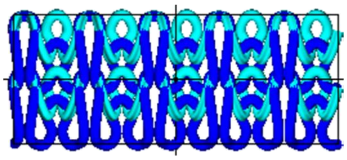
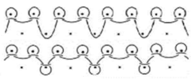
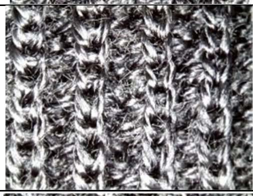
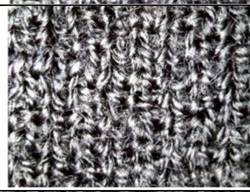
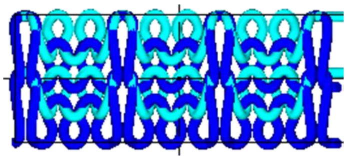
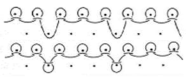
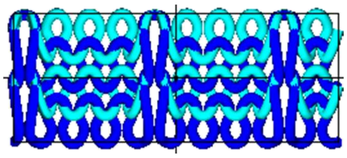
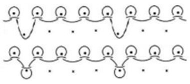
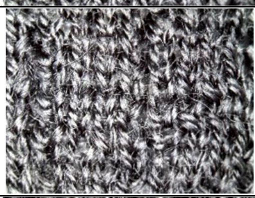
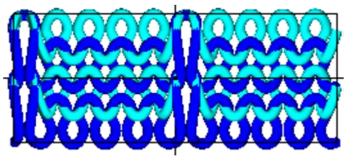
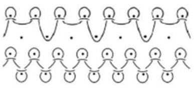
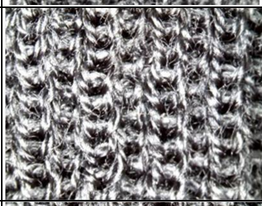
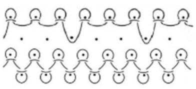
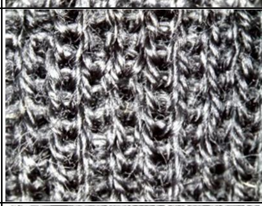
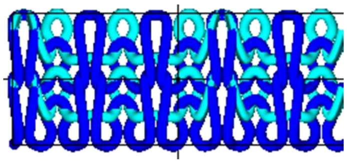
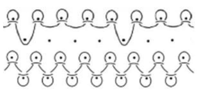
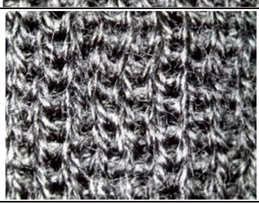
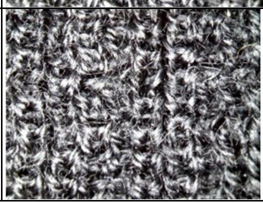
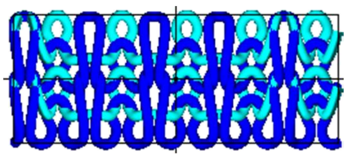
In order to study the effects of the pattern and of the number of tuck loops on the structure and the properties of knitted fabrics two sets of samples were produced. They differ in the repeat of tuck and regular loops alternation as well as in the order of needles work in different systems (Table 1):

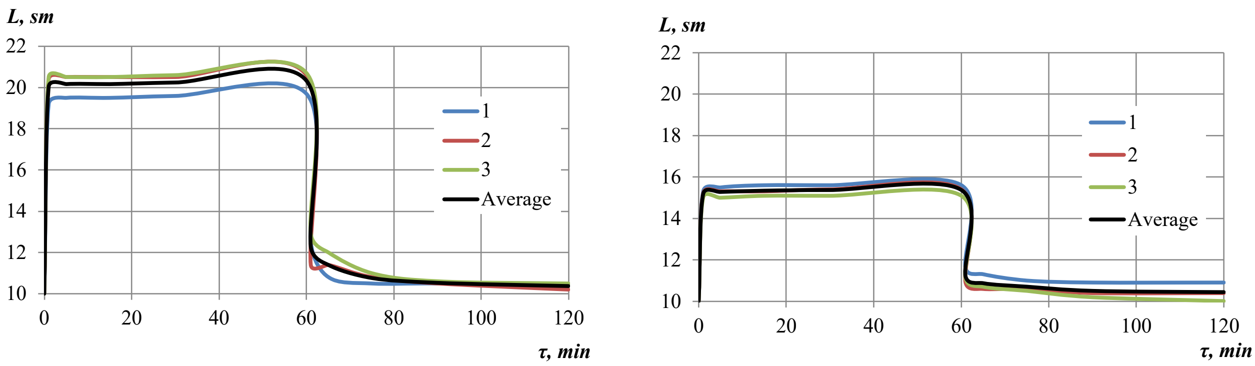
- the first set of samples (1.1 ÷ 1.3) – tuck stitches on the single rib (2/1, 3/1 and 4/1);

– the second set of samples (2.1 ÷ 2.3) - alternation of rib 1+1 course and course with tuck loops formed according to repeat;

– rib 1+1 and a half cardigan as basic structures for comparison.

Table 1 Developed knitted fabrics with tuck stitches

Variant		Grafical	Sample photo front	Sample photo back	Structure
Rib 1+1	R				
Half cardigan	HfC				
tuck stitches on the incomplete rib	1.1				
	1.2				
	1.3				
alternation of rib 1+1 course and course with tuck loops	2.1				
	2.2				
	2.3				



a) coursewise b) walewise

Figure 2 Specimen`s length during the study on the relaxometer for variant 1.1.

For the manufacture of the first set, the needles of the front bed are taken out of action according to repeat. So, there are plain areas on the fabric surface, which changes the properties of the rib structure. This part is the subject to curl with an increase in the number of adjacent plain loops. The tuck loop is formed on the rib of structure. The tuck stitches form straight wales and create relief at the front side of the fabric. On the fabric back side, wales connected with rib on the front side are curved due to uneven redistribution of yarn on both sides of the loop. There are one or more straight wales between curved ones with increases the number of adjacent plain loops. This difference creates a tint effect on the fabric.

For the manufacture of the second set of fabrics, needles work in the following order: all needles form loops at the first feeder; all needles of one bed form loops and certain needles of other bed form tuck loops at the second feeder. The wales on the front side are straight and formed by held loops some of them with tuck loops. There is a slight tint effect due to the different perceptions of tuck stitches and float stitches. The wales on the back side are formed by tightened loops and round or regular loops that reflected in the surface irregularity.

The percentage of needles of the front needle bed which formed tuck loops (TS) was chosen as an input factor of the experiment.

All knitted fabrics after knitting before the study are brought to a conditionally balanced state by washing and ironing according to ISO 6330:2013 [24]. Shrinkage during washing and ironing was determined according to ISO 3759-2007 [25] and ISO 5077-2007 [26].

Studies of the structural parameters of the fabrics were conducted according to standard methods:

– stitch density is according to BS EN 14971: 2006 [23]
– the loop length is according to BS EN 14970: 2006 [24],
– mass per square meter is according to ISO 3801: 1977 [25],
– thickness is according to ISO 5084: 1997 [26].

Ten parallel measurements were carried out for each fabric variant. Taking into account the relief effect of knitted fabrics of the first set, the study of thickness was carried out with a double number of measurements. The average values are used for the analysis.

The deformation of the knitted fabrics was investigated on a relaxometer both coursewise and walewise. The test on the cycle "load-unload-rest" was carried out according to ASTM D2594-20 [31] at 6 N load. The time of loading and rest was 60 minutes each. 3 specimens for each fabric variant were tested; the results show high convergence (Figure 2).

3 RESULTS AND DISCUSSION

3.1 Fabrics shrinkage

As a result of shrinkage investigation (Figure 3), it was found that the width of all studied fabrics variants increases after washing, drying and ironing. In general, the value ranges from 5 to 10% and is primarily related to the production conditions on the knitting machine. The draw-off force is directed walewise and therefore the loops are extended in length and reduced in width. The shape of the loop and its dimensions changes as a result of relaxation processes during wet-heat treatments. The value is more evident for the first set of fabric. An increasing the distance between adjacent plain and rib wales in rib knitted fabric by reducing the telescopic approach between adjacent loops is another reason for the fabric's width increase. The value is more evident for the first set of fabric because of eliminating curl areas of plain in single ribs. Shrinkage coursewise is observed only for the second set of knitted fabric. Length reduction is from -5 to -10% as a result of held loop reshaping.

It should be noted that the size changes of knitted fabrics occur generally during the first wash, and after that they are stable. This fact must be taken into account when developing technological modes of wet-heat treatment of semi-finished products in order to ensure high-quality knitted clothes.

3.2 Structural parameters

The study results of the structural parameters (stitch density, the loop length, the thickness and mass per area unit) of the developed knitted fabrics with tuck stitches are summarized in Table 2.

The loop length is the main structural parameter that determines the density and properties of knitted fabrics. Studies results have shown some difference between the loop length at the first feeder, which forms only loops, and the loop length at the second feeder, which forms both loops and tucks. This difference is not too significant (up to 6%), so the analysis is performed on the average value of the indicator (Table 2). The experimental data shows that neither the interlooping nor its repeat affects the loop length which is on mean equal to 5.85±0.19 mm. All fabrics are produced from the same yarn on the same knitting machine with the same technological parameters (yarn tension, sinking depth, draw-off force). Therefore, the further analysis of experimental data is expedient to think about the influence of the number of tuck stitches (not loop length) on the investigated properties of knitted fabrics.

The study result shows that the tuck stitches significantly affect the stitch density of the knitted fabrics. The height of the tuck stitch is usually two times more than the height of a regular loop (Figure 1). The tuck stitches are positioned at the front side of the studied knitted fabrics that leads to a difference in the number of courses on both sides of the fabric (Table 2). The number of courses per 100 mm of half cardigan is 15% less on the front side and 75% more on the backside compared to the rib 1+1 knitted fabric. It was found (Figure 4) that the number of courses per 100 mm decreases with decreasing number of tuck loops in interlooping repeat in both sets of knitted fabrics.

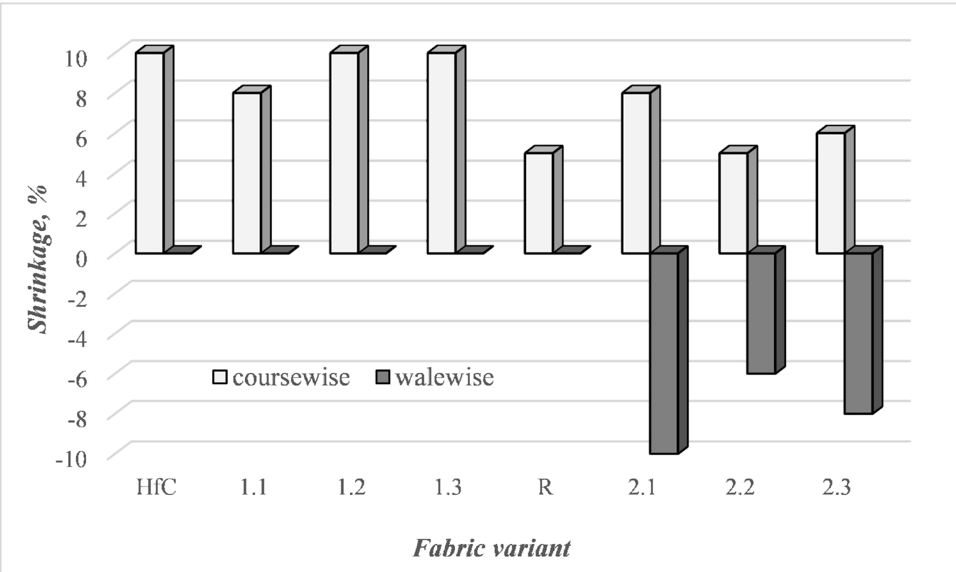
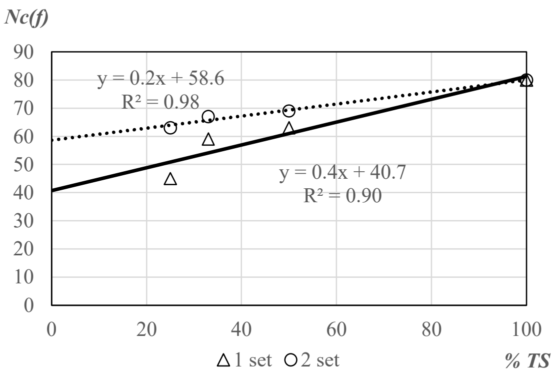


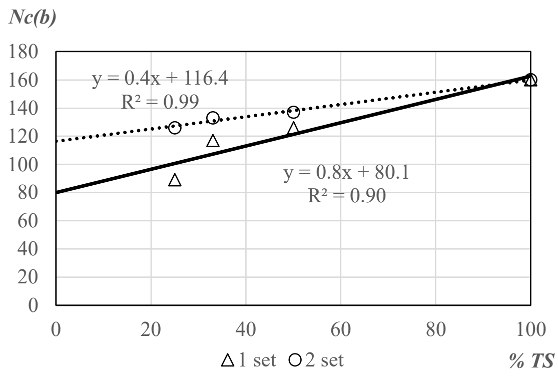
Figure 3 Shrinkage of knitted fabric

Table 2 Structural parameters of knitted fabrics

Variant	TS [%]	Thickness [mm]	Stitch density				Mass per square meter [gr/m^2]	Loop length [mm]
			Wales per 100 mm		Courses per 100 mm			
			front	back	front	back		
R	0	1.27±0.11	53±2	53±2	92±2	92±2	348.7±12.2	5.82±0.21
HfC	100	1.77±0.18	36±1	36±1	80±2	159±4	473.1±20.8	5.78±0.14
1.1	50	1.23±0.20	26±2	50±2	63±2	126±3	352.4±24.3	5.89±0.12
1.2	33	1.10±0.13	20±0	57±1	59±2	117±3	329.9± 8.4	5.80±0.14
1.3	25	0.94±0.10	15±1	56±1	45±2	89±3	270.8±23.3	6.00±0.16
2.1	50	1.72±0.15	49±1	49±1	69±2	137±3	466.2±22.1	5.84±0.10
2.2	33	1.75±0.07	54±1	54±1	67±2	133±4	481.5± 6.9	5.88±0.08
2.3	25	1.58±0.15	54±1	54±1	63±2	126±5	446.9±16.1	5.90±0.07

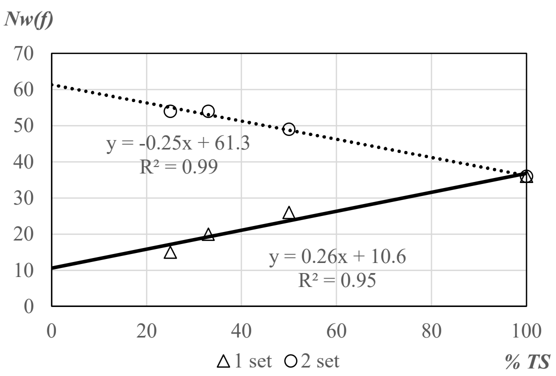


a) front side

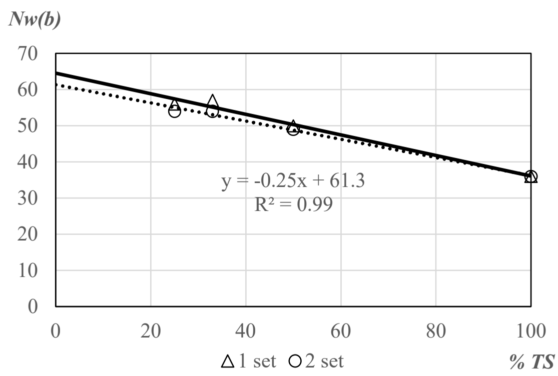


b) back side

Figure 4 Number of courses per 100 mm



a) front side



b) back side

Figure 5 Number of wales per 100 mm

It is well known that the tuck stitch is wider than a regular loop due to straightening up the yarn of tuck loop. It leads to a reduction in the number of wales per 100 mm. The conducted research has confirmed this state: the density of half cardigan is third less than rib 1+1 knitted fabric (Table 2). Accordingly, the value is growing with reducing the number of tuck stitches (Figure 5). It is necessary to emphasize that tendency is opposite for the front side of the first set of fabric (Figure 5a): the wales number per 100 mm increases with an increase in the number of tuck stitches in the interlooping repeat. This is due to the fact that fabric produced with complete taking out of action the needles according to repeating in front bed.

The fabric thickness is mostly determined by the disposition of different loops in the structure as well as skeletons and junctures of the same loops. The results of the study (Table 2) showed that the half cardigan is almost 40% thicker than rib 1+1 fabric. It is due to a change in the shape of the backside loop that connected to the tuck loop. This loop has got rounded shape and curved into the fabric thickness. It should be noted that the number of tuck loops in repeat does not affect fabric thickness for the second set (Figure 6).

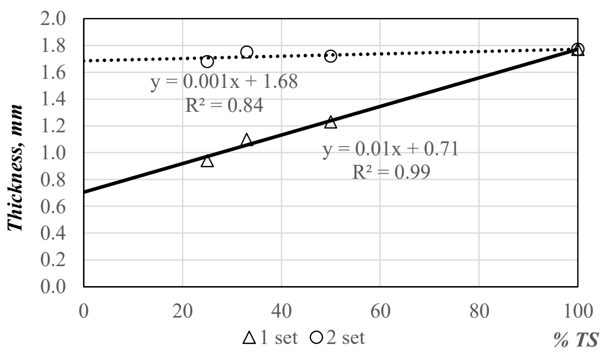


Figure 6 Thickness of knitted fabric

Therefore, it can be stated that tuck stitches in the rib 1+1 knitted structure significantly affect its thickness, regardless of their number in repeat. There is a directly proportional relationship between the number of tuck stitches in the interlooping repeat and fabric thickness for the first set (Figure 6).

But it is the result of different thicknesses of plain and rib structure mostly. Therefore, with a decrease in the number of tuck stitches increases the thinner plain areas which, in turn, reduces the fabric thickness.

The mass of the fabric is an indicator of both raw material consumption and, indirectly, the heat-protective properties of the knitted fabric. The mass per square meter of the half cardigan is almost 25% higher than the mass per square meter of rib 1+1 knitted fabric (Table 2) due to the presence of a tuck loop behind the held loop and greater thickness of the fabric. The influence of the interlooping repeat on the mass value for the first set of fabric is obvious (Figure 7). As for the thickness, it is a consequence of taking out of action the needles according to repeat and the formation of plain surfaces of different widths. The effect of the number of tuck stitches on the mass per square meter is less significant for the second set of fabric. Value is mainly related to the difference between the length of the tuck loop and the float loop behind held loops.

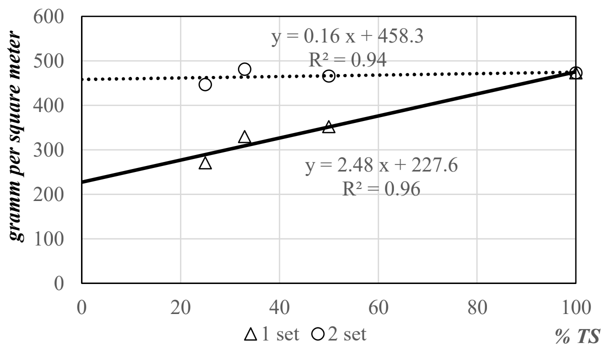


Figure 7 Mass per square meter

3.3 Stretch properties

The widespread use of knitted fabric is due primarily to its high extensibility and elasticity compared to weaving fabric. That is why it is important to test the stretchability of knitted fabric before recommending it for usage in a certain product. Full deformation and its components are preferred single-cycle characteristics [32]. The results of processing the experimental data (Table 3) show that the stretch property of developed knitted fabrics along the courses exceeds its stretch property along the wales. The full deformation of half cardigan along the courses is 40% less, and along the wales is almost 60% higher than the corresponding indicators of the rib 1+1 fabric. This difference is conditioned by the type and the shape of the loops. The stretchability of rib 1+1 fabric coursewise is increased due to the telescopic approach between the front and back loops, and at the same time, the tuck loops limit stretchability in this direction. The rods of loops skeletons oriented along the stretching create the main resistance to stretching in the wales direction. At the same time, the tuck stitch is a complex of loops of different shapes and sizes, which increases the stretchability of fabric.

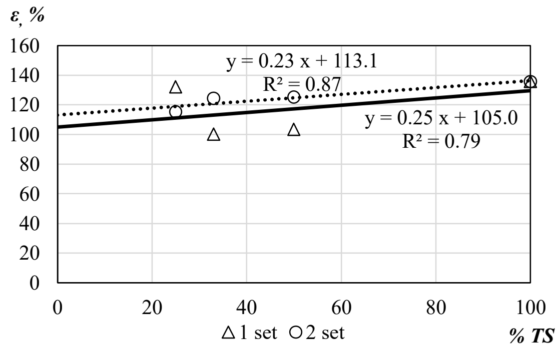
Both the interlooping type and the number of tuck stitches affect the full deformation of knitted fabrics. Thus within the experiment, the full deformation of the fabrics when stretching coursewise (Figure 8a) increases by 15-30% with an increase in the number of tuck loops, while the effect of the basic weave is negligible. The difference in the performance of the fabrics of both sets is in the 10-20% range. At the same time, the full deformation of the fabrics when stretching walewise maintaining the tendency to increase is more significant (Figure 8.b): the full deformation increases by 60%.

The elastic component is the main part of full deformation. All tendencies that revealed for full deformation remain: increase in the number of tuck loops leads to growth of an elastic component both at stretching coursewise and walewise. The tendency is more expressed at stretching walewise; indicators are higher for second set of fabrics (variants 2.1-2.3).

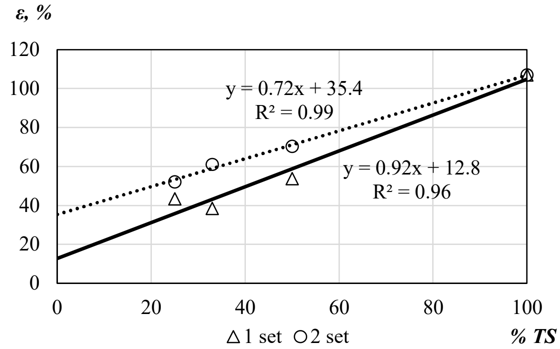
The residual component of the full deformation is an indicator of the stability of the knitwear. It depends primarily on the basic interlooping (Figure 9). Attention should be paid to the high value of residual deformation for the second set of fabric (variants 2.1-2.3). It is primarily due to the irreversible yarns redistribution between the different loops in the structure. The residual deformation for the first set of fabrics (variants 1.1-1.3) is much smaller. It increases with increasing number of tuck stitches.

Table 3 Deformation characteristics of knitted fabrics with tuck stitches

Variant	TS [%]	Deformation in direction of courses [%]				Deformation in direction of wales [%]			
		Full, ε	Elastic, ε_1	Plastic, ε_2	Residual, ε_3	Full, ε	Elastic, ε_1	Plastic, ε_2	Residual, ε_3
R	0	176.6	151.6	19.0	6.0	47.0	38.0	7.7	1.3
HfC	100	135.7	100.4	25.0	10.3	107.0	85.7	14.3	7.0
1.1	50	103.4	80.7	19.0	3.7	53.7	41.7	7.7	4.3
1.2	33	100.3	88.3	10.7	1.3	38.4	30.7	5.7	2.0
1.3	25	132.0	107.4	19.3	5.3	43.4	33.7	7.7	2.0
2.1	50	125.3	96.3	16.7	12.3	70.3	56.0	9.0	5.3
2.2	33	124.4	89.7	22.0	12.7	61.0	42.7	11.3	7.0
2.3	25	115.3	93.0	12.0	10.3	52.0	38.4	8.3	5.3

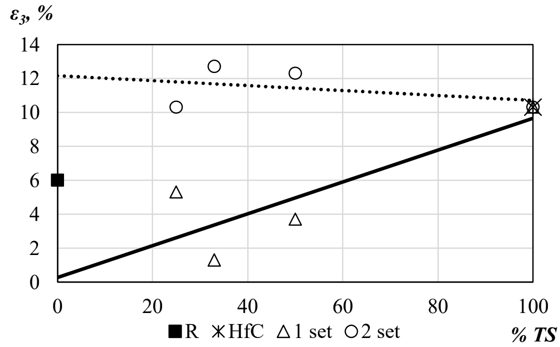


a) coursewise

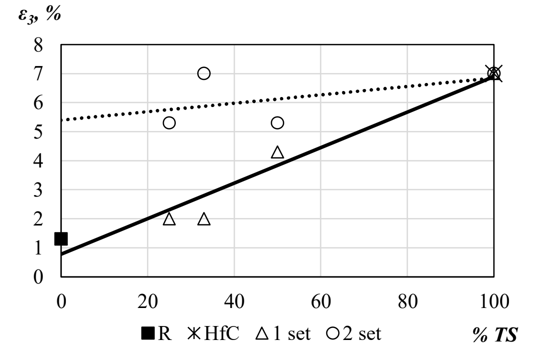


b) walewise

Figure 8 Effect of tuck stitches on full deformation

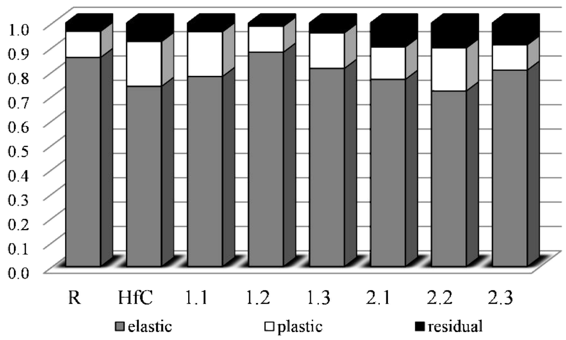


a) coursewise

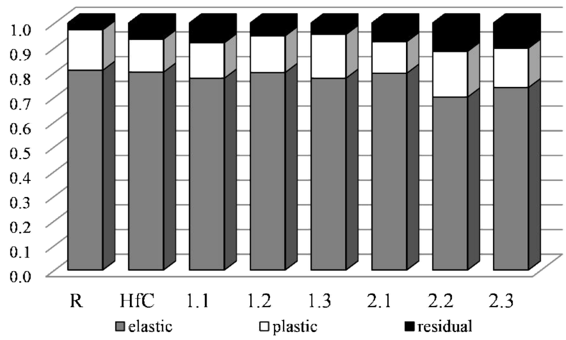


b) walewise

Figure 9 Effect of tuck stitches on residual deformation



a) coursewise



b) walewise

Figure 10 The components contribution in full deformation during stretching

The components' contributions in full deformation are important indicators of the quality of textile materials along with their actual values (Figure 10). It is obvious that the elastic component is a significant part and the residual component is the smallest part of the full deformation.

The study results show that when stretched walewise (Figure 10b), the elastic contribution is 0.8 and does not depend on the knitted fabric variant. The contribution of residual deformation does not exceed 0.1. At the same time, when stretching coursewise (Figure 10a), the effect of the number of tuck stitches on the elastic contribution is observed. The value decreases with an increasing number of tuck stitches. It is 0.86 for the rib 1+1 and 0.74 for the half cardigan fabric. It should be noted that the residual contribution for rib 1+1 and the first set of fabrics (1.1.-1.3) does not exceed 0.04. The residual contribution for the half cardigan and for the second set of fabrics (2.1-2.3) reaches 0.1.

4 CONCLUSION

The investigation of tuck knitted fabric, made on the basis of the single rib of different repeats and on the basis of the rib 1+1 with a different number of tucks in the repeat allowed us to conclude the following:

- The number of tuck stitches in the interlooping repeat is significantly affecting the structural parameters as well as deformation properties of the knitted fabric.
- The number of courses per 100 mm, the thickness and mass per unit areas of the fabric increases, and the number of wales per 100 mm decreases with the increasing number of tuck loops.
- The full tensile deformation walewise is much smaller than coursewise. The increase in the number of tuck stitches in the repeat leads to a value increase. The tendency is greater extent when stretching walewise.
- The elastic component is a significant part of the full deformation. its value is 0.8 when stretching walewise. The value decreases from 0.86 for rib 1+1 to 0.74 for the half-cardigan with increasing the number of tuck stitches in the repeat when stretching coursewise.
- The residual deformation reaches 10-12% for the second set of knitted fabric when stretched coursewise. The residual deformation does not exceed 7% when fabrics stretched walewise. It is 0.1 of full deformation. This must be taken into account when designing clothes from such fabrics.

Developed knitted fabrics are recommended for demi-season outerwear clothing.

5 REFERENCES

1. Matkovic V.M.P.: The power of fashion: The influence of knitting design on the development of knitting technology, Textile 8(2), 2010, pp. 122-147, DOI: 10.2752/175183510x12791896965493
2. Gryschenko I.M., Goncharov Y.V.: Retrospective analysis of the influence of Ukraine joining WTO upon textile market, Actual Problems of Economics 139(1), 2013, pp. 58-70 (in Ukrainian)
3. Morhulets O., Arabuli S., Nyshenko O., Arabuli A.: Analytical assessment of the apparel industry in Ukraine: Problems and opportunities, Vlakna a textil (Fibres and Textiles) 27(3), 2020, pp. 111-118, http://vat.ft.tul.cz/Archive/VaT_2020_3.html
4. Meißner M., Eberhardt B.: The art of knitted fabrics, realistic & physically based modelling of knitted patterns, Computer Graphics Forum 17(3), 1998, pp. 355-362, DOI: 10.1111/1467-8659.00282
5. Truevtsev A.V., Polyakova S.V.: Calculation of technological parameters of single jersey knit with tuck loops of a high index, Izvestia VUZov: Technologiya tekstilnoy promyishlennosti (6), 1996, pp. 67-70, https://ttp.ivgpu.com/wp-content/uploads/2016/01/235_20.pdf (in Ukrainian)
6. Holovnia O.: Wechselwirkungen von Kräften im Faden und Maschenschrägstellung bei RR-Fang-Gestricken, Melliand Textilberichte 98(3), 2017, pp. 139-141 (in German)
7. Holovnia O., Kyzymchuk O.: Study of structural effects on double weft tuck knit, Bulletin of the Kyiv National University of Technologies and Design. Technical Science Series 132(2), 2019, pp. 60-73, DOI: 10.30857/1813-6796.2019.2.6.
8. Wilson J.: Handbook of Textile Design, Woodhead Publishing, 2001, 160 p., ISBN: 978-1-85573-573-6
9. Kudriavin L. (Ed.): Laboratory Practice in Knitting Technology, Mir Publishers, Moscow, 1985, 432 p.
10. Spencer D.J.: Knitting Technology, 3rd ed., Woodhead publishing, 2001, 386 p., ISBN: 9781855733336
11. Kurbak A., Kayacan O.: Basic studies for modeling complex weft knitted fabric structures. Part V: Geometrical modeling of tuck stitches, Textile Research Journal 78(7), 2008, pp. 577-582, DOI: 10.1177/0040517507087672
12. Mikucioniene D., Ciukas R., Mickeviciene A.: The influence of knitting structure on mechanical properties of weft knitted fabric, Materials Science (Medziagotyra) 6(3), 2010, pp. 221-225
13. Kurbak A., Alpyildiz T.: Geometrical models for cardigan structures. Part II: Half cardigan, Textile Research Journal 79(18), 2009, pp. 1635-1648, DOI: 10.1177/0040517508102228
14. Rahman S., Smriti S.A.: Investigation on the changes of areal density of knit fabric with stitch length variation on the increment of tuck loop percentages, Journal of Polymer and Textile Engineering 2(3), 2015, pp. 1-4, DOI: 10.9790/019X-0230104
15. Singh R., Pandey R.: A study on machine knitted cotton fabrics: Comparison of physical properties, International Journal of Innovative Science. Engineering & Technology 3(2), 2016, pp. 531-534, http://ijiset.com/vol3/v3s2/IJISET_V3_I2_75.pdf
16. Uyanik S., Topalbekiroglu M.: The effect of knit structures with tuck stitches on fabric properties and pilling resistance, The Journal of the Textile Institute 108(9), 2017, pp. 1584-1589, DOI: 10.1080/00405000.2016.1269394
17. Wasim S.S., Ahmed J.U., Al-Amin MD.: Effect of wales wise increment of tuck loop on fabric width, shrinkage, spirality and areal density of weft knitted fabric, International Journal of Textile Science 6(6), 2017, pp. 143-147, DOI: 10.5923/j.textile.20170606.01
18. Uyanik S., Degirmenci Z., Topalbekiroglu M., Geyik F.: Examining the relation between the number and location of tuck stitches and bursting strength in circular knitted fabric, FIBRES & TEXTILES in Eastern Europe 24, 1(115), 2016, pp. 114-119, DOI : 10.5604/12303666.1170266
19. Wasim S.S., Ahmed J.U., Al-Amin M.D.: Effect of wales wise increment of tuck loop on fabric width, shrinkage, spirality and areal density of weft knitted fabric, International Journal of Textile Science 6(6), 2017, pp. 143-147, DOI: 10.5923/j.textile.20170606.01

20. Emirhanova N., Kavusturan Ya.: Effect of knit structure on the dimensional and physical properties of winter outerwear knitted fabrics, FIBRES & TEXTILES in Eastern Europe 16, 2(67), 2008, pp. 69-74, http://www.fibtex.lodz.pl/article130.html
21. Alpyildiz T., Icten B.M., Karakuzu R., Kurbak A.: The effect of tuck stitches on the mechanical performance of knitted fabric reinforced composites, Composite Structures 89, 2009, pp. 391-398, DOI: 10.1016/j.compstruct.2008.09.004
22. Qiu Y.: The effect of tucking courses` number on performance of knitted fabric, Advanced Materials Research 627, 2013, pp. 353-356, DOI: 10.4028/www.scientific.net/AMR.627.353
23. Kyzymchuk O., Buriak O., Holovnia O.: The influence of tuck stitches number on the properties of knitted fabric, Fashion Industry (2), 2019, pp. 36-41, DOI: 10.30857/2706-5898.2019.2.1 (in Ukrainian)
24. ISO 6330:2012. Textiles - Domestic washing and drying procedures for textile testing
25. ISO 3759:2011. Textiles - Preparation, marking and measuring of fabric specimens and garments in tests for determination of dimensional change
26. ISO 5077:2007. Textiles - Determination of dimensional change in washing and drying
27. BS EN 14971:2006. Textiles. Knitted fabrics. Determination of number of stitches per unit of length and unit area
28. BS EN 14970:2006. Textiles. Knitted fabrics. Determination of stitch length and yarn linear density in weft knitted fabrics
29. ISO 3801:1977. Textiles - Woven fabrics - Determination of mass per unit length and mass per unit area
30. ISO 5084:1997. Textiles - Determination of thickness of textiles and textile products
31. ASTM D2594-20. Standard Test Method for Stretch Properties of Knitted Fabrics Having Low Power
32. Kyzymchuk O., Melnyk L.: Stretch properties of elastic knitted fabric with pillar stitch, Journal of Engineered Fibers and Fabrics 13(4), 2018, pp. 1-10, DOI: 10.1177/155892501882072

DETERMINATION OF COMFORT PRESSURE OF SHOES ON HUMAN FEET

Maryna Leshchyshyn

Kyiv National University of Technologies and Design, Nemirovich-Danchenko st. 2, 01011 Kyiv, Ukraine
marfiichuk@gmail.com

Abstract: *The need to wear comfortable shoes has always been a topical issue for the consumer, but in mass factory production it is not always possible to meet the criteria of shoe comfort for each user due to the individual structure and biomechanical characteristics of his foot. To preserve the natural anatomical structure of the foot in its satisfactory functioning, it is necessary to provide comfort and protect the foot from the environment during the operation of the shoe. On the basis of the comparative analysis of results of anthropometric researches of feet and subjective feelings of footwear comfort the expediency to perfect the footwear designing process by the individual order with the use of a universal shoe model-transformer is proved. These studies provide an opportunity to explore the subjective feelings of foot comfort in footwear, and ensure the production of high quality shoes to individual order using the universal shoe model transformer and a computer system based on an Arduino Uno microcontroller. The results of studies of individual sensations of pressure on the feet by shoes in the state of standing and walking are presented. A study of a two-factor experiment of the dependence of pressure parameters at anthropometric points of the rise and the heel of the foot is presented. The regression equation of the dependence of the shoe comfort level on pressure acting on the foot is obtained. The mathematical model of fitting the shoe model-transformer on the foot is presented.*

Keywords: *anthropometric parameters of the foot, materials, comfort, model-transformer, shoes, computer system, pressure, modulus of elasticity.*

1 INTRODUCTION

From the theory and practice of shoe production it is known that the manufacture of high quality shoes at the level of world trends is one of the main tasks of the fashion industry. The success of the manufacturer and its competitiveness largely depends on the quality of raw materials and components. However, it should be remembered that the rational design, comfort of the product and the microclimate of the foot inside the shoe are the main factors in shaping the requirements for shoes and they must meet international standards. The products are improved annually under the influence of fashion trends, changes in the designer's worldview, as well as according to the development of science and technology. But at each stage of production, raw materials, components and products, as the final product of production, must meet the needs, desires and professional requirements of the consumers at minimal cost.

The best material of shoe uppers is traditionally considered to be natural leather, which provides comfort and high reliability of the product during operation. However, the high cost of raw materials of natural origin gives rise to a significant cost of the resulting products. Today, in the world practice, synthetic leathers and knitted fabrics are widely used to make the uppers of shoes along with natural leather. One of the best knitted materials for making summer shoe uppers is CORDURA AFT® [1]. It is a knitted material made of high-strength polyester and polyamide threads with high resistance to abrasion, tearing and repeated bending. Microfiber leather is made of polyester and polyamide fiber and polyurethane. Microfiber is artificial leather developed by CLARINO [2] a division of Kuraray Co., Ltd., which is a world leader in the production of microfiber nonwovens and continues to be a leading innovator in the production of synthetic leather. CLARINO materials have a wide range of colors, properties and thicknesses. This artificial leather can be used to make the top of special, sports and casual shoes, and can also be used to make the lining. It is resistant to scratches and abrasion, has high adhesion, vapor permeability and resistance to chemicals.

In today's conditions, the topical issue is the production of exclusive products to individual order, which emphasize the status of the customer, his character and preferences. The task of modern small private shoe companies specializing in the production of custom-made shoes is to study the preparatory and basic processes of shoe production, namely: measuring the feet and layout of the product model of different materials, design or adjustment of shoe lasts, shaping the product while tightening shoes on lasts, etc. The solution of the problem of designing and manufacturing comfortable shoes is devoted in the fundamental works of researchers and scientists such as: Liba [3], Fukin [4], Zibin [5], Das [6], Goonetilleke [7], Nadopta [8], Chertenko [9] and others. Creating a comfortable and convenient form of product design is one of the main stages of shoe production, on quality and careful execution of which depends not only the shape stability and comfort of shoes at the stage of operation, but also the appearance of the product.

Quality and affordable footwear should be made by mass production technology, but take into account the individual characteristics of the consumer. A significant role in this sense is played by the process of designing shoes taking into account the anatomical points of the foot. At any, even insignificant deviations of foot from normal indicators the footwear made on the averaged form create a certain discomfort as the foot is an organ with very difficult anatomic structure [10, 11].

The ability of the feet to freely perform full-fledged movements when walking in shoes is one of the main requirements for comfort and quality of footwear. Ideally comfortable shoes can be called ones in which the biomechanical performance of the feet when moving will be identical to those when running without shoes. Creating comfortable shoes is a complex engineering task, because when designing you need to take into account not only the parameters of the foot in statics, but also in the dynamics. The foot is a complex static-dynamic system, the mathematical description of which requires taking into account many factors and individual features in order to ensure a sufficient level of shoe comfort. The effect of the same factor on different feet is completely different. The human foot is one of the important elements of the musculoskeletal system and has a complex structure. It consists of 28 bones, 56 ligaments that hold the bone structures in the correct position and 38 muscles that support the foot. The foot makes contact with the support, redistributes the reaction force of the support to the higher segments and performs an important spring function, provides stability of the lower limb and adhesion to the support surface. The ability of the foot to withstand the load is due not only to biomechanical perfection, but also the properties of its constituent tissues.

2 ANALYSIS OF PREVIOUS RESEARCHES AND SOURCES OF INVESTIGATION

As shown by the analysis of works on the problem of shoe comfort [12-15], we can conclude that the authors considered the comfort of shoes from the standpoint of mass production. Today, more and more consumers are turning to individual tailoring due to factors such as: environmental friendliness, small or large foot size, consumer segment, varieties of exotic leathers, activities (working in show business, celebrity), etc. which require a certain design of shoes. Due to the pursuit of fashion and aesthetic appearance of shoes, most manufacturers generally miss the most important task: to make shoes for consumers that protect the foot from external influences and are comfortable to use.

The force interaction between the foot and the shoe is a very complex process. At the upper of the shoe there are active pressure forces of the back of the foot, and at the bottom of the shoe there are reactive forces of pressure of the plantar part of the foot and active forces of support pressure of the foot [16-19].

The physiological effect of dynamic foot loading depends on many factors: size; places of application and directions of forces acting on the foot; the general scheme of the tense state of the foot, etc. The magnitude, direction and location of the application of force factors acting on the foot, change dramatically during walking and running. The manufacture of individual footwear begins with measurements of the basic anthropometric parameters of the feet, which are taken into account when designing the shoe last. But to create comfortable shoes, it is necessary to take into account the subjective consumer's feeling of pressure on the foot.

Knowledge of footwear as an object of study in terms of actual comfort can be assessed on the basis of sensation and perception by direct consumers. That is, the consumer's perception of shoes can be considered as an integrated image or objective-subjective assessment of shoes, which contains a set of properties that an individual receives through the sensory organs. By its nature, perception, like sensation, is reflexive.

The elasticity of the foot due to individual anatomical and functional features is determined by genetic, age, gender and other multiple factors. Many authors have studied the modulus of elasticity and other physico-mechanical properties of foot tissues. Previously it was established that the normal bone density is 2.4 kg/m^3, Young's modulus is E=2000 MPa, tensile strength is σ=100 MPa, relative deformation reaches 1%. Young's modulus of the tendon is 160 MPa. Collagen material is characterized by a Young's modulus value of 10-100 MPa, and elastin -0.5 MPa [20].

Wright and Rennels [21] first determined the modulus of elasticity of plantar aponeurosis, which was 342-822 MPa. For comparison, these values are in the range of 50-500 MPa, given for connective tissue of other localizations studied in vitro; and exceed the modulus of elasticity of fascial and ligament structures of the foot and leg [22-24].

Adipose tissue of the supporting surface of the foot has a unique structure, which is due to the load that the foot experiences when walking. The amortization capacity of the fat layer in this part of the human body is due to its thickness, size and shape of fat particles, the development of fibroelastic skeleton, which strongly connects the dermis with plantar aponeurosis and periosteum of the overlying bones [25]. The main mechanical characteristic of adipose tissue of the plantar surface of the foot is the modulus of elasticity (Young's modulus), which is normally 1.076-1.364 kg/cm^2 [26]. Researchers Perepelkin, Mandrikov, Krayushkin and Atroshchenko [27] studied the mechanical properties of healthy feet of boys and girls. In this paper, the elastic deformation of the foot in the vertical plane was considered. Normally, the modulus of elasticity of the foot in boys is 616.9 kPa; in girls the modulus of elasticity is 6012 kPa. The authors Hashemi, Chandrashekar and Mansouri [28] found that the increase in tissue rigidity in males is due to increased collagen synthesis, and the decrease in elasticity in women is determined by the smaller number of fibers, their diameter and the relative amount of collagen in each ligament fiber of their foot.

3 MATHEMATICAL MODELLING

The analysis of orders for individual tailoring of shoes showed that when adjusting the parameters of the shoe last on the individual parameters of the foot and fitting the prototype of the shoe, customers often experience certain feelings of discomfort in the area of the rise of the foot. For individual tailoring of comfortable shoes you need to more meticulously determine the parameters of the human foot and based on them, satisfy the wishes of a particular customer. After all, the comfort and safety of the lower limbs during walking and physical activity depend on the right shoes.

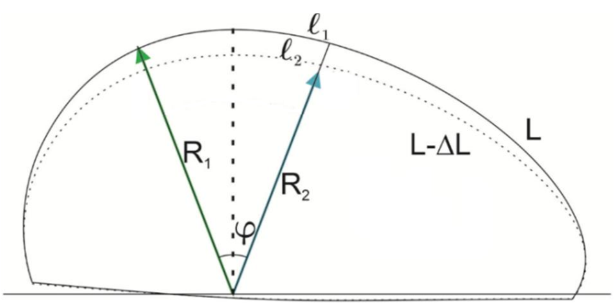


Figure 1 Cross section of the foot at the point of rise: R_1 and R_2 - the outer radius of the deformation zone of the foot before - and after compression, respectively; L - the length of the cross section of the shoe; φ - the central angle of the cross-sectional segment of the foot in the deformation zone; l_1 and l_2 - the length of the shoe upper segment before - and after compression, respectively;

To assess the level of shoe comfort, it is important to analyze the influence of various factors on the pressure exerted by the upper of the shoe on a person's foot in the area of rise. The calculation scheme for determining this pressure is shown in Figure 1.

Assume that the pressure between the foot and the shoe upper at the contact area is equal to the compressive stress in the surface layers of the foot. Then the magnitude of the pressure, according to Hooke's Law:

$$P = k_1 E_1 \varepsilon \tag{1}$$

where: E_1 - modulus of elasticity of the foot; k_1 - coefficient that takes into account the individual elastic properties of the foot; ε - relative deformation of the foot.

The relative compression deformation of the foot in the rise zone can be represented as:

$$\varepsilon = \frac{R_1 - R_2}{R_1} \tag{2}$$

where: R_1 and R_2 - the outer radius of the deformation zone of the foot before - and after compression, respectively.

According to the properties of the circle segment:

$$R_1 \varphi = l_1 \tag{3}$$

$$R_2 \varphi = l_2 \tag{4}$$

where: φ - the central angle of the cross-sectional segment of the foot in the deformation zone; the length of the shoe upper segment before - and after compression, respectively.

Taking into account (2), (3) and (4), the relative compression deformation will be:

$$\varepsilon = \frac{l_1 - l_2}{l_1} \tag{5}$$

The length of the shoe upper segment after tightening the shoe on the foot, taking into account the shortening of the segment will be:

$$l_2' = l_2 + \Delta l_2 \tag{6}$$

where: Δl_2 - the elongation of the segment.

The shortening of the segment will be determined by the ratio:

$$\frac{\Delta l_2}{l_2} = \frac{\sigma}{E_2} \tag{7}$$

where: σ - tensile stresses acting in the segment; E_2 - modulus of elasticity of the segment.

From expression (7) we have:

$$\Delta l_2 = l_2 \frac{\sigma}{E_2} \tag{8}$$

Substituting (7) into (8), after the transformations we obtain:

$$l_2{}' = l_2\left(1+\frac{\sigma}{E_2}\right) \tag{9}$$

Substituting (9) into (5), we obtain:

$$\varepsilon = 1-\frac{l_2}{l_1}\left(1+\frac{\sigma}{E_2}\right) \tag{10}$$

Substituting (10) in (1) we have:

$$P = k_1E_1\left[1-\frac{l_2}{l_1}\left(1+\frac{\sigma}{E_2}\right)\right] \tag{11}$$

We will express tensile stresses in the segment by means of the formula for definition of circular stresses in a cylindrical shell which for our case will be:

$$\sigma = \frac{k_2PR_1}{h} \tag{12}$$

where: k_2 - a coefficient that takes into account the uneven distribution of pressure on the surface of the foot; h - thickness of the segment.

Substituting (12) in (11), we have:

$$P = k_1E_1\left[1-\frac{l_2}{l_1}\left(1+\frac{k_2PR_1}{E_2h}\right)\right] \tag{13}$$

Solving equation (13) with respect to P, we obtain:

$$P = \frac{1-\dfrac{l_2}{l_1}}{\dfrac{1}{k_1E_1}+\dfrac{l_2}{l_1}\dfrac{k_2R_1}{E_2h}} \tag{14}$$

When tightening the length of the cross section of the shoe upper decreases by the value of ΔL. Assume that the length of the cross section of the shoe upper segment adjacent to the deformation zone of the foot will decrease by the value of $l_1 - l_2$ according to the proportion:

$$\frac{l_1-l_2}{l_1} = \frac{\Delta L}{L} \tag{15}$$

From (15) follows:

$$\frac{l_2}{l_1} = 1-\frac{\Delta L}{L} \tag{16}$$

Substituting (16) in (14), we obtain:

$$P = \frac{\Delta L}{\dfrac{L}{k_1E_1}+\dfrac{k_2R_1}{E_2h}(L-\Delta L)} \tag{17}$$

Expression (17) allows you to determine the amount of pressure on the foot at the point of the rise, which affects the feeling of comfort level of shoes.

4 EXPERIMENTAL

According to the results of theoretical and analytical, marketing and experimental research, the paper presents a shoe model-transformer (Figure 1) using a computer system based on the Arduino Uno microcontroller to measure the costumer's level of subjective comfort.

An analog signal will appear on the output terminal when a load is applied to the resistive pressure sensor. The Analogue to Digital Convertor converts this signal into a digital value of the pressure applied to the sensor and displays it on the monitor display.

The model is a blank of the top of the closed leather shoes, with a leather lining, tightened on a men's shoe last, to which is glued a thin, flat sole with a heel, size 275 mm. The shoe model-transformer consists of 7 fasteners on which the scale from 70-100 mm in length is marked, each of which is placed in the corresponding places: 1 - zone of the resistive sensor at the point of direct rise of the foot, 2 - zone of the resistive sensor at the point of the outer bundle of the foot, 3 - zone of the resistive sensor at the point of the inner bundle of the foot, 4 - zone of the resistive sensor at the point of height of the heel of the foot; 5 - the highest point of height of an ankle of a half-shoe (from point C + 70 mm upwards in the center of a crest); 6 - on a direct rise (0.55 foot length); 7 - point of the calcate point C (center of the line of the inner and outer bundles (calcate)); 8 - the middle of the foot on the outside (0.5 foot length); 9 - point of the outer bundles(0.68 foot length); 10 - the middle of the foot on the inside (0.5 foot length); 11 - point of the inner bundle (0.72 foot length), 12 - Arduino UNO microcontroller.

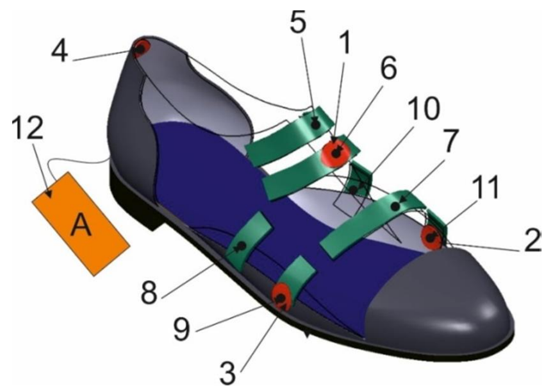


Figure 1 Shoe model-transformer

The computer system consists of the following elements: Arduino UNO microcontroller, 3.3 kΩ resistor, resistive pressure sensor FSR402. The pressure power sensor and voltage divider are connected to the output of the Arduino Uno microcontroller. The supply voltage is 5 V.

Resistive pressure sensors are essentially resistors that change the value of their resistance (in ohms) depending on the force of pressure on the sensitive element.

The principle of operation of the device is as follows. When the pressure applied to the sensor is zero, its resistance will be almost infinite, respectively, the signal from the sensor is also zero.

To evaluate the feeling of comfortable pressure on the foot, the proposed answer options (ranging from minor to significant findings in accordance with the lower to upper thresholds of sensitivity (Table 1), the customer was asked to evaluate in points by direct scaling.

The perception of shoes should always be considered as an integral, objective and complex phenomenon, because it combines human feelings coming from a number of analyzers. Therefore, the actual comfort of the shoes can be established by the results of fitting the experimental shoe model-transformer on the basis of the analysis of the customer's feelings. The following scale of sensations was offered: unsatisfactory condition, severe discomfort, moderate discomfort, perfect comfort.

Table 1 Rating scale for the shoe comfort evaluation

Rating	Feeling of comfort
90-100	Perfect comfort
60-80	Moderate discomfort
30-50	Severe discomfort
1-20	Unsatisfactory condition

Obtaining information on the basis of the measurement of the pressure of the inner surface of the shoe in different parts on the foot taking into account basic anatomical parameters of the foot with the use of shoe model-transformer according to the method [11, 12] involves the following steps:

1. Installation of pressure sensors from the inner space of the shoe in these anthropometric zones, which are attached to the layout with PVC tape;
2. Connection of sensors to the block diagram of the prototype;
3. Fixation of the shoe model-transformer on the customer's foot with the help of "Velcro" fasteners and evaluation of the comfort level of pressure in points 1 to 4 (Figure 1) according to the rating scale (Table 1) at different fixed tightening states of the fasteners;
4. Registration of pressure in points 1 to 4 (Figure 1) and corresponding comfort levels of the shoe model-transformer in the different tightening states of the fasteners in statics and dynamics;
5. Getting results - saving information.
6. Implementation of the necessary automated measurements by comparative, calculation and graphical procedures.

Fixing sensors on the inner surface of the shoe model-transformer allows you to measure the pressure of the inner surface of the shoe upper on the foot in both static and dynamic conditions.

5 RESEARCH RESULTS

When measuring the pressure of the inner surface of the shoe on the foot in areas, where the sensors are installed, the readings of the device are translated into the values of pressure. In the interior of the shoe model-transformer there are 4 resistive pressure sensors FSR402 in the marked areas (Figure 1 (1-4)). On pressing the sensor depending on the resistance value, software uses one of several formulas to calculate the force applied to the sensor and displays its digital value to the monitor.

The values of pressure at different fixed tightening states of the fasteners were estimated by the customer in terms of the feeling of comfort of the foot. Fixed subjective consumer`s scores of comfort levels of pressure when fitting the shoe model-transformer and corresponding pressure values in points 1 to 4 (Figure 1) are given in Table 2.

From Table 2 it follows that the highest estimation of comfort in the conditions of standing the customer feels at tightly fitted fasteners of the shoe to the foot. Fixed pressure on the foot at different points with such tightening is in the range from 8209.1 to 10491.2 Pa.

The next task of the experiment was to determine the comfort level of pressure applied to the foot by the shoe model-transformer when walking (Table 3).

Table 2 Comfort levels of pressure of the shoe model-transformer on the foot while stand

Tightening states of the fasteners:	Detached	Very loosely fitted	Loosely fitted	Fitted	Tightly fitted	Very tightly fitted	Squeezed
Subjective feeling of comfort [mark]	30	70	80	90	100	60	22
The pressure at the measuring point 1 [Pa]	-	688.4	2944.4	8269.5	10491.2	16227.9	16952.8
The pressure at the measuring point 2 [Pa]	-	614.1	2540.7	7475.3	8869.9	14544.8	16090.1
The pressure at the measuring point 3 [Pa]	-	628.0	2221.8	7224.5	9645.0	15070.2	16952.8
The pressure at the measuring point 4 [Pa]	-	628.0	1861.1	4964.3	8209.1	13259.7	15831.8

Table 3 Comfort levels of pressure of the shoe model-transformer on the foot while walking

Tightening states of the fasteners:	Detached	Very loosely fitted	Loosely fitted	Fitted	Tightly fitted	Very tightly fitted	Squeezed
Subjective feeling of comfort [mark]	10	52	79	100	81	61	12
The pressure at the measuring point 1 [Pa]	-	4065.8	8869.9	11039.1	14146.0	16664.9	18860.9
The pressure at the measuring point 2 [Pa]	-	3856.3	8209.1	9367.7	10647.5	13691.0	17818.5
The pressure at the measuring point 3 [Pa]	-	3961.0	8759.5	9922.8	11263.3	14430.8	16090.1
The pressure at the measuring point 4 [Pa]	-	2923.8	7224.5	8209.1	8869.9	11656.4	16377.3

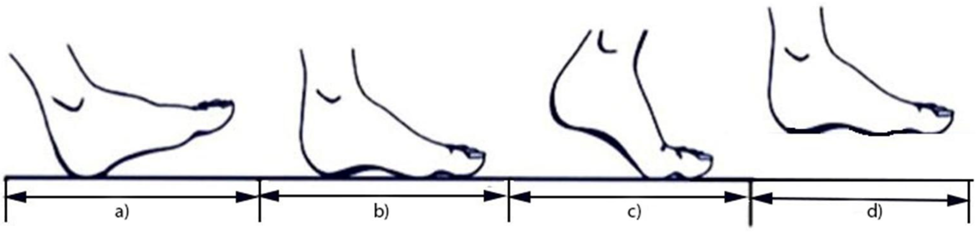


Figure 2 Phases of the step

Walking is a complex cyclic movement involving interaction of the body with the support surface and its change in space. Characteristic of walking is the constant preservation of support on the one or the other foot. The movement of the human body is the result of the interaction of external and internal forces. The external forces are: the force of gravity of the body; support reactions; resistance of the environment. The external forces are generated inside the human body as a result of the interaction of its individual parts [16].

Based on the mechanism of movement when walking the following phases of the step are distinguished [17] (Figure 2):

a. roll around the heel;
b. support on the whole foot;
c. roll around the front section;
d. the transfer period.

To determine the comfortable pressure while walking the same tightening states of the fasteners were ensured as in case of standing.

The results of measurements of subjective comfort level of pressure exerted by the shoe model-transformer on the foot while walking are given in Table 3.

Analyzing data in Tables 2 and 3, we observe a difference in customer's perception of the comfort level of pressure exerted by the shoe model-transformer on the foot while standing and walking. In the state of standing, the highest level of comfort is with the tightly fitted fasteners, and in the state of walking with the fitted fasteners.

Figure 3 shows the results of measuring the pressure of the shoe model-transformer on the foot in selected points while walking with the fitted fasteners.

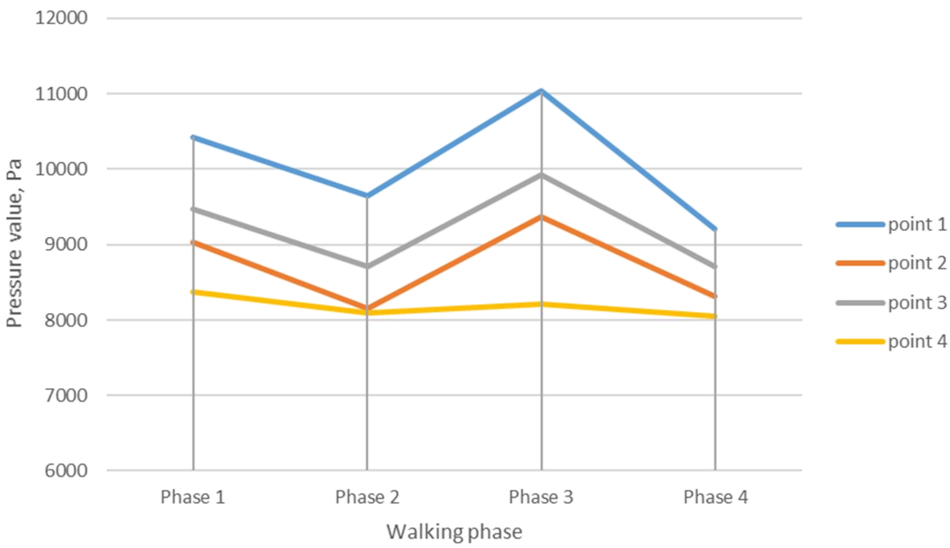


Figure 3 Pressure of the shoe model-transformer on the foot while walking

As a result, it can be noted that the most comfortable pressure in the standing position reaches 10491.2 Pa, and when walking the value increases to 11039.0 Pa. The difference between these values is 547.8 Pa. In order for the customer to feel comfort not only while standing, but also when walking, it is necessary to reduce the pressure on the foot by a difference of 547.8 Pa when adjusting the fasteners in fitted state during standing. Thus the pressure in the statics conditions should be: 10491.2 - 547.8 = 9943.4 Pa. Then, given the magnitude of the increase in pressure when walking, a person will feel comfortable pressure on the foot, equal to that determined in standing conditions.

To study the parameters of the pressure of the inner surface of the shoe on the foot, a two-factor experiment was planned and performed [29]. To identify the dependence of the feeling of subjective comfort C on pressure P_1 and P_4 in points 1 and 4 respectively (Figure 2) in the third most representative phase of walking according to the previous experiment (Figure 3) the method of multifactorial experiment was performed.

The minimum and maximum values of pressure in the points of the rise and the heel are determined by the satisfactory values of measurements of the previous experiment.

Therefore, the maximum values of factors P_1 and P_4 are the following: 16×10^3 Pa and 11×10^3 Pa. The minimum value of the factor P_1 is determined from a previous experiment and is equal to 8×10^3 Pa. The minimum value of the factor P_4 is 5×10^3 Pa.

The experiment was planned using a rotatable Box plan [29] for a two-factor experiment. As a result of processing of the experimental data the function of dependence of level of comfort of footwear on pressure in the point of the rise (P_1) and on pressure in the point of the heel (P_4) of the foot is received:

$$C=-98.6209+4.3473P_1+1.1909P_4+ \\ +0.9375P_1P_4-5.2616P_1^2-6.6987P_4^2 \quad (18)$$

Figure 4 shows the graphical dependence of the foot comfort level on pressure in the points of the rise and of the heel of the foot.

To find the optimal pressure parameters of the comfortable fit of the model to the foot, the relaxation method was used [17]. Thus, it was found that the optimal values of the technological parameters of the process of fitting the template to the foot are the pressure in the point of the rise of 13165 Pa and in the point of the heel of 8251 Pa. At these values of technological parameters the maximum value of level of comfort of footwear 99.611 is reached.

The comfort indicator has a dualistic nature due to the presence of two components - objective, which is determined by the criteria of shoe quality and depends on environmental conditions, and subjective, which is determined by direct organoleptic sensations of the consumer, which dominate in determining the ergonomic properties of shoes.

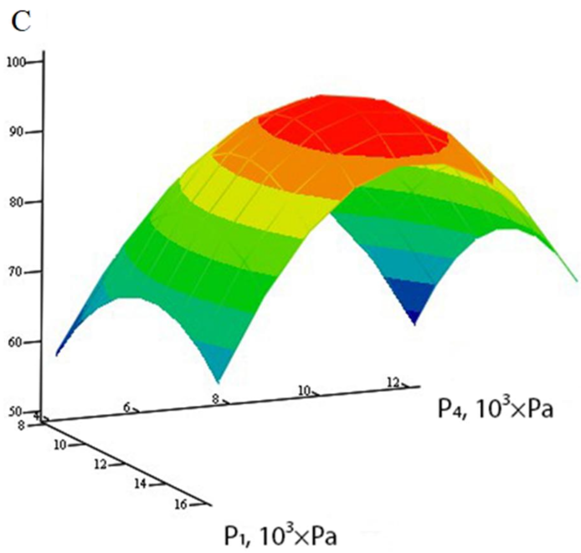


Figure 4 Dependence of the comfort level on pressure in the points of the rise and of the heel of the foot

The aim of the work was to investigate the subjective comfort of the inside shape of shoes on the foot, on the example of an individual consumer by experimental prototyping of shoes.

Given the defined subjective comfort values of pressure at different anthropometric points for the consumer, men's ankle boots were made to order Figure 5.

Figure 5 Men's ankle boots by individual order

6 CONCLUSIONS

Based on a computer system with an Arduino Uno microcontroller and resistive pressure sensors FSR402, a device for determining the pressure between the foot and the inside surface of the shoe has been developed. As a result of the calibration of the device the unambiguous dependence between indications of the device and the values of the measured pressure is established that allows defining pressure of the inside surface of footwear on the foot both in the state of standing, and in the course of walking.

The proposed method of measuring the pressure of the inside surface of the shoe on the foot, taking into account its basic anatomical parameters using the shoe model-transformer of the prototype allows you to design and manufacture comfortable individual shoes for the customer.

The optimal values of technological parameters of the process of fitting the model-transformer to the foot were experimentally determined, as well as recommendations for comfortable tightening of working fasteners on the shoe model were given and the peak comfort pressure was adjusted to ensure comfortable walking in different walking conditions.

The mathematical model of fitting of a template in a separate zone of foot by means of the Shoe model-transformer is developed.

As a result of measuring the pressure in the standing position and walking position, fixed values of comfortable pressure on the foot at different points and at different phases of walking are given. The results of the study of the influence of pressure parameters in anthropometric points of the rise and the heel of the foot are presented. Given the satisfactory pressure values for the customer, a pair of men's shoes was made to order.

7 REFERENCES

1. Knitted fabric CORDURA AFT®, Access mode: https://www.cordura.com/Fabrics/aft-fabric
2. Synthetic leather CLARINO, Access mode: http://www.clarino-am.com/science.php 2
3. Lyba V.P.: Theory and practice of designing comfortable shoes, Doctor's thesis, Moscow, 1996, 314 p. (in Russian)
4. Fukin V.A., Saakulina D.O., Kostylev V.V.: On the complex of properties that determine the comfort of footwear, Leather and Footwear Industry No. 1-2, 1994, pp. 37-38 (in Russian)
5. Zybin Yu.P., Klyuchnikova V.M., Kochetkova T.S.: Designing of leather goods, Light and Food Industry, 1982, pp. 264, (in Russian)
6. Goonetilleke R.S., Luximon A.: Designing for Comfort: A Footwear Application, Computer-Aided Ergonomics and Safety Conference '2001, Das B., Karwowski W., Mondelo P., Mattila M. (Eds.), 2001, pp. 1-6
7. Goonetilleke, R.S.: Designing to Minimize Discomfort, Ergonomics in Design: The Quarterly of Human Factors Applications 6(3), 1998, pp. 12-19, https://doi.org/10.1177/106480469800600304
8. Nadopta T.A.: Principles of analytical modeling of shoe prototype outlines, Bulletin of Kyiv National University of Technology and Design Bulletin of Kyiv National University of Technology and Design 112(4), 2017, pp. 168-173 (in Ukrainian)
9. Chertenko L.P., Tukalo N.M., Garkavenko S.S.: The development of the original design for the development of 3D model functions, Technology and Design 26(1), 2018, pp. 1-12, Access mode: http://nbuv.gov.ua/UJRN/td_2018_1_8 (in Ukrainian)
10. Nadopta T.A.: Anatomical and morphofunctional substantiation of the rational design of low-heeled shoes, Bulletin of Khmelnytsky National University № 1, 2010, pp. 283-286 (in Ukrainian)
11. Ochkurenko O.M., Fedotov O.V.: Human Anatomy: textbook, Kiev, Higher school, 1992, pp. 286-289 (in Ukrainian)
12. Zamarashkin N.V.: Investigation of the patterns of shaping, manufacturing accuracy, the creation of methods and tools for design, processing, control of pads and shoe parts Doctor's thesis of Technical Sciences, LITLP, 1977 (in Russian)
13. Alexandrov S.P., Parshina O. V.: Automatic profiling of the surface of the insole unit, Light and Food Industry No. 8, 1998, pp. 12-16 (in Russian)
14. Nadopta T.A., Soltyk I.T., Mykhaylovska O.A.: Principles of analytical design of the basic basis shoe upper details, Bulletin of Khmelnytsky National University № 5, 2019, pp. 114-120 (in Ukrainian)
15. Lyps'kyy T.M.: Research of the possibility of using progressive 3d technologies for shoe design by individual order, Bulletin of Khmelnytsky National University № 5, 2019, pp. 120-126 (in Ukrainian)
16. Utkin V.L.: Biomechanics of physical exercises, Textbook - manual for students fac. physical education ped, Education No. 2114, 1989, 210 p. (in Russian)
17. Gorbachik V.E.: Fundamentals of anatomy, physiology, anthropometry and biomechanics: a tutorial , Vitebsk: Publishing house of VSTU, 2011, p. 125 (in Russian)
18. Goroshko A., Royzman V., Zembytska M.: Quality and Reliability of Technical Systems: Theory and Practice, Book Series on Vibroengineering, Vol. 2, 2018, p. 310, https://doi.org/10.21595/9786099603636
19. Rumyantseva E.G., Bartosh O.N., Kostyleva V.V.: On the biomechanics of human lower extremities, Design and Technologies № 15, 2010, pp. 32-34 (in Russian)
20. Dubrovsky V.I., Fedorova V.N.: Biomechanics. Textbook for higher and secondary institutions, 2003, 672 p. (in Russian)
21. Wright D.G., Rennels D.C.: A study of the elastic properties of plantar fascia, The Journal of Bone and Joint Surgery 46(3), 1964, pp. 482-492
22. Kitaoka H.B., Luo Z.P., Growney E.S.: Material properties of the plantar aponeurosis, Foot & Ankle International 15(10, 1994, pp. 557-560, https://doi.org/10.1177/107110079401501007
23. Hurschler C., Vanderby R., Martinez D.A., Vailas A.C., Turnipseed W.D.: Mechanical and biochemical analyses of tibial compartment fascia in chronic compartment syndrome, Annals of Biomedical Engineering 22(3), 1994, pp. 272-2799, DOI: 10.1007/BF02368234

24. Kura H., Luo Z.P., Kitaoka H.B., Smutz W.P., An K.N.: Mechanical behavior of the Lisfranc and dorsal cuneometatarsal ligaments: in vitro biomechanical study, Journal of Orthopaedic Trauma 15(2), 2001, pp. 107-110, DOI: 10.1097/00005131-200102000-00006
25. Jahss M.H., Kummer F., Michelson J.D.: Investigations into the fat pads of the sole of the foot: heel pressure studies, Foot & Ankle 13(5), 1992, pp. 227-233 DOI: 10.1177/107110079201300501
26. Lyabakh A.P., Mikhnevich O.E., Zinchenko V.V., Pyatkovsky V.M., Yakimov D.Yu.: Mechanical power of adipose tissue of the adipose surface of the foot in the norm in patients with diabetes and regional atherosclerosis with trophic growth, International Journal of Endocrinology 3(5), 2006, pp. 62 (in Ukrainian)
27. Perepelkin A.I., Mandrikov V.B., Krayushkin A I., Atroshchenko E.S.: Some features of the mechanical properties of the human foot, Bulletin of Volgograd State Medical University 3(59), 2016, pp. 22-24 (in Russian)
28. Hashemi J., Chandrashekar N., Mansouri H., Slautrrbeck R., Hardy D.M.: The human anterior cruciate ligament: Sex differences in ultrastructure and correlation with biomechanical properties, Journal of Orthopaedic Research 26(7), 2008, pp. 945-950, https://doi.org/10.1002/jor.20621
29. Tikhomirov V.B.: Planning and analysis of the experiment (when conducting research in the light and textile industries), Moscow, Light Industry, 1974, 262 p. (in Russian)

QUALITATIVE INDICATORS OF A FIBROUS SEMI-FINISHED PRODUCT (WOOL) FOR THE BASE OF A LAYERED NON-WOVEN MATERIAL

Umida Mirzarakhimovna Maksudova[1], Dilnoza Ziyovutdinovna Pazilova[1], Hamidulla Ne'matullayevich Ahmadov[1], Mavjuda Saidaliyevna Niyazova[1] and Zokhid Normatovich Abdurakhimov[2]

[1]Department of Design and Technology of Leather Products, Tashkent Institute of Textile and Light Industry, Uzbekistan
[2]Academy of the Armed Forces of the Republic of Uzbekistan, Tashkent, Uzbekistan
umida_m_m@mail.ru, dilnoza7474@list.ru, khamid.akhmadov.1990@mail.ru, niyazovamavjuda@mail.ru, zohidabduraximov@mail.ru

Abstract: *With the aim of creating a lining nonwoven laminate for lining winter shoes, the article presents the results of studies of the properties of sheep wool as one of the layers of a composite material. Substantiated: classification of wool, taking into account the countries of origin; technological characteristics of woolen fibrous semi-finished product; for the basis of a layered nonwoven material, semi-coarse sheep wool with an average fiber fineness of 14.5-60 microns and quality class 60 is justified.*

Keywords: *nonwovens, wool, felt, composition, fiber, classification, fineness, semi-finished product, technology, contamination.*

1 INTRODUCTION

One of the priority directions of development of the leather and footwear industry is the development of environmentally friendly technologies for the production of products and the use of effective materials [1]. Currently, one of the main methods for obtaining materials with desired properties is the creation of compositions based on known high-molecular compounds and various ingredients of synthetic or natural origin. When obtaining shoe lining nonwoven compositions, two options are possible: either multilayer structures are created, consisting of layers of various purposes and, accordingly, different structures, or single-layer materials, as a rule, heterogeneous, consisting of various components and having a complex internal structure [2]. Analysis of innovative technologies in the production of lining composite footwear for winter footwear, made it possible to draw a conclusion about the use of combinations of fabrics, natural and synthetic fur, knitwear, nonwovens and polymer films when designing a set of lining materials, depending on the thermal conductivity properties of the components [3]. A characteristic feature of nonwoven composites is a complex, multi-layer structure (fibrous base, base and finishing coatings). Each element of the macrostructure, each layer of the system contributes to the total strength, heat-shielding and other properties of materials, predetermining the period and degree of preservation of the aesthetic, hygienic and other properties of the product [4]. One of the layers of the developed composite non-woven cushioning protective material is felt, which is made by rolling wool fibers [5]. Thus, various types of sheep's wool are the main raw materials for felt. The share of wool in the structure of world fiber production is 57%. The volume of wool produced in Uzbekistan ensures the functioning of the sectors of the national economy and satisfies the population's need for essential clothing. Therefore, wool has a special place in the finished product market.

Wool, as a complex fibrous material, has the ability to easily dye, retain heat and moisture with high strength and low fire hazard. Wool is used in the production of suit and coat fabrics, felted shoes, carpets, rugs, etc. One of the main measures for the effective use of wool is the preservation of its valuable properties at all stages of production during harvesting, storage and primary processing [6]. There are several types of wool: thin, semi-thin, semi-coarse and coarse. Fine wool is characterized by high crimp, strength and other technical properties. They get fine wool from purebred fine-wool sheep, the best fine wool is merino. The highest quality products are made from it [7]. Semi-thin wool consists of coarser fluff or a mixture of fibers that are difficult to distinguish in diameter. The average diameter of all fibers is greater than 25 μm. Semi-coarse wool consists of fluff, transitional fibers and relatively thin awn. Coarse wool consists of a mixture of all types of fibers, with their greater thickness.

The surface of unwashed wool is sticky, so it easily attracts dust and other soil particles. With poor feeding of sheep, the amount of sweat in the unwashed wool increases, and with poor content, the amount of organic (basic) contaminants, which affects the properties of the wool. So, for example, merino wool has much more pollution than wool of other types and therefore it has the lowest yield after washing 35-50%. As a result, the modes of processing wool of different types are not the same [8].

Before washing, the wool is clogged with various impurities introduced from the outside (dust, remnants of roughage, particles of weed vegetation, paint) and secreted by the animal's body (fat, sweat, dandruff, fecal particles). The content of contamination in unwashed wool varies widely from 40 to 70% and depends on many reasons: breed, sex and age of sheep, their feeding and maintenance regime, soil and climatic conditions. The purpose of washing is to remove grease, vegetable and mineral impurities from the wool in order to make it suitable for further processing. When washing wool, a rule is followed: first, the most valuable wool is washed, then the less valuable.

The quality and appearance of woolen products, as well as their wear during operation, largely depends on the primary processing of the wool. Determination of the quality indicators of unwashed wool (type, name, condition, fineness, color, etc.) in accordance with GOST and TU and its distribution into classes is called classification. Industrial sorting of wool is carried out on conveyor lines by dividing fleece into separate parts, representing certain grades with different physical, mechanical and technological properties of fiber. The following indicators are used as a basis for sorting wool: fiber fineness and length, strength, condition, color. In the process of sorting production assortments of wool are formed for further primary treatment and processing. For the acceptance of wool in terms of quality, a control classification is carried out with the selection of wool samples for laboratory tests. Not all wool is subjected to control classification, but only 10-20%, and the results obtained apply to the entire incoming batch of raw materials. The quality of wool is determined by such indicators as fineness, crimp, strength, extensibility, resilience, elasticity, color, shine, moisture, grease content, as well as the percentage of fibers of various types: down, transitional hair and awn. [8].

Analysis of special literature [9, 10] and other sources of information made it possible to establish that, despite the difference in the requirements for wool in different countries, quality characteristics can be distinguished, which, first of all, affect the choice of fiber raw materials for solving a specific problem - creating layered interlining nonwoven fabric.

Wool fiber packages are usually labeled according to the grade (type) established according to the classification of the country of origin. The work carried out a comparative analysis of the classifications adopted in the countries that are the main producers of fibrous semi-finished products (Table 1). The analysis was based on such characteristics as the fineness and class (quality) of wool, which are used in almost all producing countries when classifying wool raw materials at one or another hierarchical level [11]. As can be seen from Table 1, despite the general terminology, each of the countries of wool producers has its own division of wool by grades (types), depending on the fineness of the fiber.

Table 1 Classification of wool by grades (taking into account the country of origin)

Characteristics		Variety (type) according to the classification adopted in the countries			
Class (quality) fineness	Fineness [μm]	Germany, Italy		England	Russia
		for merino	for other breeds		
80	14,5-17,5	ultra-thin	thin	extra thin	thin
	17,6-18,1	super thin	thin	extra thin	thin
70	18,1-18,5	super thin	thin	super thin	thin
	18,6-19,5	thin	thin	super thin	thin
	19,6-20,5	medium thin	thin	super thin	thin
64	20,6-22,5	average	thin	thin	thin
	22,6-23	solid	thin	semi-thin	thin
60	23,1-24,5	solid	thin	semi-thin	thin
	24,6-25	solid	average	semi-thin	thin
58,56,50	25,1-31	solid	average	semi-thin	semi-thin
48	31,1-34,1	solid	average	rough	semi-coarse
	31,5-34	solid	semi-coarse	rough	semi-thin
46	34,1-35,4	solid	semi-coarse	rough	semi-coarse
	35,5-36,1	solid	rough	rough	semi-coarse
46,44	36,1-40	solid	rough	very rude	semi-coarse
40,36,32	40,1-67	solid	rough	very rude	rough

Table 2 Characteristics of the woolen fibrous semi-finished product

№	Type of fibrous semi-finished product	Type of fibrous semi-finished product	Fineness [µm]	Fiber length [mm]
1	Combed tape	Wool, combed and stretched in the form of a ribbon	14.5-60	30 and more
2	Cardoches	Carded wool, but not decorated with a combed ribbon	16-60	up to 55
3	Sliver	Coarse, unpeeled, undyed and unbleached, combed sheep's wool, without guard hairs	23-25	up to 55
4	Whitewash	Long, combed and bleached wool	18-20	30 and more
5	Tow	Fibers left after brushing the wool and combed tape	2-60	up to 55

Fineness is one of the most important indicators in the assessment and classification of wool. The fineness is determined by measuring the cross-sectional diameter of the woolen fiber and is expressed in fractions of a millimeter - micrometers (µm). The fineness of the coat depends on the breed, conditions of feeding and maintenance, the sex of the animals, their age and individual characteristics. The average fineness of the fibers of the fluff is about 10-25 µm; transitional hair 30-50 µm; awn 50 µm and more [10].

Depending on the fineness, homogeneous wool is divided into 13 classes, called qualities, which are designated by the numbers 80, 70, 64, ... 32. The fineness of the wool affects the possibilities of using the fibrous semi-finished product in the production of felt and the properties of the finished fabric.

In addition to fineness, when classifying sheep's wool, length is used as the main division - as a characteristic of its quality, which ranges from 20 to 450 mm. Depending on the length, a distinction is made between short-wavy (fiber length less than 55 mm) and long-wavy (more than 55 mm length) wool. The length of woolen raw materials mainly affects the peculiarities of yarn production, and is not of fundamental importance for felting. Other characteristics of wool quality do not affect the assessment of wool raw materials by the felt manufacturer.

Sheep wool in felting is used as a fibrous semi-finished product. Currently, there are several types of woolen fibrous semi-finished product used as raw material for felting (Table 2). The most widespread is the combed tape and carding [10,12]. The main advantage of the combed tape is that its use allows you to control the location of wool fibers in the thickness of the felt. Since all the fibers in the thickness of the felt are located in the same direction, with the correct layout, which implies a change in the direction of the fibers in each layer, it is possible to create a material with different properties in different areas. Wool with a fineness of less than 18 mm is produced mainly in the form of a combed tape; therefore, for the production of thin uniform webs, it is also desirable to use this type of fibrous semi-finished product. Unlike combed tape, carded tape does not make it possible to create a more uniform texture of the material, but it makes it possible to roll more form-stable things without additional impregnation with adhesives.

Also, the types of fibrous semi-finished product include sliver, whitewash and waste. Sliver - coarse, unpeeled, undyed and unbleached sheep's wool without guard hair; it is used mainly for the inner layer in thick, hard products - carpets, headdresses. Whitewash - combed, bleached and stretched wool, which can be easily dyed in the desired color, a surface layer or a light background of the product is created from it. Waste is small hairs of sheep's wool left after brushing the wool and is used to make felt.

2 CONCLUSION

Thus, based on the results of exploratory experiments and analysis of literature data, we can conclude that as a fibrous semi-finished product for the base of layered nonwoven material semi-coarse sheep's wool is justified. A combed ribbon (average fiber fineness 14.5-60 µm; fiber length 30 mm and more, quality class 60) is justified as a type of fiber semi-finished material, which allows to create thin uniform webs and control the arrangement of wool fibers in the thickness of the layered lining of footwear material.

3 REFERENCES

1. Klimova L.A., Dokholyan S.A.: Design of footwear to ensure human eco- and biocomfort, Science-intensive technologies at the service of human ecology, monograph, Novocherkassk, LIK, 2015, pp. 98-101 (in Russian)
2. Cherunova I.V (Ed.): Innovative nonwovens for medical use, Science-intensive technologies at the service of human ecology, monograph, Novocherkassk, VCI, 2015, pp. 43-46 (in Russian)
3. Maksudova U.M., Rafikov A.S., Mirzaev N.B.: Theoretical foundations of obtaining lining composite materials, International Journal of Advanced Research in Science, Engineering and Technology 5(10), 2018, pp. 6994-6996
4. Maksudova U.M., Mirzaev N.B., Pazilova D.Z., Sheraliev Sh.Sh.: Analysis of innovative technologies in the manufacture of composite lining materials, International Journal of Advanced Research in Science, Engineering and Technology 5(10), 2018, pp. 7013-7015

5. Maksudova U.M.: Fundamentals of creating import-substituting polymer materials for the production of leather goods, Report on scientific research, Work under the grant OT-F7-41-2017, Tashkent, 2020, 115 p. ((in Russian)
6. Gorbunova L.S., Rogachev N.V., Vasilieva L.G., Koldaev V.M: Primary processing of wool, Textbook for the studios, Institution, Easy and Food Industry, Moscow, 1981, 352 p. (in Russian)
7. Dzhabarova G.A.: Development of technology for simultaneous washing and disinfection of sheep wool using electrochemically activated chloride solutions, Dissertation of the candidate of veterinary sciences, Moscow, 2008, 161 p. (in Russian)
8. Rogachev N.V., Vasilyeva L.G., Timoshenko N.K., et al.: Wool. Primary processing and the market, Timoshenko N.K. (Ed.), Moscow, 2000, 600 p. (in Russian)
9. Maksudova U.M., Akhmadov Kh.N., Niyazova M.S.: Innovative technologies in the production of composite lining materials, Composite Materials Magazine No. 2, 2019, p. 122 -124 (in Russian)
10. Muntyan V.A.: Analysis of technological processes and devices for primary processing of wool, NTP and Production Efficiency No. 1, 2010, pp. 62-65 (in Russian)
11. Zhogova M.V., Sheromova I.A.: Analysis of the raw material base for the production of felt, Troitsk worsted factory: wool for felting, available 10.03.2018 on: http://www.troitskwool.com/wool-for-felting/ (in Russian)
12. Strong A.B.: Plastics: Materials and Processing, 3rd ed., Pearson, 2005, 944 p., ISBN: 0131145584

MAGNETIC NANOTECHNOLOGY IN THE PRODUCTION OF FOAMED TEXTILE MATERIALS FOR MEDICAL PURPOSES

Mykola Riabchykov, Alexandr Alexandrov, Yuriy Sychov, Tetiana Popova and Svitlana Nechipor

Ukrainian Engineering Pedagogic Academy, Universitetskaya st. 16, 61003 Kharkov, Ukraine
nikolryab@uipa.edu.ua

Abstract: *A new technology for creating foam materials for medical purposes is proposed. This process involves the addition of magnetite nanoparticles followed by foaming under magnetic field conditions. An experimental device that allows to regulate the magnetic field voltage has been created. Experimental studies have shown that under conditions of magnetite content of 0.1-0.3%, magnetic field strength of 1-3.10^{-3} Tesla significantly improves the performance of the foamed material. The variance of the size of the foam cavities decreases. The number of cavities and the degree of foaming increases. In the case of magnetic field voltage regulation, the average cavity size can be predicted. Ensuring the required size of the cavities creates the preconditions for the manufacture of wound dressings with the specified parameters of exudates removal.*

Keywords: *foamed textile materials, nanotechnology, magnetite, statistical distribution, magnetic technology.*

1 INTRODUCTION

Foam materials are widely used in the chemical, building, food industries [1-3]. One of the current areas of use of foam materials, which is actively developing in recent years, is the creation of foam dressings for the treatment of wounds. Due to the porous structure in such materials, a negative pressure is created, which helps to remove exudates from purulent wounds, which accelerates their healing [4, 5]. Thus, in [6, 7] the main characteristics of foamed materials used in medicine are described. The main indicators of action materials include the average pore size, the percentage of porosity, which determines the ratio of pore volume to the total volume of foamed material [8, 9]. It should be noted that the variation in pore size for existing technologies is quite large. According to [8], the average pore size has a rather large scatter (50-130 μm), which raises the question of the actual regulation of the exudates removal process and implies the need to improve existing technologies. The importance of simultaneous therapeutic effect on the removal of exudates and giving the materials antimicrobial properties is also noted [10, 11]. Some publications determine the possibility of using foamed materials with magnetic properties [12, 13]. The basis of this study is the use of nanomagnetic powder, produced by technology developed at the Ukrainian Engineering Pedagogic Academy. Its main properties are nanosized particles, magnetic properties, indifference to hygienic properties, as evidenced by a set of studies [14, 15].

The idea of this study is that nanoparticles of magnetic material associated with particles of foaming material under magnetic field conditions are included in the force interaction together with the particles of the mixture. The control of the magnetic field can allow to direct the magnetic forces acting on these particles in a direction favourable to the process.

If we are talking about products with the formation of foam, such as foam dressings, the positive direction of the process can be considered as leading to an increase in the proportion of cavities in the material, increasing the number of cavities forming foam, reducing the dispersion (scatter) of cavity sizes, alignment of their sizes, control over the sizes is possible that can create the set cavities. If we imagine a cavity of foam in the form of a gap sphere, then in the normal course of the technological process it is difficult to identify the forces that create and maintain such a cavity. At the same time, the magnetic nanoparticles in the magnetic field associated with the particles of the product in which the foam is created, under the action of the magnetic field are able to stretch it, creating favourable conditions for creating and maintaining the shape of the cavities.

Research hypothesis - the foaming process in the process of manufacturing foamed dressings will improve if magnetic nanomaterials are used if the foaming process takes place in a magnetic field.

2 EXPERIMENTAL PART

The main method of research was an experiment in the manufacture of foamed materials in a magnetic field, followed by measuring the volume of foam, conducting microscopic studies to determine the size of the microcavities of the foam, the dispersion of their size and the density of their location.

The basis of the experimental setup (Figure 1) is an annular electromagnet having an annular core 1, electric windings 2, which are connected via an autotransformer 3 to the electric current network. The autotransformer regulates the voltage and, accordingly, the strength of the electric current in the plates, resulting in a magnetic field inside the electromagnetic. The indicator of the magnetic field is its voltage, as well as magnetic induction.

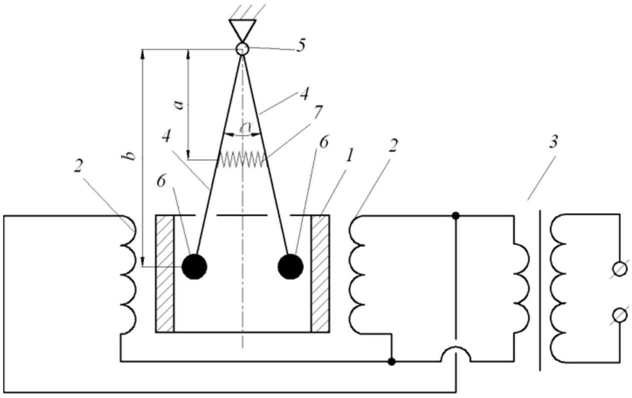


Figure 1 Device for determining the magnetic induction of the annular electromagnet

The voltage of the magnetic field *H*, measured in amperes [A] ,divided by a meter, is related to the magnetic induction B (unit of measurement Tesla [T]) by the expression $B=\mu_0 \cdot H$, where $\mu_0=4\pi.10^{-7}$ [Henri/m] is the magnetic constant.

The force of attraction that arises in this case can be defined as:

$$F = \frac{B \cdot H}{2} A = \frac{B^2 A}{2\mu_0} \tag{1}$$

where. *A* is the area of the surface attracted.

The magnetic field voltage, like magnetic induction, is generally very difficult to measure directly. To assess this value, a measuring device was developed, which includes two rods 4, hinged to the support 5. Two steel (magnetic) balls 6 are suspended on the rods (Figure 1). In the middle part of the rods are connected by a spring 7. The distance from the support to the spring *a*=100 mm, the distance from the support to the balls *b*=200 mm.

When current is applied to the windings of the electromagnet there is a magnetic field that attracts the balls, as a result of which the spring is stretched, the angle *α* between the rods changes. Having measured the angle of dilution of the balls at different currents in the electromagnet, we can construct the dependence of the magnetic field voltage on the current in the windings of the electromagnet (Figure 2).

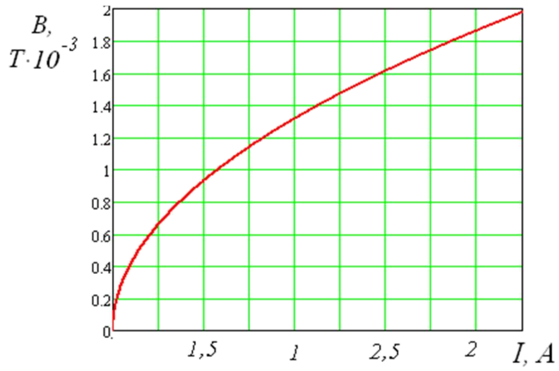


Figure 2 Diagram in the coordinates "Current - magnetic field induction"

The ability to adjust and determine the value of magnetic induction allows you to plan and conduct an experiment on the effects of magnetic fields on the parameters of the foamed material.

The traditional technology of manufacturing polyurethane foam for wound dressings consists of mixing isocyanate prepolymer and a polyol in the presence of a blowing agent [16], (Figure 3). During the experiment in the magnetic chamber (Figure 4) polyurethane foaming was performed.

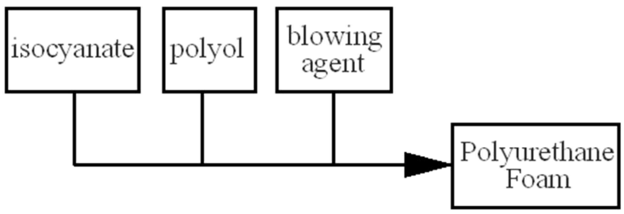


Figure 3 Traditional technology of production of the foam polyurethane

3 INFLUENCE OF MAGNETITE CONTENT AND MAGNETIC FIELD STRENGTH ON FOAM PARAMETERS

The first result was the volume of the product, depending on the magnetite content and the magnetic field induction. The volume of the foam was divided by the initial volume.

Figure 5 shows the increase in volume depending on the content of magnetite when processed in a magnetic field of 0.1 mT. Similar curves are constructed in the differences of volume increase in percentage (*P*) - increase in magnetite content in percentage (*M*) for different values of magnetic field induction (Figure 6).

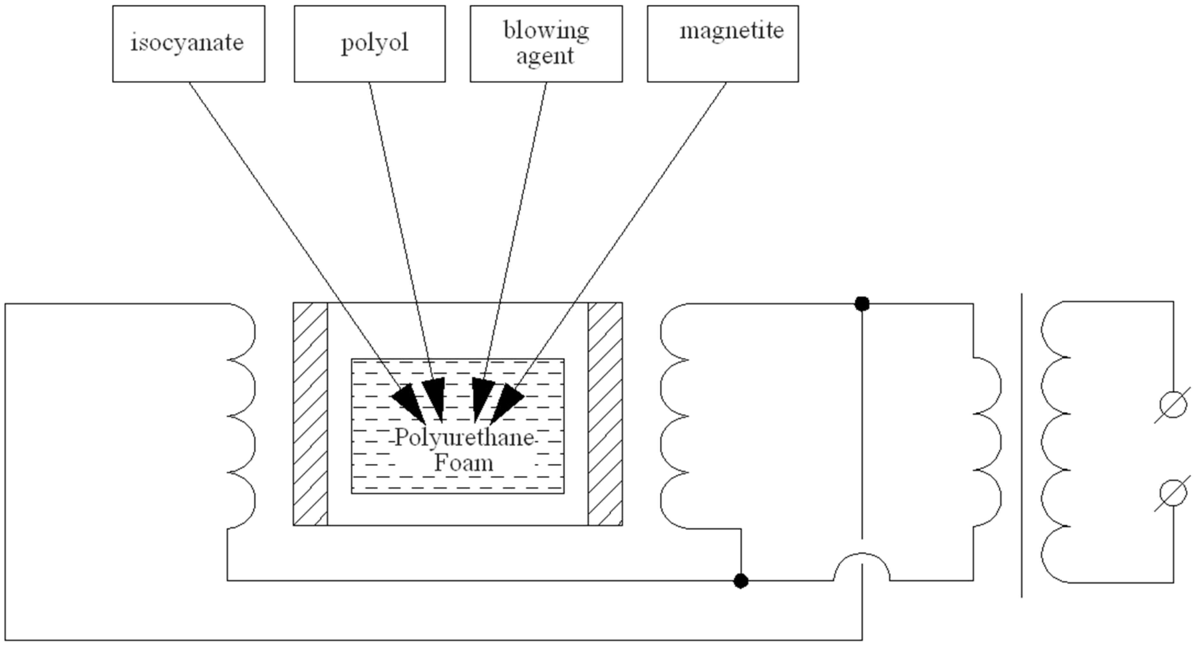


Figure 4 Foaming technology in a magnetic field

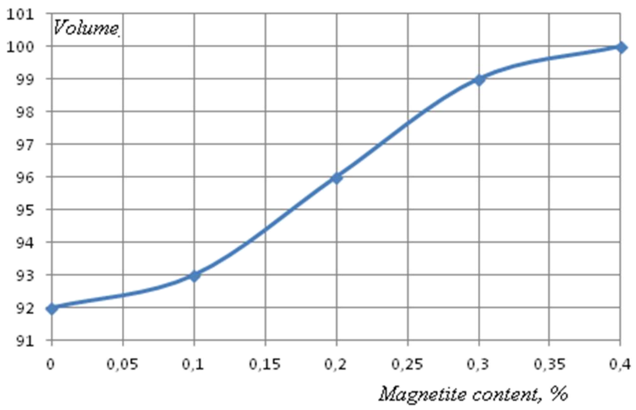


Figure 5 Curve of volume dependence on magnetite content

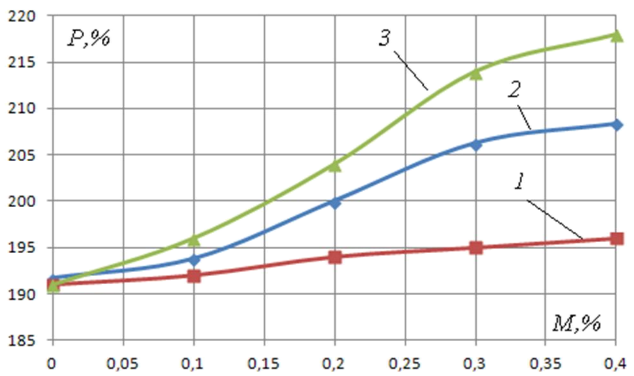


Figure 6 Percentage of increase in foam for samples with different composition of magnetite, 1) without the action of a magnetic field, 2) in a magnetic field of 1 mT and 3) in a magnetic field of 2 mT

The results show an increase in foaming with increasing magnetite composition and magnetic field strength, and at certain magnetite content there is a saturation, at which the effect of foam growth decreases. The same considerations apply to the effects of increasing magnetic field induction.

A drop of the mixture was taken for each sample at the end of the process and examined under a microscope. Typical photographs at different magnifications are shown in Tables 1-3.

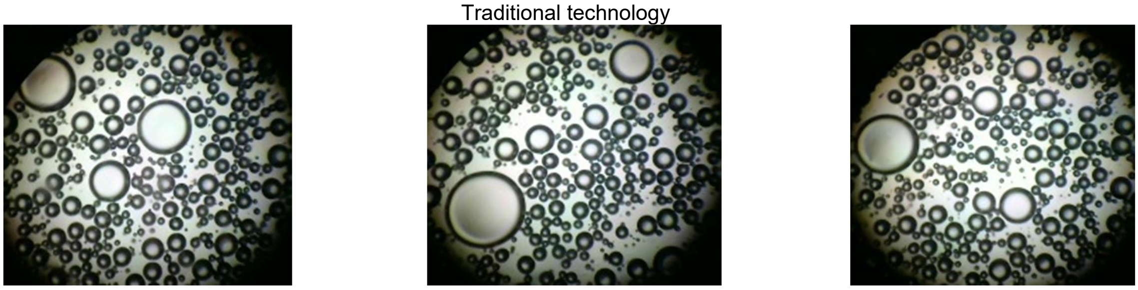
The analysis of the results shows a clear tendency of positive changes in the characteristics of the foamed material in the case of the addition of magnetite nanoparticles, especially in the case of the action of a magnetic field during the technological process. Moreover, in the case of foaming the material in a magnetic field without filling the magnetite, no noticeable effects are observed.

The presence of magnetite content, even in small volumes in the case of a magnetic field, leads to an increase in the number of cavities in the foamed material (Figure 7), a decrease in their average size (Figure 8) and a significant decrease in cavity size dispersion (Table 1). Quite a large effect of changing the parameters of the foamed material in the presence of magnetite nanoparticles gives an increase in the magnetic field strength (Table 2).

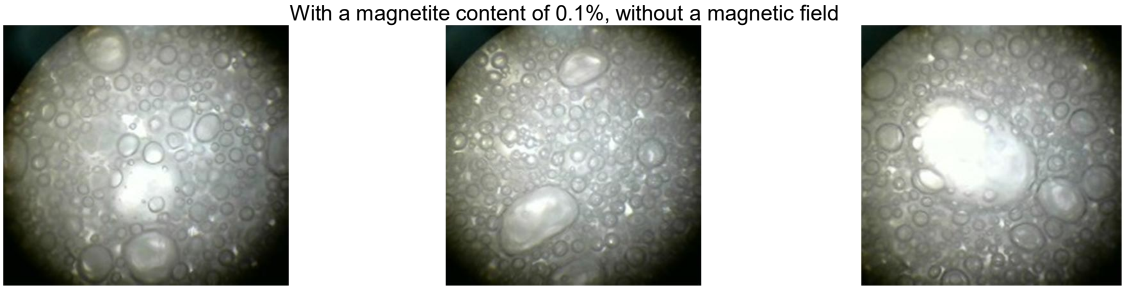
At the same time the dispersion of the sizes of cavities considerably decreases, their sizes decrease. The obvious dependence of the average size of the cavities on the magnetic field voltage in terms of the content of magnetite allows you to create adjustable technological conditions to ensure the specified size of the cavities.

Table 1 Typical photomicrographs of foam involving magnetite and magnetic field, magnification 100x

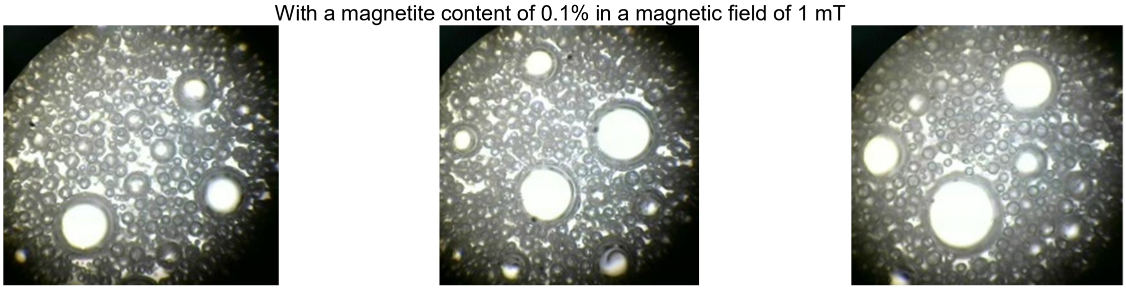
Traditional technology



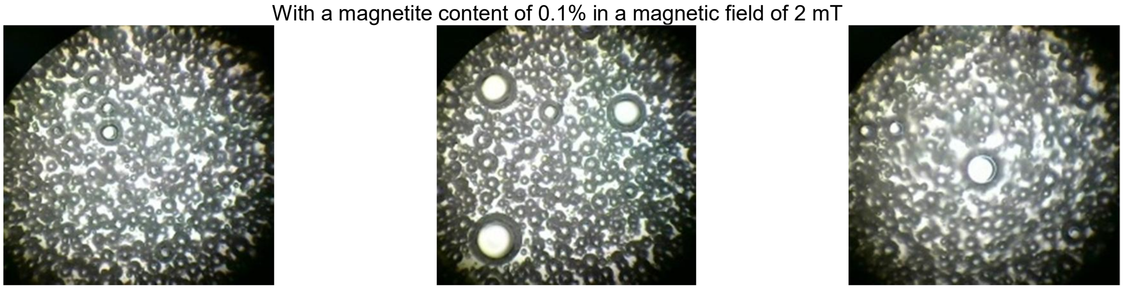
With a magnetite content of 0.1%, without a magnetic field



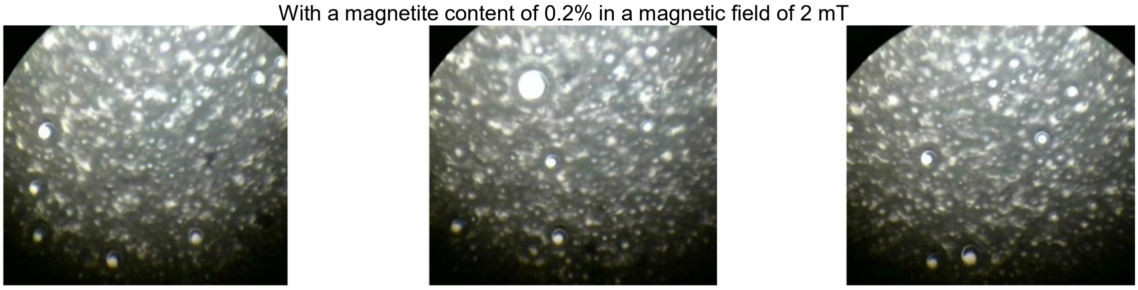
With a magnetite content of 0.1% in a magnetic field of 1 mT



With a magnetite content of 0.1% in a magnetic field of 2 mT



With a magnetite content of 0.2% in a magnetic field of 2 mT



With a magnetite content of 0.3% in a magnetic field of 2 mT

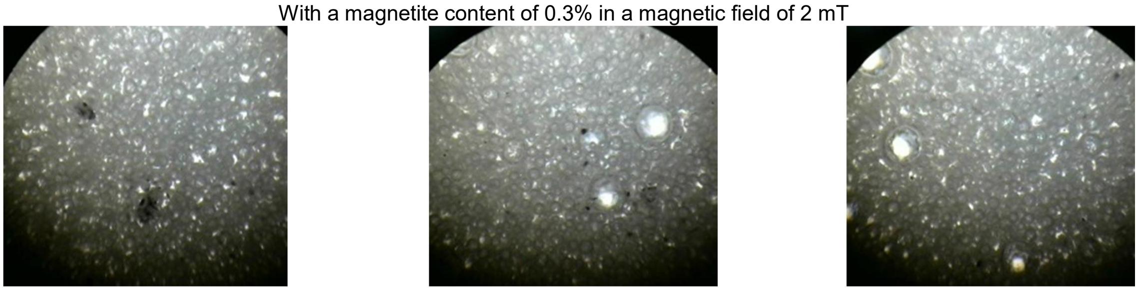
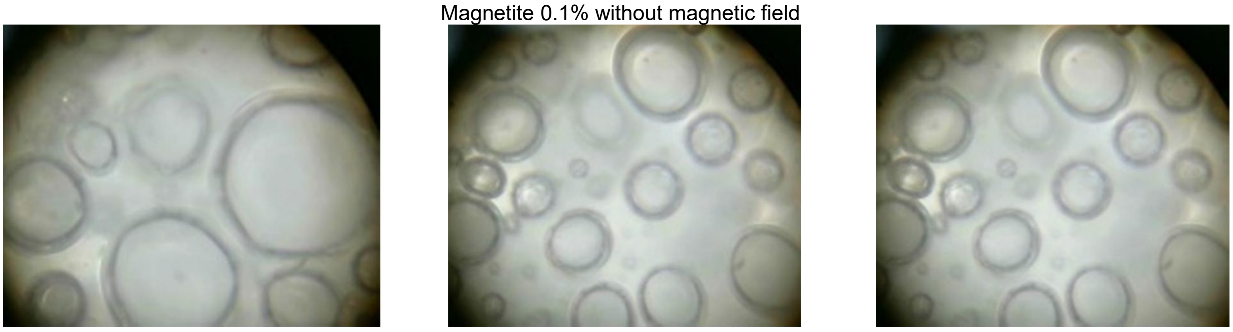
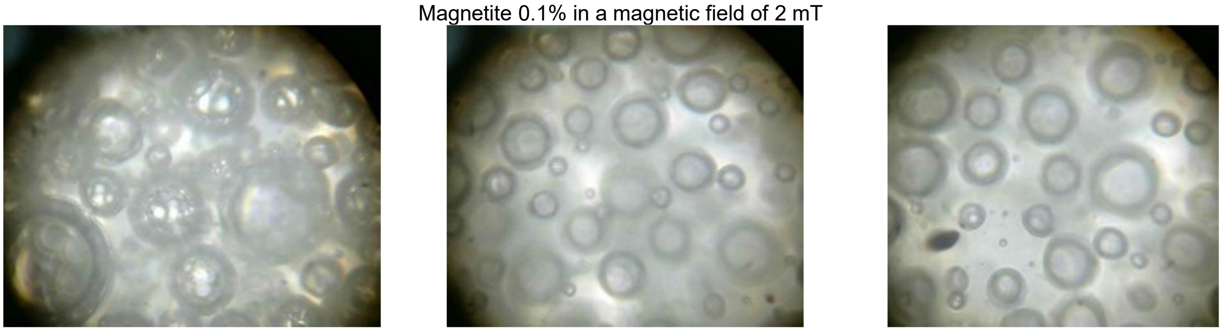


Table 2 Typical photomicrographs of foam involving magnetite and magnetic field, magnification 400x

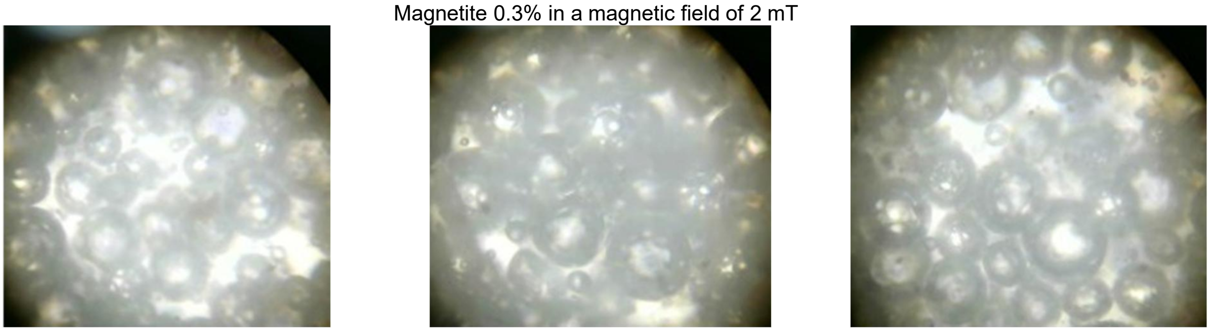
Magnetite 0.1% without magnetic field



Magnetite 0.1% in a magnetic field of 2 mT



Magnetite 0.3% in a magnetic field of 2 mT



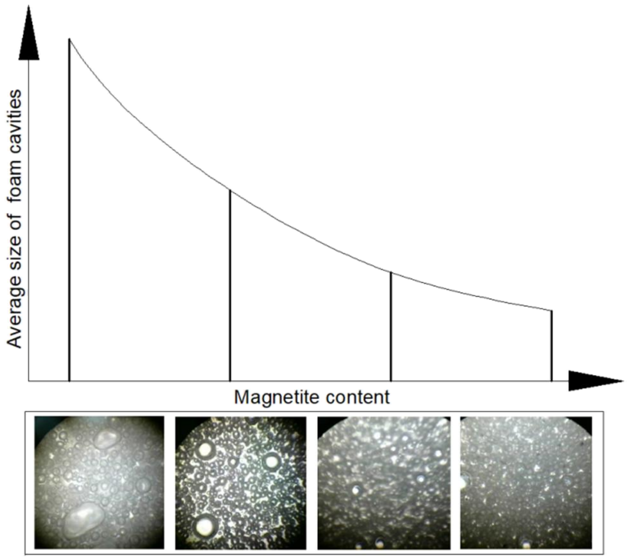


Figure 7 The average size of the foam cavities depending on the content of magnetite

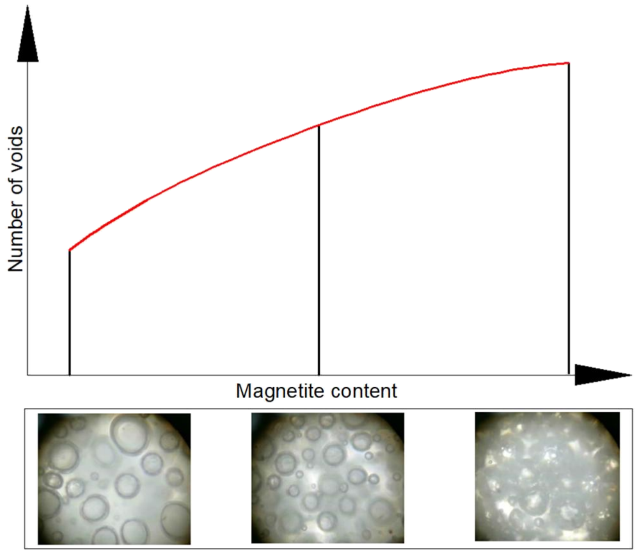


Figure 8 The number of cavities depending on the content of magnetite

This fact, in turn, allows you to create foamed materials with specified sorption properties. In particular, when creating medical materials for the treatment of wounds, it is possible to ensure the regulation of the intensity of exudates removal from the wound, including taking into account the time of treatment.

4 CONCLUSION

The use of magnetite nanoparticles in foaming technologies increases the efficiency of processes and the quality of results. The proposed technology provides for the presence of a magnetic field with the possibility of regulation. In order to provide the magnetic properties of the material to be foamed, it is added ferromagnetic powder with nanoscale. Magnetic field strength 1-2.10^{-3} T with a magnetite content of 0.1-0.4% increases the volume of foam by 5-7%. The average size of cavities decreases by 1.5-2 times, the number of cavities increases by 1.5-2 times. The dispersion of the sizes of cavities considerably decreases, thus the made foam material acquires more stable predicted properties. The proposed method provides the ability to adjust the magnetic field voltage. This fact allows you to create materials with a given size of cavities. As a result, it is possible to create medical materials for the treatment of wounds with the specified parameters of exudates removal.

5 REFERENCES

1. Zhang Y.Q., Yang, X.B., Wang Z.X., Long J., Shao L.: Designing multifunctional 3D magnetic foam for effective insoluble oil separation and rapid selective dye removal for use in wastewater remediation, Journal of Materials Chemistry A 5(16), 2017, pp. 7316-7325, https://doi.org/10.1039/C6TA11252H
2. Parveen F., Berruti F., Briens C., McMillan J.: Effect of fluidized bed particle properties and agglomerate shape on the stability of agglomerates in a fluidized bed, Powder Technology 237, 2013, pp. 46-52, https://doi.org/10.1016/j.powtec.2012.12.057
3. Suet Li T., Sulaiman R., Rukayadi Y., Ramli S.: Effect of gum Arabic concentrations on foam properties, drying kinetics and physicochemical properties of foam mat drying of cantaloupe, Food Hydrocolloids 116, 2021, 106492, https://doi.org/10.1016/j.foodhyd.2020.106492
4. Faust E., Opoku-Agyeman J.L., Behnam A.B.: Use of negative-pressure wound therapy with instillation and dwell time: An overview, Plastic and reconstructive surgery 147(1S-1), 2021, pp. 16S-26S, doi: 10.1097/PRS.0000000000007607
5. Kim P.J., Applewhite A., Dardano A.N., et al.: Use of a novel foam dressing with negative pressure wound therapy and instillation: Recommendations and clinical experience, Wounds 30(3), 2018, pp. S1-S17, PMID: 29723142
6. Wojcik M., Kazimierczak P., Benko A., et al.: Superabsorbent curdlan-based foam dressings with typical hydrocolloids properties for highly exuding wound management, Materials Science and Engineering: C 124, 2021, 112068, https://doi.org/10.1016/j.msec.2021.112068
7. Vivcharenko V., Wojcik M., Palka K., Przekora A.: Highly porous and superabsorbent biomaterial made of marine-derived polysaccharides and ascorbic acid as an optimal dressing for exuding wound management, Materials 14(5), 2021, 1211, doi: 10.3390/ma14051211
8. Lundin J.G., McGann C.L., Daniels G.C., Streifel B.C., Wynne J.H.: Hemostatic kaolin-polyurethane foam composites for multifunctional wound dressing applications, Materials Science and Engineering: C 79, 2017, pp. 702-709, DOI: 10.1016/j.msec.2017.05.084
9. Liu X., Niu Y., Chen K.C., Chen S.: Rapid hemostatic and mild polyurethane-urea foam wound dressing for promoting wound healing, Materials Science and Engineering: C 71, 2017, pp. 289-297, https://doi.org/10.1016/j.msec.2016.10.019
10. Kim W.I.I., Ko Y.-G., Park M.R., Jung K.H., Kwon O.H.: Preparation and characterization of polyurethane foam dressings containing natural antimicrobial agents for wound healing, Polymer - Korea 42(5), 2018, pp. 806-812
11. Dou Y., Chen Y., Zhang X.: Non-proinflammatory and responsive nanoplatforms for targeted treatment of atherosclerosis, Biomaterials 143, 2017, pp. 93-108, DOI: 10.1016/j.biomaterials.2017.07.035
12. Zhang X., Pan Y., Gao Q.: Facile fabrication of durable superhydrophobic mesh via candle soot for oil-water separation, Progress in Organic Coatings 136, 2019, 105253, https://doi.org/10.1016/j.porgcoat.2019.105253
13. Valentina V., Auria M.D., Sorrentino L., Daniele D., Pantani R.: Foam injection molding of magneto sensitive polymer composites, AIP Conference Proceedings 2055(1), 2019, 060012, https://doi.org/10.1063/1.5084844
14. Riabchykov M., Alexandrov A., Tsykhanovska I.: Distribution of the sizes of microcapsules in two-phase emulsions for treatment of textile materials, Vlakna a textil (Fibres and Textiles) 26(4), 2019, pp. 47-52
15. Riabchykov M., Sychov Y., Alexandrov A., Nikulina N.: Bacteriostatic properties of medical textiles treated with nanomaterials based on Fe_2O_3, IOP Conference Series: Materials Science and Engineering 1031, International Conference on Technics, Technologies and Education 2020 (ICTTE 2020), 4-6 November 2020, Yambol, Bulgaria, 2021, pp. 1-5, https://doi.org/10.1088/1757-899X/1031/1/012036
16. Sambasivam M., White R., Cutting K.: Exploring the role of polyurethane and polyvinyl alcohol foams in wound care, chapter 12, In: Wound Healing Biomaterials, Volume 2: Functional Biomaterials, 2016, pp. 251-260, https://doi.org/10.1016/B978-1-78242-456-7.00012-X

THE INFLUENCE OF THE CURVATURE RADIUS OF THE GUIDING SURFACE ON THE TENSION OF POLYETHYLENE AND POLYAMIDE COMPLEX YARNS DURING PROCESSING ON WEAVING AND KNITTING MACHINES

Volodymyr Shcherban'[1], Oksana Kolysko[1], Gennadiy Melnyk[1], Marijna Kolysko[1], Ludmila Halavska[1] and Yuriiy Shcherban'[2]

[1]Kyiv National University of Technologies and Design, Nemirovicha-Danchenko str. 2, 01011 Kyiv, Ukraine
[2]Department of Light Industry Technologies State Higher Educational Establishment «Kyiv College of Light Industry» Ivana Kudri str. 29, 01601 Kyiv, Ukraine
melnik2000@ukr.net

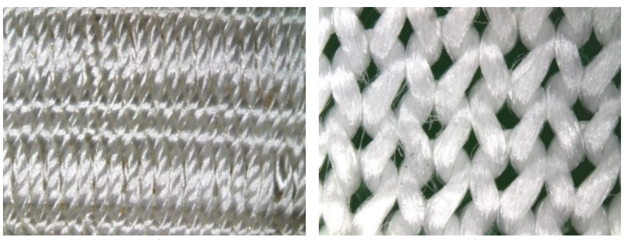
Abstract: *Researches that have been carried out to determine polyethylene and polyamide multifilament yarns tension when interacting with guides and operative parts (of large and small curvature) of looms and knitting machines, helped to establish the mechanism for the process of increase in polyethylene and polyamide multifilament yarns tension after the guide which can be attributed to friction forces in the contact area. It has been proved that increase in tension is explained by varying contact angle between polyethylene and polyamide multifilament yarns and large curved and small curved guides; notably, actual angle for multifilament yarns will be larger comparing to nominal one due to distortion of yarn's cross-section in the contact area. Based on experimental researches for polyethylene and polyamide multifilament yarns, regression dependencies were obtained between the value of tension for polyethylene and polyamide multifilament yarns after the guides and tension before a guide, radius of guide surface curve, a contact angle. Analysis of these regression dependencies allowed to establish extreme values of guide's curve radius at which tension will have the minimum value. As a result, it has been made possible (still at the initial stage of the computer aided manufacturing and usage of recursion) to determine polyethylene and polyamide multifilament yarns tension before fabric and knit formation area depending on geometric and design parameters of equipment and their mechanical and physical properties. Thereby leading to decrease in polyethylene and polyamide multifilament yarns breakages, increase in looms and knitting machines performance due to reduced downtime, and improvement of quality of manufactured fabric and knit. Whereby, we can state that the offered engineering solutions are practically attractive. In particular, the latter deal with determining most suitable geometrical dimensions of guide and operative parts of looms and knitting machines, at which output tension will have minimum necessary value. The procedure has been determined to regulate directionally the process of change in yarns tension at looms and knitting machines by fitting of geometrical dimensions of large curved and small curved guides for polyethylene and polyamide multifilament yarns.*

Keywords: *polyethylene and polyamide multifilament yarn, tension, large curved and small curved guides, contact angle, guide's curve radius.*

1 INTRODUCTION

Industrial fabrics made of polyamide multifilament yarns (Figure 1a) and knits made of polyethylene multifilament yarns (Figure 1b) are the most commonly used in different industry spheres [1-5]. It can be explained by their unique physical and mechanical properties.

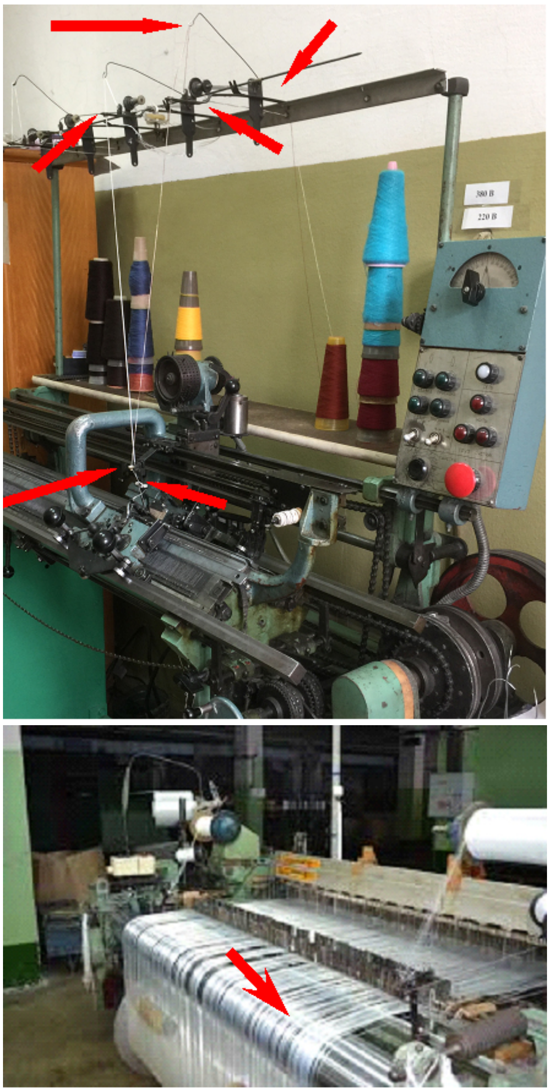
Determination of the value of yarn tension in the working site of technological machine during spun yarn rewinding [6, 7] (loom [8-10], knitting machine [3, 4, 11-14]) makes it possible to evaluate progress density of technological process. The main peculiarity of the most technological processes in textile industry is interaction between yarns and guides and operative parts of large and small curvature [9, 11].



a) b)

Figure 1 Industrial fabrics and knits: (a) multilayer industrial fabric of polyamide multifilament yarns; (b) knit of polyethylene multifilament yarns

Tension of polyamide and polyethylene multifilament yarns before knit manufacturing area (Figure 2a) and multilayer industrial fabric formation area (Figure 2b) includes threading tension and additional tension arising due to friction forces between warp yarns and guides and operative parts of the loom, which are of cylindrical or relatively equal form [13].

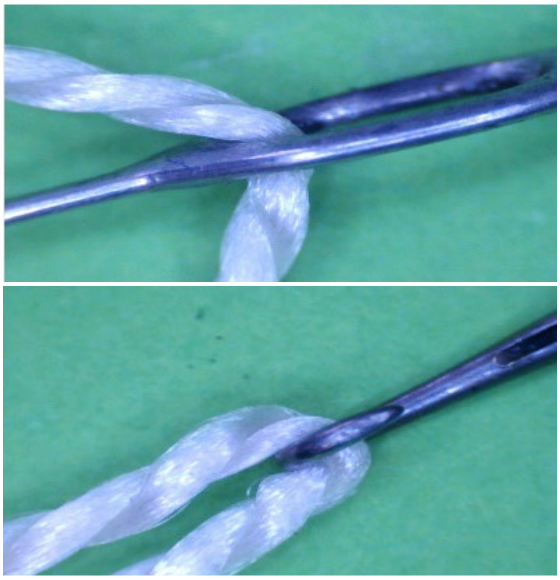


a)

b)

Figure 2 Threading line in the knitting machine (a) and in the loom (b)

Updating of technological processes for manufacturing of multilayer industrial fabrics [2, 3] and knits made of polyethylene and polyamide multifilament yarns involves enhancement of technological efforts based on minimization of yarns tension in the multilayer industrial fabric formation area and knit manufacturing area [4, 11, 14]. Simulation of polyethylene and polyamide multifilament yarns processing process on the loom and knitting machine involves research of interaction between yarns and cylindrical surfaces simulating the following: back-rest surfaces, surfaces of separating rod of yarn break detector, surfaces of heddle eyes of heald frame (Figure 3a) for looms [9]; surfaces of yarns guides, knitting needles surfaces (Figure 3b) for knitting machines [14].



a)

b)

Figure 3 Operative parts of looms and knitting machines: a) heald frame; b) knitting needle

It has been proved that the value of yarns tension before formation area is affected by the number of guides of each specific technological machine, each guide's curve radius, contact angle between yarn(s) and a guide, radial contact angle of yarn(s), mechanical, physical and structural properties of yarns [9, 11, 14]. Values of contact angle between yarn(s) and guides and contact angle between guide's surface and yarn(s) are determined based on geometric parameters and design of both yarn(s) threading system at the production equipment and specific guides [12]. Increase in yarn(s) tension derives from friction forces in the area of contact between the yarns and guides. The value of friction forces is based on yarn(s)' and guides' material [9], curvature of guides' surfaces and operative parts of looms and knitting machines [12], actual contact angle between yarn(s) and large and small curved guides, mechanical, physical and structural properties of polyethylene and polyamide multifilament yarns, as well as tension before a guide. When a yarn passes all guides consecutively from the input area to the fabric and knit formation area, it will result in step-type increase in tension [14]. Output tension parameter after the foregoing guide will be the input parameter for the next guide, thus making it possible to use recursion while calculating tension before the formation area of multilayer industrial fabric [2, 3] and knit. Implementation of this algorithm for determining yarn(s) tension at the production equipment using recursion allows for determining values of yarns tension before fabric and knit formation area at the production equipment [3]. As a result, the possibility appeared (still at the initial stage of the computer aided manufacturing) to determine yarn(s) tension before the multilayer industrial fabric and knit formation area based on geometric and design parameters of equipment, as well as on mechanical, physical and structural properties of polyethylene and polyamide multifilament yarns [14]. Experimental research carried out to determine tension of polyethylene and polyamide multifilament yarns after guide's surface requires to design specific strain-gauge unit. In a proactive planning of the experiment, it is necessary to consider the following: direction of relative shifting of friction surface [16], yarn sliding speed or guide surface movement speed [17, 18], and radius of cylindrical surface curve (guide's curve radius) [19, 20]. The paper [15] emphasizes necessity to consider that spinning of polyamide multifilament yarns affects their bending rigidity. Bending rigidity is significantly affecting the value of actual contact angle between a yarn and guide surface. This has been verified during the research of interaction conditions between polyamide multifilament yarn and guide surface and represented in the paper [4, 14] afterwards.

The papers [9, 11-14] show results of experimental determining of yarns tension with the use of specific units. To increase accuracy of measured polyethylene and polyamide multifilament yarns tension and possibility of ensuring the metrological self-verification, it is better to rely on the method of redundant measurements, which ensures that results of measurements are independent from conversion function parameters, and their deviations are independent from nominal values [21-24]. Design of the experimental unit measures accuracy of the obtained results while determining yarn tension. The papers [17, 18] show the scheme, which helps to determine yarn tension, and includes cylinders with long radius as guides. As its deficiencies, it is important to consider inability to simulate actual conditions of interaction between a yarn and guide and operative parts of looms and knitting machines. Experimental unit with revolving cylinder has the same deficiency [20]. Papers [3, 9, 11, 12] include tension determinations for a variety of cylindrical guide surfaces.

2 EXPERIMENT

As starting materials for experiment the following were chosen: a polyethylene multifilament yarn 44 tex (Figure 4a), which is used to manufacture ultra-strong knits intended to produce items for military serviceman; a polyamide multifilament yarn 58 tex (Figure 4b), which is used to manufacture ultra-strong multilayer industrial fabrics intended for forceful takeovers, laying yard-coated oil and gas pipes.

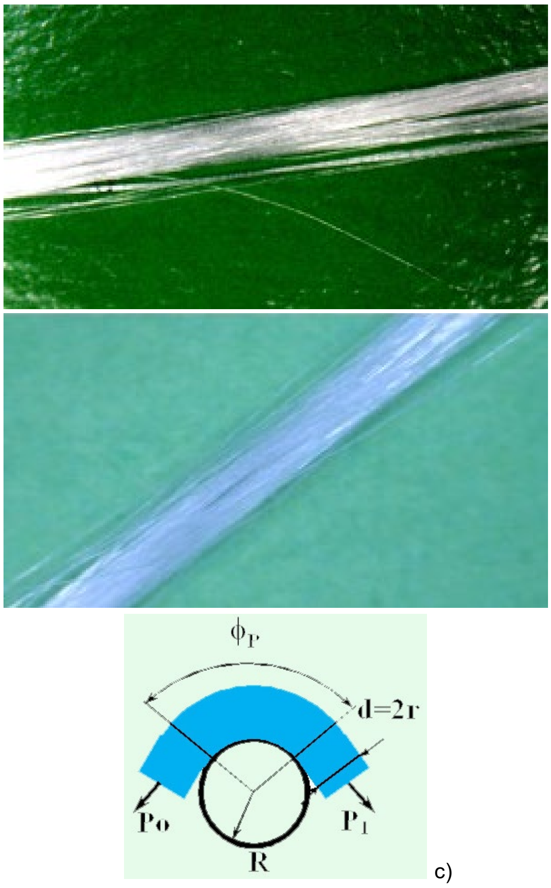


Figure 4 Multifilament yarns: a) polyethylene multifilament yarn 44 tex; b) polyamide multifilament yarn 58 tex; c) diagram of interaction between a yarn and guide

The paper includes three series of implemented experiments: A; B; C for a polyethylene multifilament yarn 44 tex and a polyamide multifilament yarn 58 tex. Series A has been conducted for small curved guides, where guide's radius significantly longer comparing to nominal radius of the yarn cross-sectional view. In addition, tension before a guide has been equal to initial tension while unwinding the yarn from a bobbin of the knitting machine or while unwinding the yarn from the beam of the loom. The value of the input tension (for Series A) varies within the following range: 10-30 cN. The value of the guide's curve radius (for Series A) varies within the following range: from 30-50 mm. The value of the contact angle between the yarn and the guide surface (for Series A) varies within the following range: from 70° to 110°. The above parameters variation ranges conform with yarns entering production area.

Series B has been performed for guides with mean curvature, when guide's radius is commensurate with the various guides' radii of looms and knitting machines. In addition, tension before the guide has conformed with tension in the centre of yarns threading line of looms and knitting machines. The value of input tension (for Series B) varies within the following range: 40-60 cN. The value of the guide's surface curve radius (for Series B) varies within the following range: from 4-8 mm. The value of the contact angle between the yarn and the guide surface (for Series B) varies within the following range: from 60° to 110°.

Series C has been performed for guides with large curvature, when guide's radius is comparable to radii of polyethylene and polyamide multifilament yarns' cross-sections. In addition, tension before the guide has conformed with yarn tension in the multilayer industrial fabric formation area of the looms and yarn tension before knitting area of the knitting machines. The value of input tension (for Series C) varies within the following range: 50-80 cN. The value of the guide's curve radius (for Series C) varies within the following range: from 0.5-2 mm. The value of the contact angle between the yarn and the guide surface (for Series C) varies within the following range: from 90° to 180°.

For series A, series B and series C the paper provides a plan and implementation of the second-order orthogonal design for three factors to determine combined influence of input tension of a yarn P_0, cylindrical guide radius R, and nominal value of contact angle φ_P to output tension of a yarn P. The diagram of interaction between a yarn and guide is shown in Figure 4c). Overall form of regression equation is as follows:

$$P = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{12} x_1 x_2 + \\ + b_{13} x_1 x_3 + b_{23} x_2 x_3 + + b_{11} x_1^2 + b_{22} x_2^2 + b_{33} x_3^2 \quad (1)$$

where: x_1 - the value of polyethylene and polyamide multifilament yarns input tension before guide surface; x_2 - guide's curve radius; x_3 - nominal value of contact angle between polyethylene and polyamide multifilament yarns and guide's surface.

Table 1 shows matrix of orthogonal design for determining polyethylene and polyamide multifilament yarns tension after guide's surface for series A.

Table 1 Matrix of orthogonal design for determining polyethylene and polyamide multifilament yarns tension after guide's surface for series A

№	Factors					
	Input tension		Curvature radius		Contact angle	
	x_1	P_{0A} [cN]	x_2	R_A [mm]	x_3	φ_{PA} [°]
1	+1	30	+1	50	+1	110
2	-1	10	+1	50	+1	110
3	+1	30	-1	30	+1	110
4	-1	10	-1	30	+1	110
5	+1	30	+1	50	-1	70
6	-1	10	+1	50	-1	70
7	+1	30	-1	30	-1	70
8	-1	10	-1	30	-1	70
9	-1.215	8	0	40	0	90
10	+1.215	32	0	40	0	90
11	0	20	-1.215	28	0	90
12	0	20	+1.215	52	0	90
13	0	20	0	40	-1.215	66
14	0	20	0	40	+1.215	114
15	0	20	0	40	0	90

Connection between open-label and coded values for series A is as follows:

$$x_1 = \frac{P_{0A} - 20}{10}, x_2 = \frac{R_A - 40}{10}, x_3 = \frac{\varphi_{PA} - 90}{20} \quad (2)$$

At the second stage the tension is determined, when guide's radius is comparable to radii of different guides of looms and knitting machines. Table 2 shows matrix of orthogonal design for determining polyethylene and polyamide multifilament yarns tension after guide's surface for series B.

Table 2 Matrix of orthogonal design for determining polyethylene and polyamide multifilament yarns tension after guide's surface for series B

№	Factors					
	Input tension		Curvature radius		Contact angle	
	x_1	P_{0B} [cN]	x_2	R_B [mm]	x_3	φ_{PB} [°]
1	+1	60	+1	8	+1	100
2	-1	40	+1	8	+1	100
3	+1	60	-1	4	+1	100
4	-1	40	-1	4	+1	100
5	+1	60	+1	8	-1	60
6	-1	40	+1	8	-1	60
7	+1	60	-1	4	-1	60
8	-1	40	-1	4	-1	60
9	-1.215	38	0	6	0	80
10	+1.215	62	0	6	0	80
11	0	50	-1.215	3.6	0	80
12	0	50	+1.215	8.4	0	80
13	0	50	0	6	-1.215	56
14	0	50	0	6	+1.215	104
15	0	50	0	6	0	80

Connection between open-label and coded values for series B is as follows:

$$x_1 = \frac{P_{0B} - 50}{10}, x_2 = \frac{R_B - 6}{2}, x_3 = \frac{\varphi_{PB} - 80}{20} \quad (3)$$

At the third stage the tension is determined when guide's radius is comparable to radii of polyethylene and polyamide multifilament yarns cross-sectional view. Table 3 shows matrix of orthogonal design for determining polyethylene and polyamide multifilament yarns tension after guide's surface for series C.

Connection between open-label and coded values for series C is as follows:

$$x_1 = \frac{P_{0c} - 60}{20},$$

$$x_2 = \frac{R_C - 0.75}{0.25},$$

$$x_3 = \frac{\varphi_{PC} - 135}{145} x_1 = \frac{P_{0B} - 50}{10}, \quad (4)$$

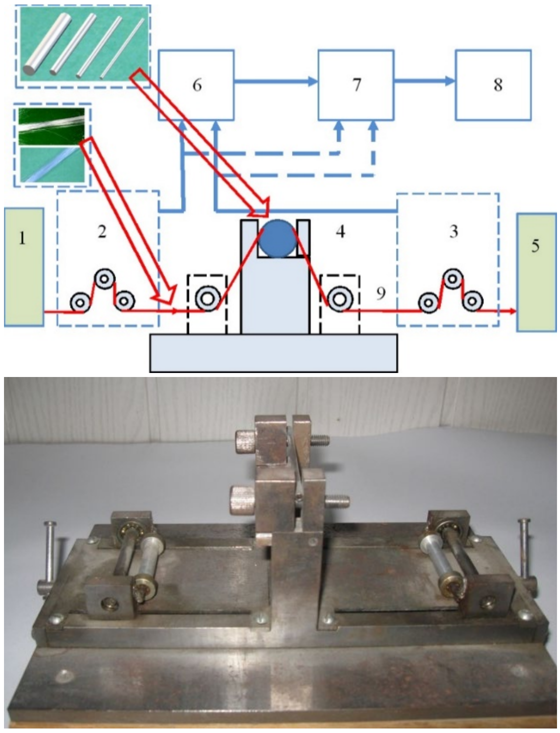
$$x_2 = \frac{R_B - 6}{2}, x_3 = \frac{\varphi_{PB} - 80}{20}$$

Table 3 Matrix of orthogonal design for determining polyethylene and polyamide multifilament yarns tension after guide's surface for series C

№	Factors					
	Input tension		Curvature radius		Contact angle	
	x_1	P_{0C} [cN]	x_2	R_C [mm]	x_3	φ_{PC} [°]
1	+1	80	+1	1	+1	180
2	-1	40	+1	1	+1	180
3	+1	80	-1	0.5	+1	180
4	-1	40	-1	0.5	+1	180
5	+1	80	+1	1	-1	90
6	-1	40	+1	1	-1	90
7	+1	80	-1	0.5	-1	90
8	-1	40	-1	0.5	-1	90
9	-1.215	36	0	0.75	0	135
10	+1.215	84	0	0.75	0	135
11	0	60	-1.215	0.4	0	135
12	0	60	+1.215	1.1	0	135
13	0	60	0	0.75	-1.215	80
14	0	60	0	0.75	+1.215	190
15	0	60	0	0.75	0	135

Figure 5a) shows principal scheme of experimental unit. Unit 1 represents yarns threader and tensioner. Input tension has been generated with a help of cymbal yarn tensioner.

Units 2 and 3 are intended to measure slack side and tight side tension of the yarn 9. They include two rollers, which are installed in bearings of the stationary axle. The third roller is installed on the cantilever fitted beam in a way that inner ring of bearing fitted on it, and roller interacting with the yarn is rigidly fixed with outer ring of the bearing. Friction forces in bearings can be neglected. The warp yarn has been loomed up to the pulley in a way that slack side and tight side have been placed at both sides of right triangle. Affected by warp yarn tension, central bar has been bending which has resulted in variations in resistance of strain-gauge indicator. These variations have been registered at the corresponding channel of the amplifier 8ANCH-7M. Lateral and longitudinal dimensions of the beam have been chosen such that free-running frequency of the beam has been 1400 Hz. This frequency goes beyond frequency of the highest tension component way more. Figure 5b) represents central metering unit 4 of the experimental unit. This metering unit is intended for simulation of interaction conditions between the yarn 9 and cylindrical guides. Two slider pairs, on which aluminium rollers are fixed in rotation bearings, are installed on the foundation in the horizontal grooves. The position of the slider pairs with respect to the central fixed bracket is changed with the help of two screw pairs by turning the two levers on the left and on the right. The central, fixed vertical bracket serves to secure the cylinder guides of different diameters, needles of knitting machine, heddles. The fastening is carried out by two screw pairs and clamping bars.



a)

b)

Figure 5 Scheme of the experimental unit: a) principal scheme: 1 - the yarn threading unit; 2 - metering unit for slack side tension of the yarn; 3 - metering unit for tight side tension of the yarn; 4 - unit for simulation of interaction conditions between the yarn and guides and operative parts of the textile machinery; 5 - yarn receiving unit; 6 - amplifier; 7 - analogue-to-digital converter ADC; 8 - PC; 9 - the yarn; b) central metering unit

The warp yarn 9 speed was varied due to a fixed ratio round belt transmission (the 5th unit at Figure 5a). Driving pulley of the transmission is rotated by AC motor that was firmly fixed to the foundation of the main measurement system. Analogue signals from the 3rd and 4th units measuring yarn tension are being received by the amplifier 6 or by analogue-to-digital converter 7, enabled as a multifunction board L-780M with signalling processor ADC 14 bit/400 kHz having 16 differential input analogue and output digital channels, which is connected to the PCI-connector 8.

3 RESULTS AND DISCUSSION

Resulting from implemented plan of the experiment (Table 2) for variant 1 (A), variant 2 (B), variant 3 (C) and variant 4 (D), I area, there were 10 parallel measurements for each variant.

Applying popular method for determining coefficients in the regression equation (1) for the second order orthogonal design the values if the coefficients have been determined and represented in Table 4 for series A, series B and series C.

Table 4 Coefficients values in regression equations (1) for series A, series B and series C

Series	Polyethylene multifilament yarn 44 tex	Polyamide multifilament yarn 58 tex
A	b_0 = 25.7908 b_1 = 11.9401 b_2 = 0.339144 b_3 = 1.37034 b_{11} = -0.138088 b_{12} = 0.14375 b_{13} = 0.52875 b_{22} = -0.0354837 b_{23} = 0.08875 b_{33} = 0.0248715	b_0 = 27.1641 b_1 = 12.8646 b_2 = 0.210052 b_3 = 1.76228 b_{11} = -0.100905 b_{12} = 0.0925 b_{13} = 0.775 b_{22} = -0.0194259 b_{23} = 0.065 b_{33} = 0.0499825
B	b_0 = 56.9215 b_1 = 10.8305 b_2 = 0.298468 b_3 = 1.64657 b_{11} = -0.0227247 b_{12} = 0.04625 b_{13} = 0.24875 b_{22} = -0.00160041 b_{23} = 0.12875 b_{33} = 0.0195239	b_0 = 62.0331 b_1 = 11.8738 b_2 = -0.0135212 b_3 = 2.978 b_{11} = -0.019865 b_{12} = -0.00375 b_{13} = 0.52125 b_{22} = 0.0857566 b_{23} = 0.09875 b_{33} = 0.06765
C	b_0 = 72.9452 b_1 = 22.9467 b_2 = -1.39519 b_3 = 3.17507 b_{11} = -0.186325 b_{12} = -0.39 b_{13} = 0.7225 b_{22} = 0.725039 b_{23} = 0.135 b_{33} = -0.0112949	b_0 = 92.5662 b_1 = 29.1817 b_2 = -6.02246 b_3 = 8.88939 b_{11} = -0.61332 b_{12} = -1.5575 b_{13} = 2.545 b_{22} = 2.82994 b_{23} = -0.58 b_{33} = -0.0731409

Resulting from the implemented second order orthogonal design for three factors (Table 1) for series A, there were 10 parallel measurements and their average values represented in Table 5.

Table 5 Results of the experimental researches aimed at determining combined influence of yarn tension before the guide, guide's radius and nominal value of the contact angle on the yarn tension after the guide, when guide's radius is far longer comparing to nominal radius of yarn's cross-sectional view (series A)

№	Factor			P_{AE} [cN]	P_{AA} [cN]
	Input tension	Curvature radius	Contact angle		
	x_1	x_2	x_3		
1	+1	+1	+1	40.35	43.18
2	-1	+1	+1	14.55	15.14
3	+1	-1	+1	39.11	42.38
4	-1	-1	+1	14.07	14.82
5	+1	+1	-1	36.26	37.87
6	-1	+1	-1	12.76	13.04
7	+1	-1	-1	35.56	37.44
8	-1	-1	-1	12.45	12.87
9	-1.215	0	0	10.95	11.25
10	+1.215	0	0	40.19	42.75
11	0	-1.215	0	25.31	26.88
12	0	+1.215	0	26.17	27.39
13	0	0	-1.215	24.11	25.06
14	0	0	+1.215	27.57	29.44
15	0	0	0	25.78	27.16

Applying known method for determining coefficients in the regression equation (1) for the second order orthogonal design, and taking into account dependencies (2) and data from Table 5, regression dependencies have been obtained for series A, where:

$8\ cN \leq P_{0A} \leq 32\ cN,\ 28\ mm \leq R_A \leq 52\ mm,$

$66° \leq \varphi_{PA} \leq 114°$

For the polyethylene multifilament yarn 44 tex:

$$\begin{aligned} P_{AE} &= 1.29 + 0.95P_{0A} - 0.007R_A - \\ &-0.013\varphi_{PA} + 0.0014P_{0A}R_A + \\ &+0.0026P_{0A}\varphi_{PA} + 0.00045R_A\varphi_{PA} - \\ &-0.0014P_{0A}^2 - 0.00035R_A^2 + 0.0000\varphi_{PA}^2 \end{aligned} \tag{5}$$

For the polyamide multifilament yarn 58 tex:

$$\begin{aligned} P_{AA} &= 1.88 + 0.94P_{0A} - 0.012R_A - \\ &-0.025\varphi_{PA} + 0.0009P_{0A}R_A + \\ &+0.0039P_{0A}\varphi_{PA} + 0.0001R_A\varphi_{PA} - \\ &-0.001P_{0A}^2 - 0.00019R_A^2 + 0.00012\varphi_{PA}^2 \end{aligned} \tag{6}$$

Table 6 represents average values of 10 parallel measurements for series B received resulting from implemented second order orthogonal design for three factors.

Table 6 Results of the experimental researches aimed at determining combined influence of yarn tension before the guide, guide's radius and nominal value of the contact angle on the yarn tension after the guide, when guide's radius is far longer comparing to nominal radius of yarn's cross-sectional view (series B)

№	Factor			P_{BE} [cN]	P_{BA} [cN]
	Input tension	Curvature radius	Contact angle		
	x_1	x_2	x_3		
1	+1	+1	+1	70.39	77.95
2	-1	+1	+1	47.66	52.64
3	+1	-1	+1	69.39	77.74
4	-1	-1	+1	46.92	52.48
5	+1	+1	-1	66.25	70.61
6	-1	+1	-1	44.59	47.45
7	+1	-1	-1	65.84	70.86
8	-1	-1	-1	44.29	47.62
9	-1.215	0	0	43.63	47.48
10	+1.215	0	0	70.14	76.51
11	0	-1.215	0	56.56	62.21
12	0	+1.215	0	57.28	62.13
13	0	0	-1.215	54.92	58.48
14	0	0	+1.215	58.99	65.80
15	0	0	0	56.92	62.04

Applying known method for determining coefficients in the regression equation (1) for the second order orthogonal design, and taking into account dependencies (3) and data from Table 6, regression dependencies have been obtained for series B, where:

$38\ cN \leq P_{0B} \leq 62\ cN,\ 3.6\ mm \leq R_B \leq 8.4\ mm,$

$56° \leq \varphi_{PB} \leq 104°$

For the polyethylene multifilament yarn 44 tex:

$$\begin{gathered}P_{BE}=2.22+0.993P_{0B}-\\-0.219R_B-0.0068\varphi_{PB}+\\+0.0023P_{0B}R_B+0.0012P_{0B}\varphi_{PB}+\\+0.0032R_B\varphi_{PB}-0.00023P_{0B}^2-\\-0.0004R_B^2+0.000049\varphi_{PB}^2\end{gathered} \tag{7}$$

For the polyamide multifilament yarn 58 tex:

$$\begin{gathered}P_{BA}=3.71+0.99P_{0B}-0.45R_B-\\-0.023\varphi_{PB}+0.00019P_{0B}R_B+\\+0.0026P_{0B}\varphi_{PB}+0.0025R_B\varphi_{PB}-\\-0.0001P_{0B}^2+0.021R_B^2+0.00017\varphi_{PB}^2\end{gathered} \tag{8}$$

Table 7 represents average values of 10 parallel measurements for series C received resulting from implemented second order orthogonal design for three factors.

Table 7 Results of the experimental researches aimed at determining combined influence of yarn tension before the guide, guide's radius and nominal value of the contact angle on the yarn tension after the guide, when guide's radius is far longer comparing to nominal radius of yarn's cross-sectional view (series C)

№	Factor			P_{CE} [cN]	P_{CA} [cN]
	Input tension	Curvature radius	Contact angle		
	x_1	x_2	x_3		
1	+1	+1	+1	99.40	128.42
2	-1	+1	+1	51.58	66.79
3	+1	-1	+1	102.29	143.95
4	-1	-1	+1	53.32	75.51
5	+1	+1	-1	91.09	106.62
6	-1	+1	-1	46.57	54.59
7	+1	-1	-1	94.93	119.25
8	-1	-1	-1	48.44	61.57
9	-1.215	0	0	44.79	56.74
10	+1.215	0	0	100.58	126.95
11	0	-1.215	0	76.31	106.98
12	0	+1.215	0	72.08	88.12
13	0	0	-1.215	68.95	81.89
14	0	0	+1.215	77.00	103.59
15	0	0	0	72.88	92.17

Applying known method for determining coefficients in the regression equation (1) for the second order orthogonal design, and taking into account dependencies (4) and data from Table 7, regression dependencies have been obtained for series C, where

$36\,cN \leq P_{0C} \leq 84\,cN,\ 0.4\,mm \leq R_C \leq 1.1\,mm,\ 80° \leq \varphi_{PC} \leq 190°$

For the polyethylene multifilament yarn 44 tex:

$$\begin{gathered}P_{CE}=-1657.39+56.78P_{0C}-\\-29.26R_C+0.012\varphi_{PC}+\\+0.078P_{0C}R_C+0.0008P_{0C}\varphi_{PC}+\\+0.012R_C\varphi_{PC}-0.465P_{0C}^2+\\+11.6R_C^2+0.00005\varphi_{PC}^2\end{gathered} \tag{9}$$

For the polyamide multifilament yarn 58 tex:

$$\begin{gathered}P_{CA}=20.75+1.49P_{0C}-66.32R_C+\\+0.056\varphi_{PC}-0.31P_{0C}R_C+\\+0.0028P_{0C}\varphi_{PC}-0.052R_C\varphi_{PC}-\\-0.0015P_{0C}^2+45.28R_C^2+0.0001\varphi_{PC}^2\end{gathered} \tag{10}$$

For nominal value of the contact angle $\varphi_{PA}=90°$ in the centre of experiment, equations (5), (6) rearrange as follows:

$$\begin{gathered}P_{AE}=0.59+1.19P_{0A}+0.03R_A+\\+0.0014P_{0A}R_A-0.0014P_{0A}^2-0.00035R_A^2\end{gathered} \tag{11}$$

$$\begin{gathered}P_{AA}=0.64+1.29P_{0A}+0.018R_A+\\+0.00093P_{0A}R_A-0.001P_{0A}^2-0.00019R_A^2\end{gathered} \tag{12}$$

For nominal value of the contact angle $\varphi_{PB}=80°$ in the centre of experiment, equations (7), (8) rearrange as follows:

$$\begin{gathered}P_{BE}=1.98+1.09P_{0B}+0.039R_B+\\+0.0023P_{0B}R_B+0.00023P_{0B}^2-0.0004R_B^2\end{gathered} \tag{13}$$

$$\begin{gathered}P_{BA}=2.94+1.21P_{0B}-0.23R_B-\\-0.00019P_{0B}R_B-0.0002P_{0B}^2+0.021R_B^2\end{gathered} \tag{14}$$

For nominal value of the contact angle $\varphi_{PC}=135°$ in the centre of experiment, equations (9), (10) rearrange as follows:

$$\begin{gathered}P_{CE}=-1655.70+56.89P_{0C}-27.64R_C+\\+0.078P_{0C}R_C-0.465P_{0C}^2+11.6R_C^2\end{gathered} \tag{15}$$

$$\begin{gathered}P_{CA}=29.03+1.88P_{0C}-73.27R_C-\\-0.31P_{0C}R_C-0.0015P_{0C}^2+45.28R_C^2\end{gathered} \tag{16}$$

Figure 6 represents response surfaces for series A, series B, and series C. Adequacy of obtained regression dependencies has been verified with SPSS program for statistical processing of experimental data [9, 10].

For nominal value of the contact angle $\varphi_{PA}=90°$, yarn tension before the guide $P_{0A}=20\,cN$, in the centre of experiment, equations (11), (12) rearrange as follows:

$$P_{AE}=23.87+0.062R_A-0.0004R_A^2 \tag{17}$$

$$P_{AA}=26.01+0.036R_A-0.00019R_A^2 \tag{18}$$

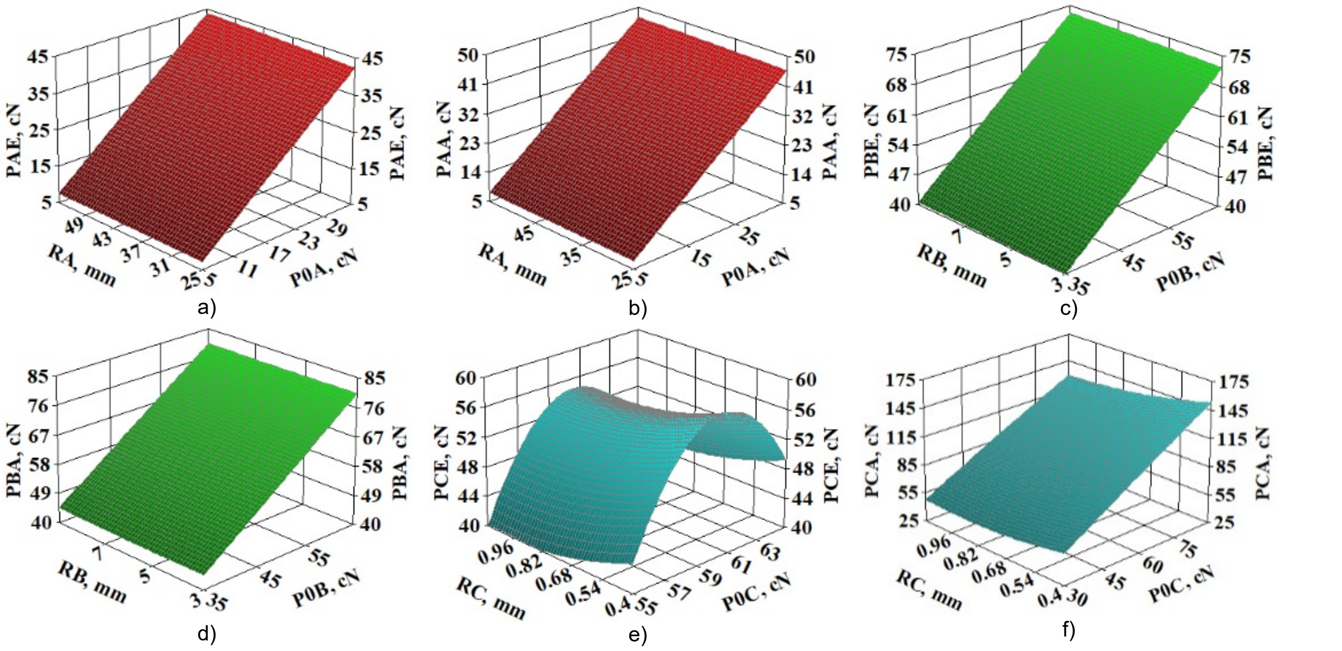


Figure 6 Response surfaces for series A, B and C created to determine combined influence of the yarn tension before the guide and guide's radius on the yarn tension after the guide: for the polyethylene multifilament yarn 44 tex: a) series A, c) series B, e) series C; for the polyamide multifilament yarn 58 tex: b) series A, d) series B, f) series C

Figure 7 represents graphical dependencies (curves) reflecting influence of guide's radius on yarn tension after the guide for series A, that have been obtained with the use of dependencies (17), (18).

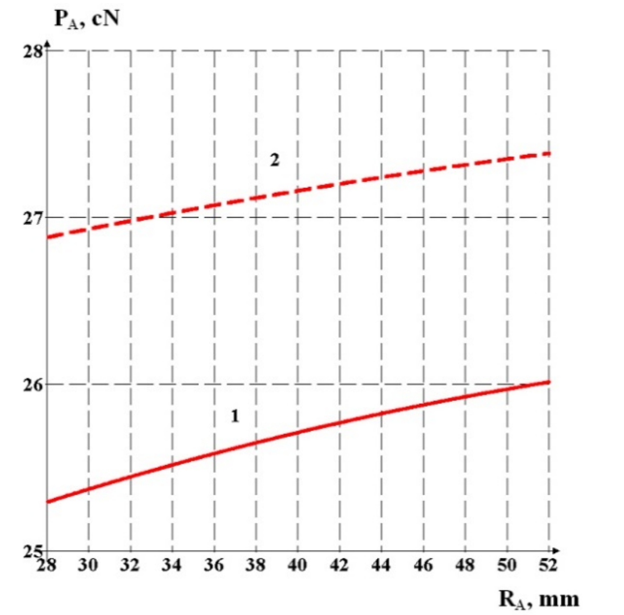


Figure 7 Graphical dependencies (curves) reflecting influence of guide's radius on yarn tension after the guide for series A: 1 - for the polyethylene multifilament yarn 44 tex; 2 - for the polyamide multifilament yarn 58 tex

For nominal value of the contact angle $\varphi_{PB} = 80°$, yarn tension before the guide $P_{0B} = 50\ cN$, in the centre of experiment, equations (13), (14) rearrange as follows:

$$P_{BE} = 56.01 + 0.154R_B - 0.0004R_B^2 \qquad (19)$$

$$P_{BA} = 62.84 - 0.24R_B + 0.021R_B^2 \qquad (20)$$

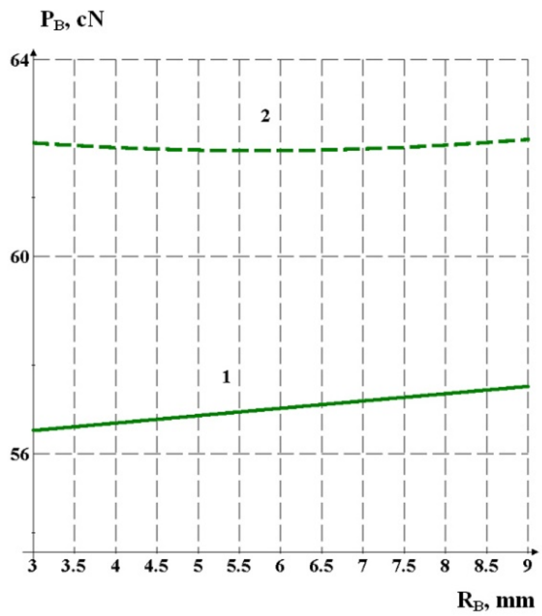


Figure 8 Graphical dependencies (curves) reflecting influence of guide's radius on yarn tension after the guide for series B: 1 - for the polyethylene multifilament yarn 44 tex; 2 - for the polyamide multifilament yarn 58 tex

For nominal value of the contact angle $\varphi_{PC} = 135°$, yarn tension before the guide $P_{0C} = 60\ cN$, in the centre of experiment, equations (15), (16) rearrange as follows:

$$P_{CE} = 83.86 - 22.96R_C + 11.6R_C^2 \quad (21)$$

$$P_{CA} = 136.07 - 91.99R_C + 45.28R_C^2 \quad (22)$$

Figure 9 represents graphical dependencies (curves) reflecting influence of guide's radius on yarn tension after the guide for series C, that have been obtained with the use of dependencies (21), (22).

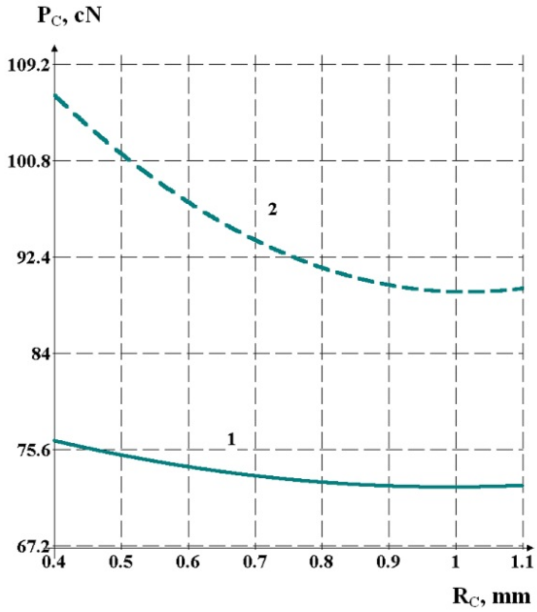


Figure 9 Graphical dependencies (curves) reflecting influence of guide's radius on yarn tension after the guide for series C: 1 - for the polyethylene multifilament yarn 44 tex; 2 - for the polyamide multifilament yarn 58 tex

4 CONCLUSIONS

Resulting from carried out complex experimental researches for polyethylene and polyamide multifilament yarns, there have been obtained regression dependencies between value of yarn tension after the guide and yarn tension before the guide, guide's surface curve radius, and contact angle. Researches that have been carried out to determine polyethylene and polyamide multifilament yarns tension when interacting with guides and operative parts (of large and small curvature) of looms and knitting machines, helped to establish the mechanism for the process of increase in polyethylene and polyamide multifilament yarns tension after the guide which can be attributed to friction forces in the contact area. It has been proved that increase in tension can be explained by varying contact angle between polyethylene and polyamide multifilament yarns and large and small curvature guides. In addition, the actual contact angle for multifilament yarns will be larger than nominal one due to distortion of the yarn's cross-section in the contact area.

The paper includes three series of experiments (A; B; C) implemented for the polyethylene multifilament yarn 44 tex and the polyamide multifilament yarn 58 tex. Series A has been carried out for small curved guides, where guide's radius significantly longer comparing to nominal radius of the yarn cross-section. In addition, tension before the guide varies within the following range $8\ cN \leq P_{0A} \leq 32\ cN$, the value of the guide's surface curve varies within the following range $28\ mm \leq R_A \leq 52\ mm$, the value of the contact angle between the yarn and guide's surface, for series A, varies within the following range $66° \leq \varphi_{PA} \leq 114°$.

Series B has been performed for guides with mean curvature, when guide's radius is commensurate with the various guides' radii of looms and knitting machines. In addition, tension before the guide varies within the following range $38\ cN \leq P_{0B} \leq 62\ cN$, the value of the guide's surface curve radius varies within the following range $3.6\ mm \leq R_B \leq 8.4\ mm$, and the value of the contact angle between the yarn and the guide surface, for series B, varies within the following range $56° \leq \varphi_{PB} \leq 104°$.

Series C has been performed for guides with large curvature, when guide's radius is comparable to radii of polyethylene and polyamide multifilament yarns' cross-section. In addition, tension before the guide varies within the following range $36\ cN \leq P_{0C} \leq 84\ cN$, the value of the guide's surface curve radius varies within the following range $0.4\ mm \leq R_C \leq 1.1\ mm$, the value of the contact angle between the yarn and the guide surface, for series C, varies within the following range $80° \leq \varphi_{PC} \leq 190°$.

As a result, it has been made possible (still at the initial stage of the computer aided manufacturing with usage of recursion) to determine polyethylene and polyamide multifilament yarns tension before fabric and knit formation area depending on geometric and design parameters of equipment and their mechanical and physical properties. Obtained results may be used when improving technological processes in textile and knitting industries.

ACKNOWLEDGEMENT: We are really grateful to Danish Textiles management and Kyiv "Factory of Technical Fabrics TEKHNOFILTR" for starting materials and equipment provided for experimental work and possibility to try out results of our research in production environment.

6 REFERENCES

1. Koo Y., Kim H.: Friction of cotton yarn in relation to fluff formation on circular knitting machines, Textile Research Journal 72, 2002, pp. 17-20, https://doi.org/10.1177/004051750207200103
2. Vasilchenko V.N., Shcherban' V.Yu., Apokin Ts.V.: Attachment for holding multilayer fabrics in the clamps of a universal tensile tester, Textile industry 8, 1987, pp. 62, https://er.knutd.edu.ua/handle/123456789/17813

3. Shcherban' V., Melnyk G , Sholudko M., Kolysko O., Kalashnyk V.: Improvement of structure and technology of manufacture of multilayer technical fabric, Vlakna a textil (Fibres and Textiles) 26(2), 2019, pp. 54-63, http://vat.ft.tul.cz/2019/2/VaT_2019_2_10.pdf
4. Weber M.O., Ehrmann A.: Necessary modification of the Euler-Eytelwein formula for knitting machines, The Journal of The Textile Institute 103, 2012, pp. 687-690, https://doi.org/10.1080/00405000.2011.598665
5. Vasconcelos F.B., Marcicano J.P.P., Sanches R.A.: Influence of yarn tension variations before the positive feed on the characteristics of knitted fabrics, Textile Research Journal 85, 2015, pp. 1864-1871, https://doi.org/10.1177/0040517515576327
6. Yakubitskaya I.A., Chugin V.V., Shcherban' V.Yu.: Dynamic analysis of the traversing conditions at the end sections of the groove in a winding drum, Izvestiya Vysshikh Uchebnykh Zavedenii. Technology of Textile Industry 5, 1997, pp. 33-36, https://ttp.ivgpu.com/wp-content/uploads/2016/04/239_9.pdf (in Ukrainian)
7. Yakubitskaya I.A., Chugin V.V., Shcherban' V.Yu.: Differential equations for relative yarn movement in the end sections of the channel in the winding drum, Izvestiya Vysshikh Uchebnykh Zavedenii. Technology of Textile Industry 6, 1997, pp. 50-54, https://ttp.ivgpu.com/wp-content/uploads/2016/04/240_14.pdf (in Ukrainian)

   Shcherban' V.Yu. : Determining the technological forces during beating-up in the production of multilayer industrial fabrics, Izvestiya Vysshikh Uchebnykh Zavedenii. Technology of Textile Industry 3, 1990, pp. 44-47, (in Ukrainian) https://er.knutd.edu.ua/handle/123456789/17888
   Shcherban' V., Melnyk G., Sholudko M., Kalashnyk V.: Warp yarn tension during fabric formation, Vlakna a textil (Fibres and Textiles) 25(2), 2018, pp. 97-104, http://vat.ft.tul.cz/2018/2/VaT_2018_2_16.pdf
8. Shcherban' V.Yu.: Interaction of stiff yarns with the working parts of knitting and sewing machines, Textile industry 10, 1988, p. 53, https://er.knutd.edu.ua/handle/123456789/17814
9. Shcherban' V., Melnyk G., Sholudko M., Kolysko O., Kalashnyk V.: Yarn tension while knitting textile fabric, Vlakna a textil (Fibres and Textiles) 25(3), 2018, pp. 74-83, http://vat.ft.tul.cz/2018/3/VaT_2018_3_12.pdf
10. Shcherban' V., Kolysko O., Melnyk G., Sholudko M., Shcherban' Y., Shchutska G.: Determining tension of yarns when interacting with guides and operative parts of textile machinery having the torus form, Vlakna a textil (Fibres and Textiles) 27(4), 2020, pp. 87-95, http://vat.ft.tul.cz/2020/4/VaT_2020_4_12.pdf
11. Shcherban' V., Makarenko J., Melnyk G., Shcherban' Y., Petko A., Kirichenko A.: Effect of the yarn structure on the tension degree when interacting with high-curved guides, Vlakna a textil (Fibres and Textiles) 26(4), 2019, pp. 59-68, http://vat.ft.tul.cz/2019/4/VaT_2019_4_8.pdf
12. Shcherban' V., Makarenko J., Petko A., Melnyk G., Shcherban' Yu., Shchutska G.: Computer implementation of a recursion algorithm for determining the tension of a thread on technological equipment based on the derived mathematical dependences, Eastern-European Journal of Enterprise Technologies 2(1), 2020, pp. 41-50, https://doi.org/ 10.15587/1729-4061.2020.198286
13. Vasilchenko V.N., Shcherban' V.Yu.: Effect of the twist of Kapron filament yarn on its bending rigidity, Izvestiya Vysshikh Uchebnykh Zavedenii. Technology of Textile Industry 4, 1986, pp. 8-9, https://er.knutd.edu.ua/handle/123456789/17812 (in Ukrainian)
14. Kovar R.: Impact of directions on frictional properties of a knitted fabric, Vlakna a textil (Fibres and Textiles) 14(2), 2007, pp. 15-20, http://vat.ft.tul.cz/Archive/VaT_2007_2.pdf.
15. Donmez S., Marmarali A.A.: Model for predicting a yarn's knittability, Textile Research Journal 74, 2004, pp. 1049-1054, https://doi.org/10.1177/004051750407401204
16. Liu X., Chen N., Feng X.: Effect of yarn parameters on the knittability of glass ply yarn, Fibres & Textiles in Eastern Europe 5(70), 2008, pp. 90-93, http://www.fibtex.lodz.pl/article152.html
17. Hammersley M.J.: 7-A simple yarn-friction tester for use with knitting yarns, The Journal of the Textile Institute 64, 1973, pp. 108-111, https://doi.org/10.1080/00405007308630420
18. Sodomka L., Chrpová E.: Method of determination of Euler friction coefficients of textiles, Vlakna a textil (Fibres and Textiles) 15(2-3), 2008, pp. 28-33, http://vat.ft.tul.cz/Archive/VaT_2008_2_3.pdf
19. Shcherban' V., Korogod G., Chaban V., Kolysko O., Shcherban' Yu., Shchutska G.: Computer simulation methods of redundant measurements with the nonlinear transformation function, Eastern-European Journal of Enterprise Technologies 2/5, 2019, pp. 16-22, https://doi.org/10.15587/1729-4061.2019.160830
20. Shcherban' V., Korogod G., Kolysko O., Kolysko M., Shcherban' Yu., Shchutska G.: Computer simulation of multiple measurements of logarithmic transformation function by two approaches, Eastern-European Journal of Enterprise Technologies 6(4), 2020, pp. 6-13, https://doi.org/10.15587/1729-4061.2020.218517
21. Shcherban' V., Korogod G., Kolysko O., Kolysko M., Shcherban' Yu., Shchutska G. : Computer simulation of logarithmic transformation function to expand the range of high-precision measurements, Eastern-European Journal of Enterprise Technologies 2(9), 2021, pp. 27-36, https://doi.org/10.15587/1729-4061.2021.227984
22. Shcherban' V., Kolysko, O., Melnyk G., Sholudko M., Shcherban' Yu., Shchutska G. and Kolva N.: Determination of tension for polyamide and basalt multifilament yarns while weaving industrial fabrics, , Vlakna a textil (Fibres and Textiles) 28(1), 2021, pp. 75-85, http://vat.ft.tul.cz/2021/1/VaT_2021_1_10.pdf

EVALUATION OF COLOR HARMONY ON THE SCALE OF PSYCHOLOGICAL PERCEPTION IN FAMILY LOOK CLOTHES

A. Slavinska, O. Syrotenko, V. Mytsa and O. Dombrovska

Khmelnytskyi National University, Institutska str. 11, Khmelnitskyi, Ukraine
syrotenko@email.ua

Abstract: *The fashion trend of Family look clothes is a complicated system of a complex wardrobe. It requires the definition of the laws of compositional construction of the family clothing system on the basis of harmonization of the stylistic unity of the multi-colored composition of products and needs an assessment of the psychological comfort of the consumer in social environment. For this purpose the following tasks are solved: gender and age categories of restriction of color combinations' variants of clothes in Family look style are defined; the algorithm of verification of means of composition in color series of family wardrobe models is developed; communicative methods of control of harmonization means of color compositions are developed. The article considers 5 basic principles of identification of the figurative decision of models of clothes from the point of view of their compositional unity (an image, color, accessories, style). Rules for combining family wardrobe based on the number of family members, their gender, age and style have been developed. It is established that the wardrobe is formed of different types of combinations: parallel, cross, mixed (collage), triangle. Based on the typology of the personality image type by O. Petrova, the typology of the color type of behavior by M. Luscher and the typology of temperaments by G. Eysenk, the categories of color formation of the Family look style are formed. On the example of the portfolio of models selected for the color type "green", image type "prestigious" the method of determining the harmony of color combinations of clothes in the Family look system by the ratio of its filling areas is verified. An algorithm for controlling the process of harmonization of the color composition of the Family look style according to the 7 phases of evaluation of the means of composition is developed, which is displayed by the level control scheme. An algorithm for forming a wardrobe in the style of Family look is developed and its practical application is shown on the example of developing different wardrobe options.*

Keywords: *Family look style, harmony of color, color types, algorithm, identity, complex wardrobe, collage of models.*

1 INTRODUCTION

The trend of Family look does not leave the lists of fashion trends in the clothing industry. This trend shows not only the style for the whole family in clothes and accessories, but also the philosophy of life in family values [1, 2]. The manner of dressing in one style has a peculiar psychological aspect: 1) unites the family and emphasizes the integrity of the relationship between children and parents; 2) emphasizes individuality and allows you to stand out from the crowd; 3) enforces good taste in children; 4) satisfies the child's need to imitate adults; 5) charges with positive emotions [3].

Family look is extremely multifaceted and varied. This is a street-holiday style with a huge number of variations and stylistic solutions [4]. It is because of the peculiarities of capriciousness and insistence of Family look that the laws of this style are so easy to break due to ignorance and turn the whole family into an ordinary clowning of imagery. Subjective perception of the decorative and color theme of complex wardrobe items in the style of Family look by consumers does not allow us to assess objectively the psychological aspect of comfort due to ignorance of the basics of the composition of this style. Scalability of harmony of color combination of wardrobe items enhances the advertising effect of imagery of a friendly, strong and happy family [5]. The development of methods for quantifying the use of colors requires the use of both instrumental methods of colorimetry and interpretation of the harmony of the collage of models.

2 DISCUSSINS IDEAS

In the history of fashion, it is believed that the homeland of this style is America, during the Great Depression (20s of last century). Women sewed fashionable dresses for themselves, and from the remnants - clothes for children [6]. The popularity of the trend grew and later the family look began to appear on the covers of magazines, on greeting cards [7].

Nowadays, Madonna singer returned to the Family look style for the first time, ordering copies of her own clothes for her daughter Lourdes [8, 9]. The next standards of Family look were Angelina Jolie and Brad Pitt, the Beckham couple, recognized fashionistas Gwen Stefani, Jennifer Lopez and Cindy Crawford [9]. After such advertising, the fashion for a Family look spread around the world.

Designers from Chanel, Lanvin, Cavalli, Dolce & Gabbana began to create actively separate collections in the style of Family look for different tastes [5, 9, 11, 12]. More affordable brands such as Benetton, Mango, Gap, ZARA, Old Navy, H&M, Hanna Anderson and Children's Place are now successfully selling the same clothing for the whole family in their online stores [11, 12]. However, you can create it yourself by buying the same style things from different brands and trademarks. If desired, original things and accessories can be sewn to order or made by yourself. In this case, the style will be individual and unique, and will save a lot of money [12-14].

The motivational choice of the consumer depends on how attractive his image is in competition with similar social status [15]. The psychological effect of color on a person is actively used in medicine. In order to justify the choice of color solution for clothing, marketing research has been conducted, which is based on the theory of harmonious combination of colors called Ittena [16]. There are a number of studies on the effect of color on the psychological and physical state of a person through the use of test questionnaires [17]. This allows you to make recommendations for choosing the main and additional colors of clothing. The informational aspect of the psychological classification of people has a scientific basis for research done by E. Kretschmer, C. Jung, M. Luscher and H. Eysenck [18].

The psychological comfort of the "clothing-appearance" relationship is assessed through the leading type of perception using the questionnaire by O. Petrova [19]. Segmentation of psychological personality types for the color formation of the wardrobe in the style of Family look is relevant, because the standard features of modern forms of clothing is obvious.

Consideration of clothing in the style of Family look on the basis of harmonization of stylistic unity of the multi-colored composition of products requires an assessment of psychological comfort in the social environment. For this purpose it is necessary to solve the following tasks: to define gender and age categories of restriction of variants of color combinations in style of Family look clothes; to develop an algorithm for verifying the means of composition in the color series of family wardrobe models; to develop communicative methods of control of harmonization means of color compositions.

3 METHODS

The complexity and diversity of the Family look is regulated by the system of identifying the features of a single style for the whole family at the stage of selecting models from Internet resources. A huge number of variations and stylistic solutions for creation a family image require the use of knowledge of the basics of composition as a method of artistic design at the initial stage. Functional, constructive and aesthetic value of the utilitarian justified form of models in the style of Family look is estimated by exact coincidence and harmony of color and accent details [20].

Achieving integrity and unity in the combination of complex wardrobe items provide the principles of style identification (Table 1).

Models presented in electronic resources, as a rule, have functional and constructive value. The control of aesthetic value is provided by the theory of composition. The objectivity of the assessment of color combinations is provided by expert and instrumental control methods of means of harmonization on the basis of observance of the basic rules of color harmony:

<u>Rule 1</u>: The colors yellow, red, green, blue are called the main, pure, without shades of others, adjacent to them in the color spectrum.

<u>Rule 2</u>: There are three groups of colors in combination - related (R), related-contrast (R-C) and contrast (C).

<u>Rule 3</u>: Related circles have at least one common (main) color in their composition. There are four groups of related colors - yellow-red, red-blue, blue-green and green-yellow.

<u>Rule 4</u>: Related-contrasting colors are located in two adjacent quarters of the color wheel and have one main color, the other two - mutually complementary to the main color. There are four groups of related contrasting colors - yellow-red and red-blue, red-blue and blue-green, blue-green and green-yellow, green-yellow and yellow-red.

<u>Rule 5</u>: Contrasting colors are located in opposite quarters of the color wheel; they are yellow-red and blue-green, yellow-green and blue-red.

The rules of formation of signs of stylistic identity are influenced by such laws of composition as dominants, integrity, balance, standardization, contrasts.

The law of dominance in the color composition, due to the image type of the consumer, determines the main color tone as a functional element of the color type of behavior.

Table 1 Principles of identification of the figurative solution of clothing models in the style of Family look

Characteristic feature	Principle	Method	Family size			
			2	3	4	5-6
A complete match of the image	The identity is the same	Dimensional copying of the mirror image of the assortment				
The identity of colors in different cuts	Identity is related	Color dominant in the gradation of rhythm metrics				
Identity of accessories	Frequency	Support with the same accessories				
Stylistic identity	Grouping	Stylistic balance of items combinations				

The law of integrity ensures the harmonious interaction of color zones according to the rules of subordination.

The unity of style implements the laws of standardization through the means of harmonization of art form: nuance, identity, and rhythm.

The law of contrasts explains polyvariety by such means as shape, tone, color, proportions, quantity from the standpoint of the unity of opposites.

The three-component theory of color vision adopted in colorimetry allows to quantitatively link the chromaticity coordinates of chromatic colors with the areas of their spots using the criterion of harmony of color composition of objects in the style of Family look [21].

The typology of Max Luscher's personality is based on the desires that determine life choices and characterizes the main type of color behavior: the blue type is the desire for harmony; the green type is a desire for prestige; red type - the desire to succeed; yellow type - the desire for change [16].

Characteristics of psychological types of temperament and attitudes to clothing are directly correlated with the degree of psychological comfort of the color type of behavior.

The sequence of work on the quantitative determination of the color type of the overall composition of the Family look models is as follows:

1. Formation of a card index of appearance of models according to the principles of identification and introduction in a grid of frontal projections on a body.
2. Determining the coordinates of color spots that form the color composition of Family look models.
3. Determining the proportions of color areas in the image type of consumers, taking into account the color type of behavior.
4. Choosing how to combine the components of the wardrobe for family members.

4 EXPERIMENTAL

The formation of models' system in the style of Family look is performed according to the general rules of selection of clothes for one person [13]. The basis of selection is to determine the number of family members, their gender and age.

Depending on the number of family members, this system can be 2, 3, 4, 5, 6-component. According to gender and age, as a rule, this system should include parents and children.

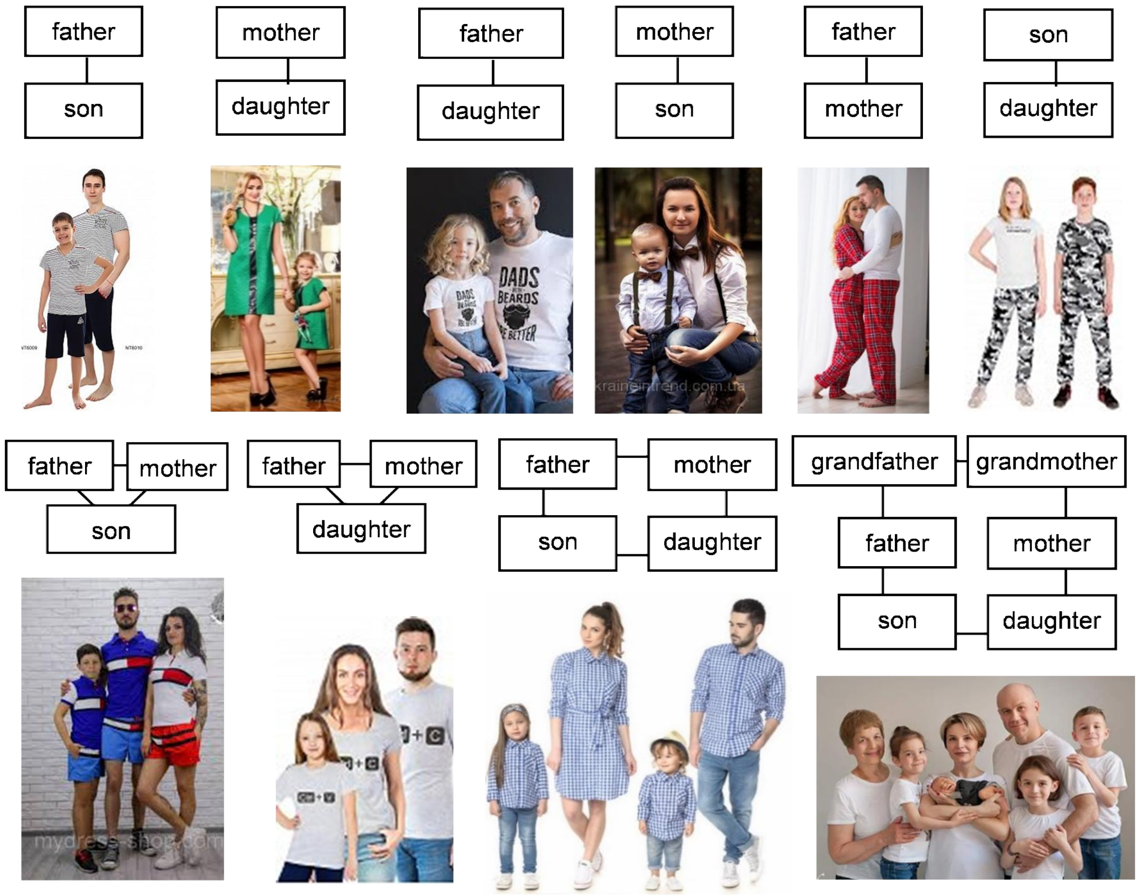


Figure 1 Ways of combining family members in the Family look system

However, sometimes it can be only parents, only children, or parents + children + grandparents, or grandchildren with grandparents. The basic options for possible combinations of family members in the Family look system are shown in Figure 1.

However, these concepts can be somewhat expanded. For example, the combination father + son also involves the combination grandfather + grandson or father + grandfather + son, and the combination mother and daughter - involves the combination grandmother + granddaughter or mother + grandmother + granddaughter. In addition, the number of children in this system can vary from 1 to 4-5. For example, the combination father + son also implies a father + 2 sons, the combination mother + daughter - provides a combination of mother + 3 daughters, and the system father + son + daughter provides, for example, a combination of father + 2 sons + 1 daughter or father + son + 2 daughters. A formalized description of the combinations of family members in the Family look system is represented by the equation (1):

$$FL = f + m + s_i + d_j + gf + gm \qquad (1)$$

where: *FL* is the number of family members in the Family look system; *f* is the father; *m* is the mother; *s* is the son; *d* is the daughter; *gf* is the grandfather; *gm* is the grandmother; *i* is the number of sons; *j* is the number of daughters.

This factor is very important, especially when determining the rules of combining the wardrobe of family members. The frequency of occurrence of different component variants of the family is presented in Figures 2 and 3.

When designing clothes in the style of Family look, the most common is a traditional family of 4 people, which allows you to describe the probable options for combining wardrobe and color in this system. The choice of products that will be included in the wardrobe primarily depends on the style and age of family members. The warm period of the year has been chosen for research, for the purpose - festive clothes and for rest; for accessories - complementary items from the main fabric or the companion fabric. The color composition is usually based on a limited number of color combinations. Such a restriction is clearly represented by sets of special purpose clothing (uniform, office, industrial). The gender and age category of consumers in a complex wardrobe has secondary intonations of accessories or variations of the main color scheme in the combination group.

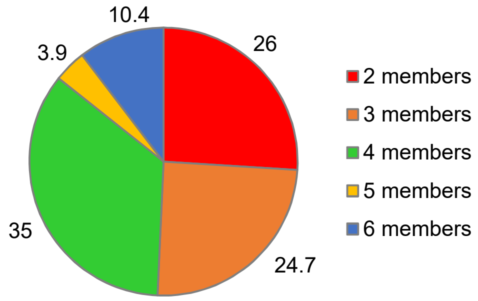


Figure 2 Frequency of occurrence of family members' number

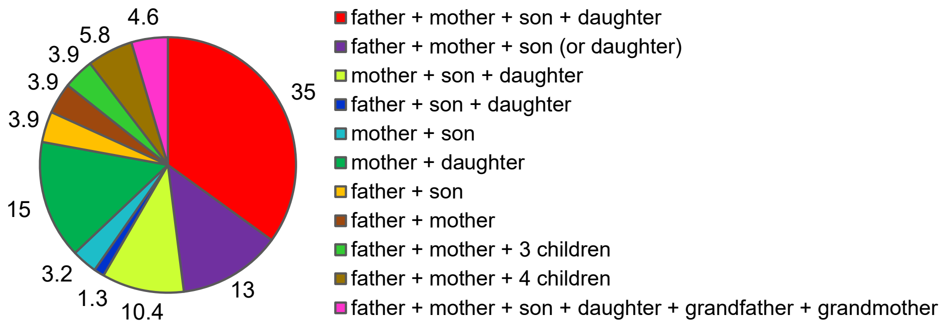


Figure 3 Frequency of occurrence a combinations of family members by gender

When combining colors between family members in the Family look system, the same rules are followed as when combining wardrobe units. The color may be the same for the same range of clothing or with different color accents and different filling areas, the color may be the same or different in different sex groups with different assortment; the color of clothes of one assortment can be different in opposite sex groups; color and ornament may be the same in certain types of clothing, regardless of gender and range; color and ornament may be different with different range of clothing and gender of family members [22]. The frequency of occurrence of different color combinations and clothing range between family members is shown in Figures 4 and 5.

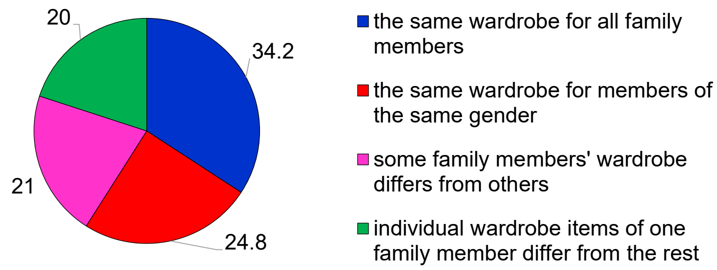


Figure 4 Frequency of combinations of wardrobe items between family members

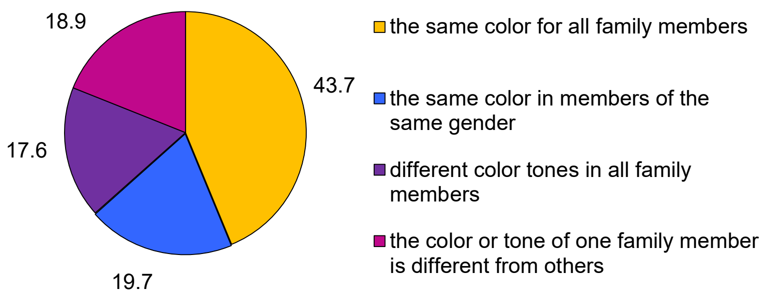


Figure 5 Frequency of color combinations between family members

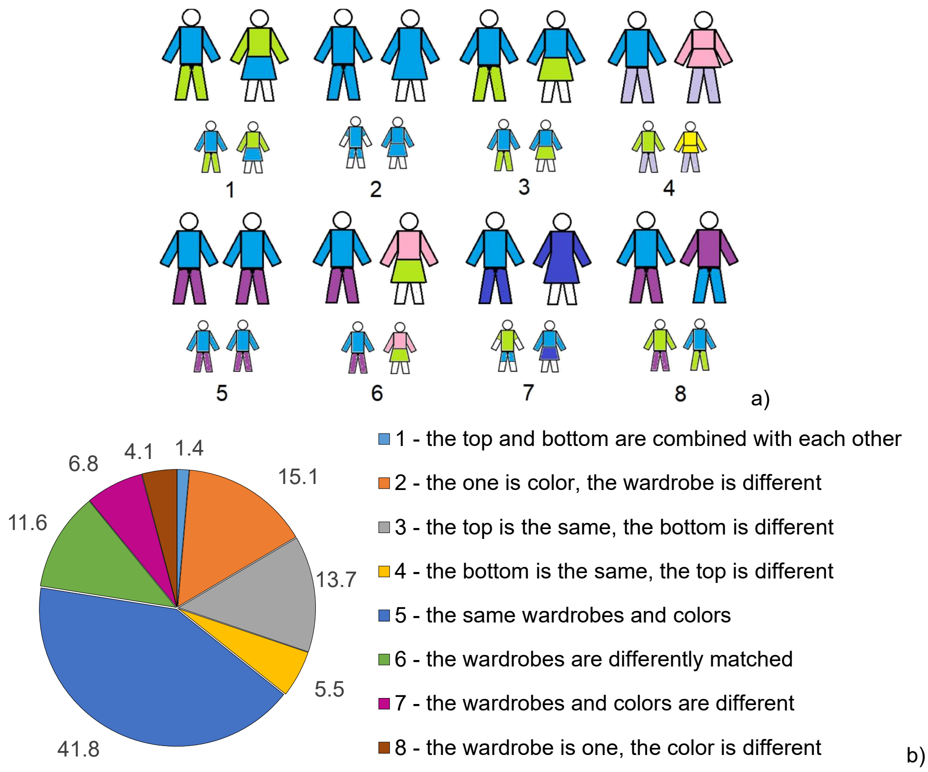


Figure 6 Options for combining colors in a wardrobe collage: a) pictogram; b) frequency of occurrence

The obtained values indicate that one of the key positions of consumer demand for Family look clothing is the predominant identification of the image solution of clothing models on the principle of "identity is the same" in the range and color. This confirms the psychological desire of family members to visually emphasize their unity.

The study of the rules of mutual combination of color and wardrobe units allowed us to determine the probable options for their combination (Figure 6).

Options of combinations (2, 3, 5, 6) with a frequency of 11.6-41.8% should be used as a base in the development of Family look clothing to provide the widest range of consumers.

Preliminary studies of the subjective color preferences of the youth group of women on the basis of a short test by M. Luscher characterizes the respondents as stylish ones, following fashion trends: first place - blue; second place - blue-green; third and fourth place belongs to yellow-red color. These colors are included in the color palette of the spring-summer season constantly. They characterize the modern woman as independent and purposeful, who keeps up with the times. This is a generalized personality – "one who constructs herself." The consistency of the respondents' opinions is characterized by the concordance coefficient *W* = 0.71 and Pearson's criterion $\chi^2_p = 71.4 > \chi^2_{tabl} = 18.5$.

The study of temperament types in the control group of clothing consumers of Family look, namely, women of younger age group was performed by G. Eysenk's test.

Choleric (35%) corresponds to the red type of behavior. It is a desire for success and victory. Sanguine (17%) corresponds to the green type of behavior. It is a desire for prestige, the search for reliability and comfort. Phlegmatic (10%) corresponds to the yellow type of behavior. It is a desire for change that is full of hope. Melancholic (27%) corresponds to the blue type of behavior. It is a desire for harmony based on unity with the world around us.

To determine the image attitude to style, a questionnaire by O. Petrova was used [19]. The relationships of the categories of the color composition of the Family look style are shown in Table 2.

Table 2 Categories of color formation of the Family look style

Consumer group	Color type of behavior	Temperament type	Image attitude to style
avantgarde	red	choleric	obsessed, aesthetic, distinctive
prestigious	green	sanguine	prestigious, harmonious
moderate	yellow	phlegmatic	standard, aesthetic, rational
practical	blue	melancholic	neat, harmonious

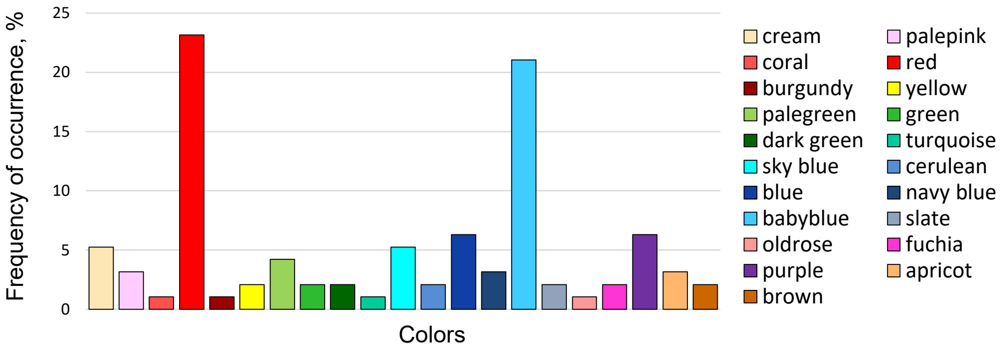


Figure 7 Diagram of the distribution of the occurrence of chromatic colors in the collage Family look

The central figure in the Family look collage is usually a mother. A two-year period of psychological perception of color was used to select mobile signs ahead of the development of shape signs. The key trends of spring-summer collections of women's light clothing of 2018-2020 years are the use of bright, often contrasting colors and pastel shades, an original combination of textures and prints, especially floral ornaments. The controlling function of color combination is illustrated by Figure 7.

The characteristic of the chromatic colors in the Family look collage corresponds to the color type of behavior and temperament type.

The verification of the portfolio of models in the style of Family look according to the scenario of determining consumers' preferences is based on the method [23]. The tectonic integrity of the three-dimensional shape of clothing models for different gender and age groups is characterized by a coefficient of proportionality on the principle of scaling [24, 25].

To study the color composition of the portfolio of Family look models in the group of "prestigious" consumers, the method of determining the ratio of areas in the grid of product dimensions was used [26]. Since the type of sanguine temperament clearly coincides with the color type of behavior "green", the portfolio of five models is composed on the principle of identity of the range and decoration in different combinations of parents with children (Figure 8).

The coefficient of proportionality of the ratios of the areas of color spots is calculated by the equation (2):

$$Cpr = \frac{S_i}{S_j} \tag{2}$$

where: *Si* is the area of the color spot of the clothes of the central figure and *Sj* is the area of the color spot of the clothes of another family member.

Verification of the ratios of the areas of color spots of the portfolio models are given in Table 3.

In the Family look collage the central figure is usually mother. The location of the models in the portfolio is estimated by approaching the harmony of the "golden section" (1.6 for women). The collage of models №4 (Figure 8) characterizes a high degree of coincidence with the harmonious proportionality of body measurements of the four-component group of the family and clearly defines the purpose of the range. The collage of models №1 shows a mirror image of the type of assortment by gender, but does not extend to the social aspect of the family. Collages of models №2 and №3 emphasize the metric rhythm of color tonality. However, the collage №3 corresponds better to the laws of composition in ensuring unity and integrity. Collage №5 identifies the color group of the central figure, but disturbs the balance due to the small area of the color spot of the boy's clothing accessories. Due to the inconsistency of the factors assessing the integrity of the composition, the collage №5 was excluded from further analysis.

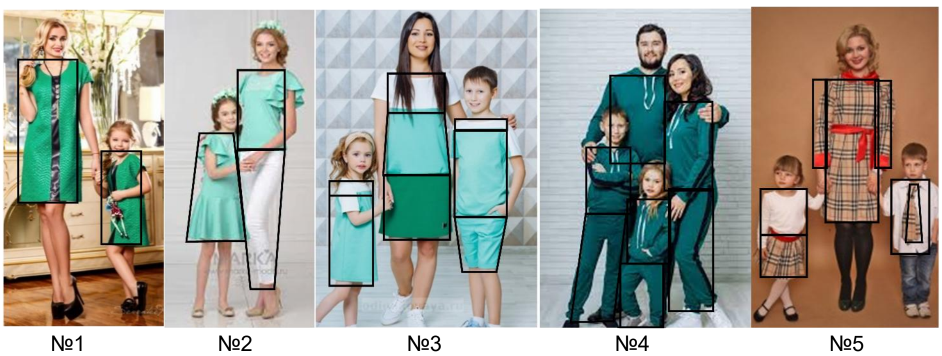


Figure 8 Portfolio of color composition of Family look models of «prestigious» type

Table 3 Verification database for determining the harmony of color combinations

Model collage number	A sign of imagery	Method of color groups identification	Area of color spots			Coefficient of proportionality		
			Si	*Sj*	*Cpr1*	*Cpr2*	*Cpr3*	*Cpr*, average
1	Complete matching of clothes m, d	Mirror coincidence of assortment	398 (m)	166 (d)	2.4 (m/d)	-	-	2.4
2	Affinity of the top m, d	Gradation of color rhythm metrics	167 (d)	123 (m)	1.33 (d/m)	-	-	1.33
3	Stylistic identity m, d, s	Equilibrium of color combinations in metric rhythm	413 (m)	236 (d) 305 (s)	1.75 (m/d)	1.35 (m/s)	1.29 (s/d)	1.46
4	Complete matching of clothes of parents and children f, m, d, s	Dimensional copying by gender	570 (f) 476 (m)	340 (s) 216 (d)	1.68 (f/s)	2.2 (m/d)	1.19 (f/m)	1.69
5	Identity of accessories m, d, s	Support of the color tone of the central figure with accessories	327 (m)	64 (d) 4.8 (s)	6.04 (m/d)	-	13.3 (d/s)	9.67

Table 4 Gradation of the quality of interpretation of the harmony of the collage of models for the conformity factors to the fashion trends

Interpretation of the quality of factor expression	Numerical value	Factors, models		
		f_1	f_2	f_3
most strongly expressed	+3	№4	№3	№3
less expressed	+2	№3	№4	№1
a little noticeable	+1	№2	№2	№4
neutral position	0	№1	№1	№2

To estimate the possible emotional feelings of potential consumers, the portfolio of color compositions of Family look models in accordance with Figure 8 the method of bipolar seven-point scale was used to assess the concept of factors of color psychological perception [27]. The initial data for assessing the harmony of color perception in the portfolio of Family look models for the image type "prestigious" are given in Table 4.

The positive correlation of the assessment of the harmony of color perception in the scale of interpretation of divisions from +3 to 0 for three factors (f_1 - assessment factor; f_2 - force factor; f_3 - activity factor) is determined by the equation:

$$r_s = 1 - \frac{6\sum d_i^2}{n(n^2-1)}, \tag{3}$$

where: d is the difference between the ranks of the characteristic on the two correlated features and n is the volume of the population.

The difference between the ranks d_i on the correlating features of models №3 and №4 is 1. The number of models is 4, then:

$$r_s = 1 - \frac{6\cdot(1^2+1^2)}{4\cdot(4^2-1)} = 1 - \frac{6\cdot 2}{4\cdot 15} = 1 - \frac{12}{60} = 1 - 0{,}2 = 0{,}8$$

r_s - corresponds to a high level of correlation: 0.8>0.79.

The algorithm of level control of the process of harmonization of color composition is based on the hierarchy of features of recognition of the image identity of the object [28]. The hierarchy of stages is organized in the order of increasing natural numbers by extended groups from the zero cell by 5 phases of evaluation of the means of composition in the Family Look models. The zero phase for the characteristics of the wardrobe contains the position 1 - style Family look. The first phase contains positions of properties: 2 - unity; 3 - integrity. The second phase (series 4, 5, 6) is the principles of identification: 4 - uniformity; 5 - recurrence; 6 - grouping. The third phase (series 7, 8, 9, 10) - basic colors of behavior: 7 - red; 8 - green; 9 - blue; 10 - yellow. The fourth phase (series 11, 12, 13, 14, 15) - the laws of composition: 11 - dominant; 12 - integrity; 13 - equilibrium; 14 - standardization; 15 - contrast. The fifth phase (series 16, 17, 18, 19, 20, 21) - components of a combination of groups: 16 - women-men; 17 - adults-children; 18 - assortment; 19 - color; 20 - accent print; 21 - accessories. The sixth phase (series 22, 23, 24, 25, 26, 27, 28) - 22 - the number of families; 23 - completeness; 24 - two-color; 25 - tricolor; 26 - related; 27 - related-contrast; 28 - contrast. The grid of horizontal and vertical rows forms a scheme of level control of the color composition of the Family look models (Figure 9a). An example of the formation of the color harmonization route of the central model of the collage №3 (Figure 9b) is shown in Figure 9c.

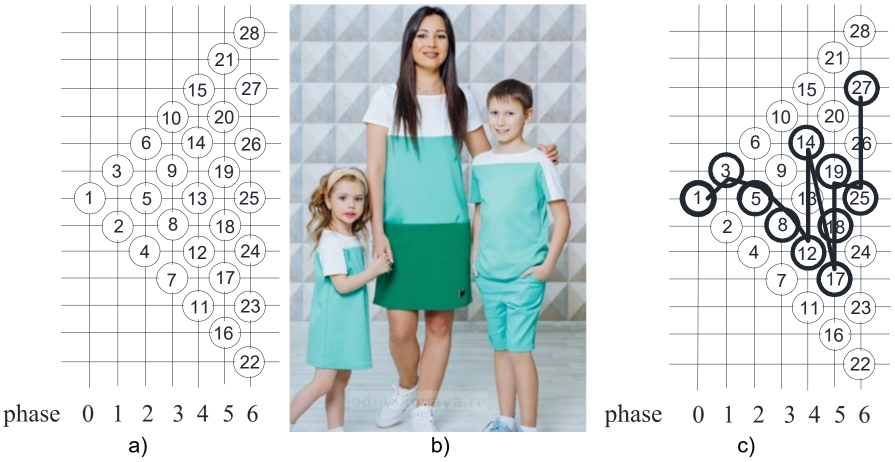


Figure 9 Scheme of level control of color harmonization of Family look models

Checking the route of color harmonization control model №3 (Figure 9), made in a related-contrast collage (27), confirms the triad combination of adults and children (17), assortment (18), color scheme (19) in a positive correlation (r_s=0.8) tricolor composition (25).

5 RESULTS

According to the results of reviewing 150 combinations of clothing models in the style of Family look in accordance with the recommendations [4, 5, 9, 10, 14] 4 rows of models have been formed on the basis of color type of behavior of 7 units each, which provides a closed color wheel (Table 1). By combining standard rules for matching wardrobe items and colors, the Family look model line has been created for 4 color types of behavior (Figure 10).

The basic model range of color type of behavior (Figure 11) illustrates the algorithm for forming a family wardrobe in the style of Family look.

The stages of formation of the family wardrobe are illustrated in Figure 12.

To assess possible emotional sensations taking into account color types used the method of correlation analysis.

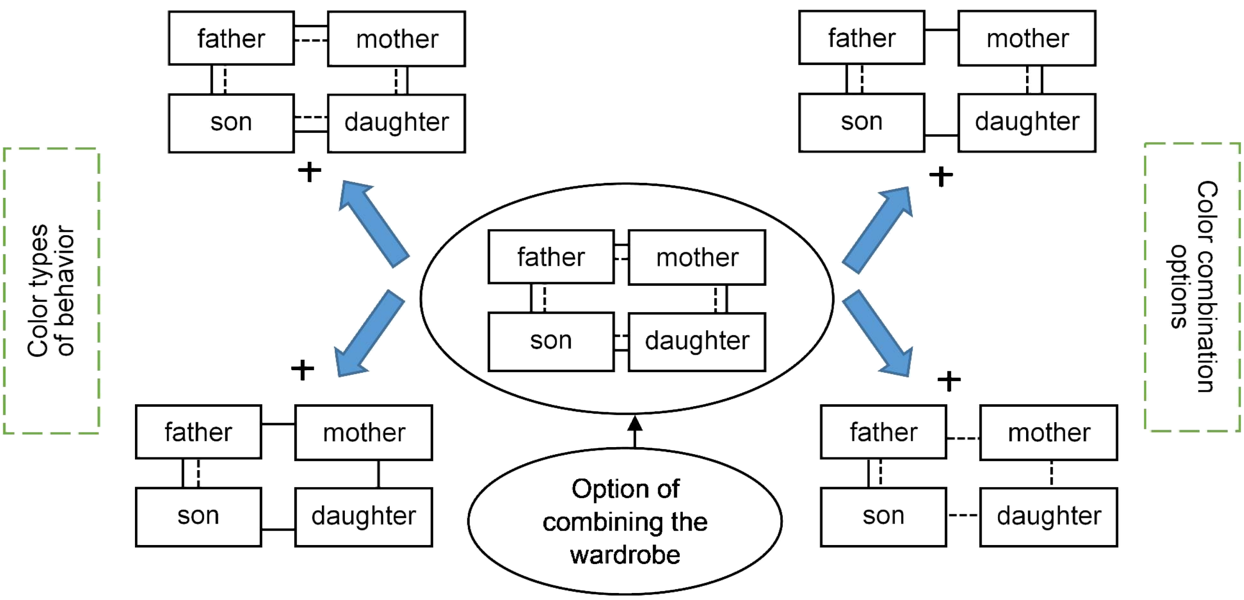


Figure 10 Variations of color and range combinations

a) b) c) d)

Figure 11 Model range of basic color types of behavior: a) red, b) blue, c) green and d) yellowish

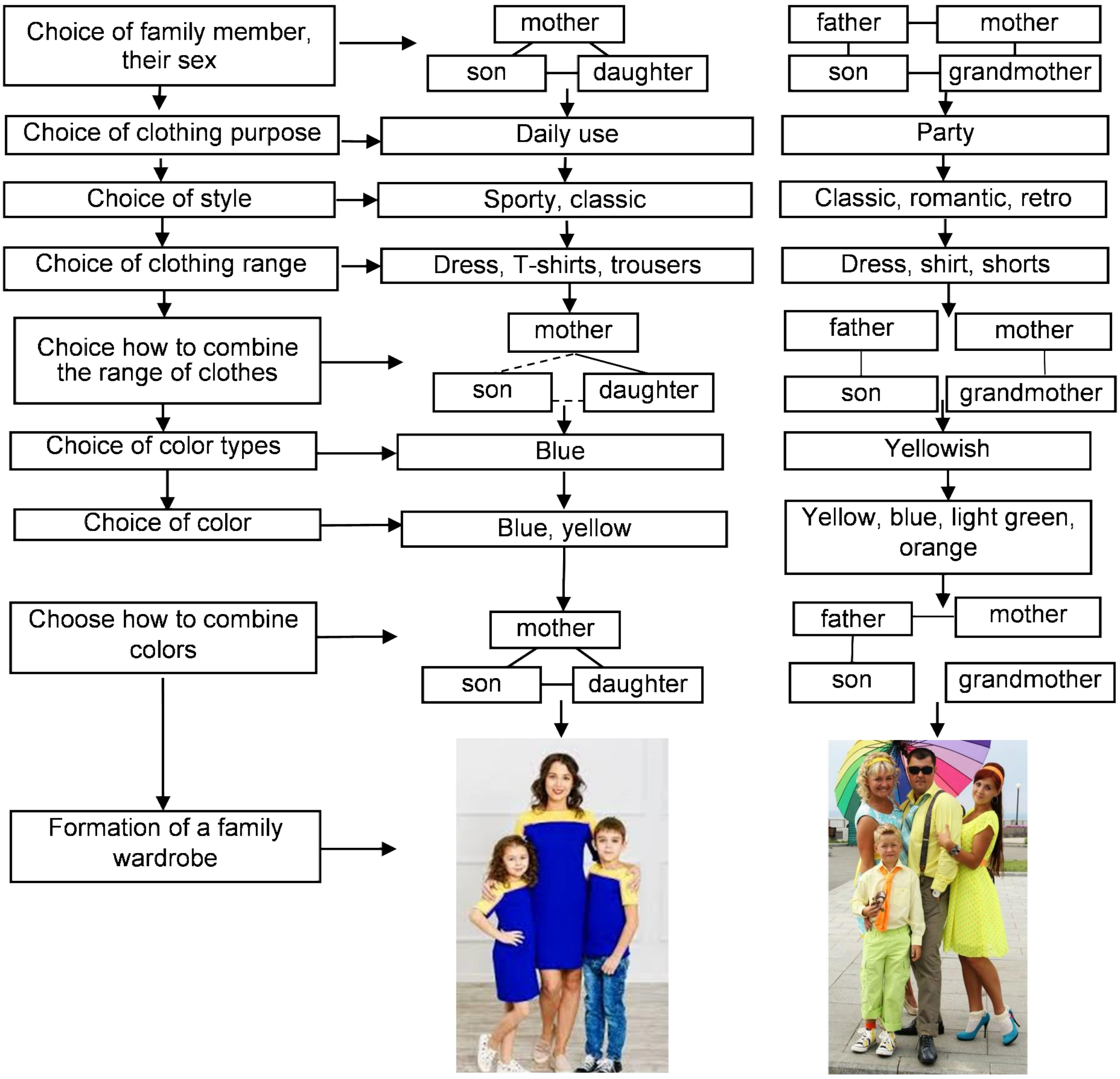


Figure 12 Algorithm of forming a family wardrobe in the style of Family look

6 CONCLUSIONS

Wardrobe in the style of Family look is formed according to the rules of combining gender and age characteristics of the family in the range, color and purpose of clothing with different types of combinations: parallel, cross, mixed (collage), triangle, which is confirmed by Figures 10 and 11.

To implement an algorithmic method of controlling the harmony of color of clothing in the style of Family look, the categories of color formation of style are analyzed (Table 2) from the standpoint of achieving integrity and unity in the combination of objects.

The application of the identification principles of the figurative solution of clothing models in the Family look style allows us to state the following:

- the main regulator of the selection of models in the style of Family look is not so much the composition of the family and purpose, as the psychological aspect of family values;
- to analyze the color composition of the family wardrobe, it is advisable to use the method of verification of color types of behavior, it allows to determine the harmony of color combinations by areas of color spots, which is important for recognizing signs of model imagery;
- the proposed method of quality gradation control of color harmony expression in the scale of psychological perception allows you to apply the bulkhead color control algorithm of any model in 7 phases of level control (Figure 9).

The suggested rules can be applied when designing clothes in one style for a group of people who do not form a family. For example, when developing branded (uniform) clothing for a particular company, school; in the development of stage clothing; clothes of members of a sports team; for themed youth parties, etc. The results can be useful for stylists, designers, marketers and university students learning to design clothes.

7 REFERENCES

1. Yang Z., Kim C., Laroche M., Lee H.: Parental style and consumer socialization among adolescents: A cross-cultural investigation, Journal of Business Research 67(3), 2014, pp. 228-236, https://doi.org/10.1016/j.jbusres.2013.05.008
2. Osmud R., Devender K.: Fashion innovativeness in India: shopping behaviour, clothing evaluation and fashion information sources, International Journal of Fashion Design, Technology and Education 11(3), 2018, pp. 287-298, http://doi.org/10.1080/17543266.2018.1429498
3. Johnson K., Lennon S.J., Rudd N.: Dress, body and self: research in the social psychology of dress, Fashion and Textiles 1(1), 2014, pp. 1-24, http://doi.org/10.1186/s40691-014-0020-7
4. Molodkina K.: Family look: what it is and why it is in your family (electronic resource), Available from: http://fly-mama.ru/family-look-chto-eto-takoe-i-zachem-on-vashej-seme, Accessed: 2021-04-01 (in Russian)
5. Baker R., Yu U.-J., Gam H.J., Banning J.: Identifying tween fashion consumers' profile concerning fashion innovativeness, opinion leadership, internet use for apparel shopping, interest in online co-design involvement, and brand commitment, Fashion and Textiles 6(8), 2019, pp. 1-17, https://doi.org/10.1186/s40691-018-0158-9
6. Rtishcheva P.: Family look. Dress like stars. Tips from a children's stylist (electronic resource), Available from: https://7sisters.ru/children/42219-family-look-odevaytes-kak-zvezdyi-sovetyi-detskogo-stilista.html, Accessed: 2021-04-01 (in Russian)
7. Family Look clothing (electronic resource), Available from: https://happywear.ru/blog/odezhda-v-stile-family-look, Accessed: 2021-04-02 (in Russian)
8. Sagalakova E.: 4 options for how to dress the whole family in the style of Family look (electronic resource), Available from: https://letidor.ru/moda/4-varianta-kak-odetsya-vsey-semey-v-stile-family-look.htm, Accessed: 2021-04-02 (in Russian)
9. Family look: a trend that unites (electronic resource), Available from: http://blog.shafa.ua/family-look-trend-kotoryiy-obedinyaet, Accessed: 2021-04-01 (in Russian)
10. Yaroshenko D.: Family look: one for all (electronic resource), Available from: http://www.cablook.com/fashion/family-look-odin-za-vseh, Accessed: 2021-04-02 (in Russian)
11. Mira Showroom Atelier: Images mom and daughter: evening dresses (electronic resource), Available from: https://www.pinterest.com/pin/592364157210639336, Accessed: 2021-04-01
12. Family look - what is it, how to choose the style of the family (electronic resource), Available from: http://vibormoi.ru/dress/1389-family-look.html, Accessed: 2021-04-02 (in Russian)
13. Family look for the whole family (electronic resource), Available from: https://shopoglot.com/family-look-for-creating-cool-images, Accessed: 2021-04-02 (in Russian)
14. Clare G., Uddin S.: Corporate image and competitive advantage for apparel companies, Trends in Textile Engineering & Fashion Technology 5(4), 2019, pp. 663-671, DOI:10.31031/TTEFT.2019.05.000618
15. Andreeva E., Kharlamova O., Mironova E., Parfenova E.: Harmonization of color relations in the clothes of children with disabilities, Sewing industry 2, 2008, pp. 39-40 (in Russian)
16. Sotchik A.N.: Method of color choices. Modification of the eight-color Luscher test, St. Petersburg: Publishing House "Rech", 2007
17. Medvedev Yu.: Color Psychology, Light Industry 4, 2007, pp. 27-28 (in Russian)
18. Bazina B.A.: Color and psyche, Monograph, Kharkov: KhGAK, 2001 (in Russian)

19. Sorina's sister's: Language of clothing, or how to understand a person by his clothes. Psychological Workshop, Moscow: Publishing House "GNOME and D", ICF "ECMOS", 2002
20. Gavish Y., Shoham A., Ruvio A.: A qualitative study of mother-adolescent daughter-vicarious role model consumption interactions, Journal of Consumer Marketing 27(1), 2010, pp. 43-56, https://doi.org/10.1108/07363761011012949
21. Beskorovaynaya G., Koryagin I.: Methods for choosing the color of finishing materials for clothing, Shewing industry 1, 2010, pp. 48-49 (in Russian)
22. Mok P.Y., Xu J., Wu Y.Y.: 9 - Fashion design using evolutionary algorithms and fuzzy set theory – a case to realize skirt design customizations, Woodhead Publishing, 2016, pp. 163-197, https://doi.org/10.1016/B978-0-08-100571-2.00009-9
23. Slavinskaya A.L., Ivanova M.A., Kotsyuk O.Yu.: Verification System of Clothing Model Portfolio According to Consumer Preferences Scenario, Proceedings of International Conference of Young Scientists & Students on Resource-Saving Technologies of Apparel, Textile & Food Industry, Khmelnytskyi, October 2019, Khmelnytskyi National University, Khmelnytsky, 2019, pp. 18-19, Accessed: 2021-03-31, Available from: http://tksv.khnu.km.ua/slavinska_ivanova_kocjuk.pdf (khnu.km.ua) (in Ukrainian)
24. Baker R., Yu U.-J., Gam H.J., Banning J.: Identifying tween fashion consumers' profile concerning fashion innovativeness, opinion leadership, internet use for apparel shopping, interest in online co-design involvement, and brand commitment, Fashion and Textiles 6(8), 2019, pp.1-17, DOI: 10.1186/s40691-018-0158-9
25. 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
26. Slavinska A., Syrotenko O., Mytsa V., Dombrovska O. Development of the production model of scaling uniformity of the assortment complex clothing family look, Vlakna a textile (Fibres and Textiles) 27(4), 2020, pp. 106-117, http://vat.ft.tul.cz/2020/4/VaT_2020_4_15.pdf
27. Etkind A.M.: Experience of theoretical interpretation of semantic differential, Questions of Psychology 1, 1979, pp.17-27 (in Russian)
28. Nada Y.A., Mesher H.: Analysis, design and implementation of intelligent expert system clothes style selection, International Journal of Computer Applications 105(4), 2014, pp. 15-20, doi:10.5120/18364-9508

WOMEN'S EXPRESSION IN CONTEMPORARY BATIK FABRIC IN INDONESIA

Eko Sugiarto[1], Triyanto[1], Meina Febriani[2] and Putri Khoirin Nashiroh[3]

[1]*Universitas Negeri Semarang, Arts and Language Faculty, Visual Art Department, Semarang, Indonesia*
[2]*Universitas Negeri Semarang, Arts and Language Faculty, Language Department, Semarang, Indonesia*
[3]*Universitas Negeri Semarang, Faculty of Engineering, Semarang, Indonesia*
ekosugiarto@mail.unnes.ac.id; triyanto@mail.unnes.ac.id, meinafebri@mail.unnes.ac.id, putrikhoiirin@mail.unnes.ac.id

***Abstract:** UNESCO's recognition of Indonesian textiles (batik) as a cultural heritage provides wider opportunities for the batik industry. The fact that needs to be known is that batik craftsmen in Indonesia are dominated by women, but research on batik textiles so far have not explored femininity in Indonesian batik motifs. This study aims to analyze the design of feminine-style batik motifs by Indonesian craftswomen. The data on batik motifs was collected in three cities, namely Pekalongan, Semarang and Solo. The visual analysis was prioritized in this research by tracing batik work documents from the aspect of the motif structure, the source of the idea and the value of feminism. The results showed that making batik fabric was dominated by women. Feminism-style batik motifs in Indonesia are dominated by plant objects (particularly flowers). The elements of red, green, light brown and blue are the most widely used than other colors. The femininity of batik motifs is depicted in an organic look that is presented in various curved lines. Femininity in batik motifs is often found, particularly in contemporary batik, which tries to break away from the rigidity of traditional batik.*

***Keywords:** contemporary batik, femininity, visual craft women expression.*

1 INTRODUCTION

Batik has become a clothing trend in Indonesia recently, particularly for women. This is shown by the widespread legitimacy of batik in various districts in Indonesia namely Kudus batik, Semarang batik, Batang batik, Cimahi batik, and even Kalimantan batik which is growing sporadically. Batik is not just a decoration on a piece of cloth, but contains aesthetic symbols [1, 2]. Previously, batik activities were only carried out by courtiers of the palace and then expanded to other areas outside the palace in Indonesia [3, 4]. Many batik fabrics are produced by women both as a main job and as a side job [5, 6]. Batik is growing very rapidly, from traditional to contemporary batik which offers more creative and contemporary motifs [7, 8]. In the midst of these developments, batik craftswomen occupied a vital position as creators, because of their ability to work with the highest efficiency with the lowest wages [9]. However, batik research about batik craftswomen had so far gone unnoticed, whereas batik craftswomen must adapt to the character, needs and desires of consumers so that traditional batik products are always in demand in line with the challenges of socio-cultural change [10, 11]. On the one hand, the aesthetic adaptation of batik craftswomen is a very important issue in the creation of batik. The right aesthetic adaptation will be able to produce artistic batik works as well [1, 12]. On the other hand, femininity usually appears as a pattern that helps form the visuals of batik motifs. Batik research has actually been carried out by other researchers in the academic and professional realms. One of the historical studies of batik was conducted by Pramono, et al. [11] about the history of Sukapura batik in the study of semiotics and Lokaprasidha, et al. [13] about the history and development of Kampung Batik Kauman Pekalongan. Batik research with a focus on motifs has also been carried out by most researchers in Indonesia [14, 15]. Meanwhile, research on the creation of contemporary batik motifs was carried out by Nurcahyati and Affanti [16]. On the other hand, the previous batik research was also conducted by Sugiarto, et al. [17] particularly about the trend of regional icon motifs.

Unfortunately, these batik studies are still limited to historical issues and aesthetic studies in general; they are not discussing women's expressions in contemporary batik motifs in Indonesia. Two research problems to be solved are „how is the visual form of contemporary batik motifs that are often made by batik craftswomen?" and "how is the value of femininity represented in the batik motif?"

In this case, this paper is important to convey. We cannot deny that most contemporary Indonesian batik motifs depict visual elements that are close to the world of women, including flower figures, plant figures and the use of colors identical to women. Batik products are also more uniquely created in women's dress products.

2 METHODOLOGY

The study uses a field research approach as part of artistic research, which focused on descriptive explanations of the expressions of craftswomen on batik products as textile heritage in Indonesia [18, 19]. The method was chosen because this study aims to find femininity (women expression) contained in the design of contemporary Indonesian batik motifs, both explicitly and implicitly presented. This research was conducted with a multiple case study design in the three most famous batik industrial areas in Indonesia, namely Pekalongan, Solo and Semarang.

The participants in this study were determined by purposive sampling, so that three batik craftswomen were selected in Kauman Villge in Pekalongan, Laweyan Village in Surakarta and the Figa Batik community in Rejomulyo Village in Semarang, which represented many batik industries in Indonesia. Craftswomen are selected based on their experience and style of contemporary motifs [20].

The main data was collected through observations of batik craftswomen in the process of making batik motifs. This study also attempts to collect various information about women's interests and orientations in artistic expression through in-depth interviews [21]. While the visual data, in the form of motifs, was collected through a visual study of the designs of the motifs made. The data analysis uses an interactive analysis model, with the following procedures: data reduction, data presentation and verification [22].

3 RESULTS AND DISCUSSION

3.1 *The development of contemporary batik of Indonesia*

As a heritage of traditional textiles in Indonesia, batik has developed from time to time, ranging from classic batik to contemporary batik creations, which increasingly gives crafters the freedom to explore the uniqueness of batik motifs, ideas and techniques [13]. Contemporary batik has been separated from the source of knowledge of traditional techniques that must use a night barrier but with variations in techniques by using canting, stamping, or painting in the process of its creation. In fact, contemporary batik can occupy a position as an artistic work of art [23, 24].

Contemporary batik keywords are "contemporary" or "newness" in the belief of postmodernism [25]. Contemporary indicators are manifested in contemporary concepts discussed [26]. Contemporary batik of Indonesia has been carried out by craftsmen, practitioners and entrepreneurs in the last ten years and has become the beginning of the rise of the national batik industry with various sources of development ideas, the majority of which rely on superior potential and local wisdom [16]. The phenomenon of batik in Indonesia is always interesting to study related to events, classification or categorization and its visualization. Some centers of the development of contemporary batik in Indonesia are in Pekalongan, Surakarta, Semarang, Cirebon and Yogyakarta, as well as the surrounding areas. These cities have always been pioneers in the development of batik in Indonesia. In fact, the batik industries continue to grow at this time to form a special brand for a good image in society [27].

Based on research on the development of batik in Pekalongan, Surakarta and Semarang, contemporary batik developed in the three areas that were developed with an orientation to novelty through four main strategies namely: (a) material processing, (b) motif design, (c) making process techniques and (d) the use in fashion. The novelty is an adjustment to the interests of consumers, particularly to the younger generation.

First, the material used is hot wax and it was scratched with a canting or stamped on the fabric. The batik cloth in traditional batik is generally *mori* fabric [28]. In contemporary batik, fabric materials that can be used include *mori* fabric, cotton fabric and silk fabric. It should be emphasized that textiles are referred to as "batik" when using wax as a barrier or color filter, whether it is applied by writing (called batik), stamped (called batik print making) or screen printing.

Second, contemporary batik that developed in Solo, Semarang and Pekalongan can use three making process techniques. Hand scratches on written batik will produce unique and specific patterns or motifs. The results of this motif pattern will later become the subject to get the main features. The results of batik with the stamp technique will produce motifs that repeat symmetrically. While the results of batik with screen printing techniques can produce repeating or specific patterns.

Contemporary batik is a modification of existing batik motifs, namely a combination of machete and Klithik motifs or an improvisation of the Sekar universe motif [29]. However, contemporary batik is now more flexible to follow the demand of the community [10].

3.2 *Batik craftswomen in Indonesia*

Based on the 15 participants spread across the Kauman, Laweyan and Rejomulyo batik industries, all of them were batik craftswomen. Two of them were single and 13 were married. The average is that they had been in the profession as batik craftswomen for more than 5 years. In fact, three of them were more than 10 years old. Meanwhile, there were both male and female of batik business owners.

In historical records, batik is included in the work of women. This work was mainly carried out in the areas of Solo and Yogyakarta. The community who participated in making batik included women, both young and old generations. They worked to earn money or because they were unemployed, to be used by themselves. However, due to changes in the socio-economic structure, batik work was currently only carried out by women who were still interested in making batik for generations for reasons of economic need [30]. Women who work as batik makers do not only string the existing motifs. But also there is an aesthetic expression expressed by craftswomen in a piece of fabric to produce an artistic batik textile work. In this condition, women's beliefs, values and aesthetic tastes are embedded in the batik fabric they make, which are visualized through specific motifs. Thus, it can be emphasized that batik work is a representation of Javanese women.

The aesthetic expression of the batik craftswomen was supported by various batik techniques, namely from writing, stamping or print making techniques. Based on observations of 15 participants, the most widely used technique was writing and printing. Most of the participants' ability to make batik was obtained from generation to generation from their parents. Some of the participants acquired skills from fellow craftswomen and attended training.

Figure 1 Batik women in Kauman Village, Pekalongan region (documentation 2020)

3.3 *Flower figure as a visual expression of batik craftswomen: motifs, colors and patterns in contemporary batik*

The visual expression of batik craftswomen will not be separated from the guidelines, values, appetites and segmentations. The following picture is used to explain systematically the aesthetic expressions of batik craftswomen in a socio-cultural context, which will have implications for the results of contemporary batik expressions (adapted from Rohidi) [31]. The characteristic of batik as an expression of women is always shown through the depiction of motifs with the subject matter of flowers and plants that are being created to become motifs. Batik motifs are generally formed through three approaches, namely stylization, deformation and distortion. The 15 participants in this study used stylization as an approach in formulating motifs. However, some of them admitted that the motifs they created were duplicating the existing ones. The first step in stylizing was to make a basic shape with simple line elements; this would be the main motif. The second step, the main motif was filled with lines, dots (*cecek*) or simpler shapes to fill the space. This was called *isen-isen*. The third step was to complete with other forms as a complement to the emptiness of space.

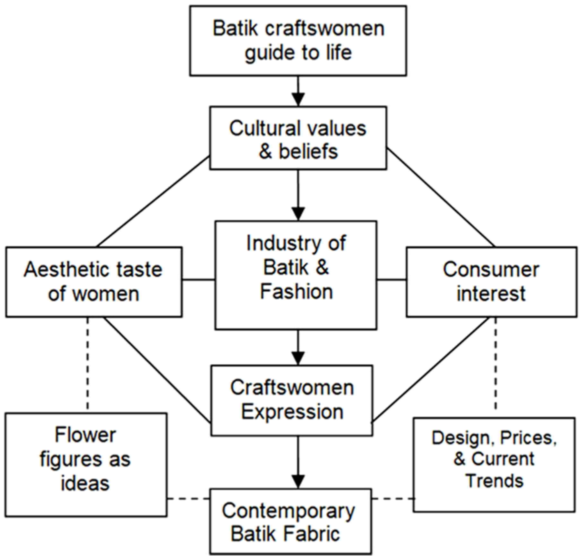


Figure 2 A chart describing the encouragement of aesthetic expression of batik craftswomen

The motifs were then arranged by using a pattern with certain techniques in a geometric fractal [32]. Among the various techniques in compiling patterns which were carried out by batik craftswomen were the full-repeat, half-drop, quarter-drop, diamond-repeat, parallel repetition and opposite repetition techniques. Through these techniques, plant figures as a source of ideas were described as main motifs, *isen-isen* and complements.

The changes and diversity in the use of batik fabric by Indonesian women are influenced by changes and developments in the role of Indonesian women themselves, starting from only doing domestic activities, but also attending school and working in the community [33]. In the development of contemporary fashion, the fashion trend factor is also an indicator of the development of batik fabric production and use, so it results adaptive and flexible batik clothing according to its era [34]. The author presents six motifs out of the fifteen motifs collected. Table 1 shows examples of plants and flowers as visual expressions and characteristics of women. This batik was developed creatively but still came from old motifs.

Table 1 Expression of women in batik fabric

Batik fabric	Main motif	Pattern	Dominant color	Women image
 *Buketan* motif		full repeat	light blue, dark blue, pink	• This is a 'batik bouquet', which has been created into a variety of new motifs. This motif is widely created in Pekalongan area. • The flower arrangement symbolizes the firm and loving personality of women.
 Blooming flower motif		diamond-repeat	pink, blue, light green	• This batik fabric was made by a batik craftswoman in Laweyan Surakarta. • This batik has the main motif of flowers in bloom with the dominance of pink on the background and light blue on the flower subject matter. • This motif has the meaning of “radiance” and elegance. • Based on the pattern and color, this batik is identical to the character of women.
 Sunflowers motif		diamond-repeat	blue, white, black	• This batik fabric is made by a batik craftswoman in Pekalongan area. • This batik has the main motif of sunflowers which are in bloom with the dominance of white on the background and blue on the sunflower petals. • This motif has the meaning of one's spirit of life that must be owned by Javanese women.
 Shoe flower pattern		full-repeat	light blue, dark blue	• This batik fabric is made by craftswomen in Semarang, namely the Batik Figa community. • This batik has the main motif of hibiscus flowers with the dominant colors blue and purple as the background. • In the perspective of Javanese women, this motif has the meaning of purity, beauty, and elegance. This flower is also popular in Sundanese and Malay culture.
 Charcoal flower motif		half-drop	purple, red	• This batik fabric is mostly made by batik craftswomen in Rejomulyo, Semarang. • This batik is an icon of the Semarang city. Its character is Semarangan batik, because at the end of the 15th century a type of tamarind or tamarind tree grew which was typical in Semarang. • Tamarind has a philosophical meaning in Javanese culture. It symbolizes spirit and welfare.
 Tulip flower pattern		parallel repeat	yellow, blue, green, red, pink	• This batik fabric is made by craftswomen in Surakarta. • This batik has the main motif of a blooming Kanthil flower with a dominant colors are red and blue on the floral pattern and yellow on the background. • In women's lives, this flower has the meaning of closeness and peace.

(Images source: documentation in 2021)

Flowers and plants are symbols of women or representations of women [35]. This belief is actually most visible in painting. Flowers are also used to symbolize women with tenderness of heart, even with great sexual desire [36]. But the symbolism of flowers in western aesthetics, especially in painting, is different from Javanese aesthetics in Indonesia, which is oriented to God's blessing [37, 38]. The symbolism of flowers as a visual expression has many meanings, not even about associations with women and sexuality. Indeed, flowers have always represented female sexuality throughout history and in almost every region of the world. This is also believed in the field of painting as well as batik textiles. Batik activities can be called as a representation of Javanese women, even though they are included in informal work that is mostly done at home with salaries that are not higher than the average salary of men [39]. Philosophically, Javanese women think of themselves as individuals who are skilled in doing many things, ranging from jobs that are done while sitting to jobs that require more energy [40]. The values of independence and discipline are inherent in Javanese women's behavior patterns, so they do not depend on men or husbands for economic needs [41]. In addition, because most Indonesians keep using batik, batik still exists today, this is inseparable from the role of women as craftswomen. However, it is proven that the current trend is changing from traditional to contemporary batik patterns. The transformation of batik mostly comes with various design changes [42]. In addition, changes occur in terms of techniques, dyes and equipment [10].

4 CONCLUSION

Batik craftswomen expressed themselves aesthetically. In making batik they used the depiction of motifs with floral ideas. Contemporarily, the resulting motifs had been creatively explored to diversify batik products, but still referred to the old forms that already exist. The visual expression of batik craftswomen were most visible in two ways, namely the selection of flowers as the main motif and the selection of pink, blue and green colors which were more dominant than other colors in fabric coloring. While the technique of batik still maintained the writing technique in addition to the development of stamp and screen printing techniques. Symbolically, this visual expression was also accompanied by a philosophical belief in the role and position of women in Javanese culture, namely as human beings who are independent and full of love in the family. Symbolically, flowers have a certain meaning (it is identical to the nature of femininity) which is widely applied in women's cultural rites in Java.

***Acknowledgments**: The authors would like to thank to the resource persons for this research, namely craftwomen in Kauman Village in Pekalongan, Laweyan Village in Surakarta, and the Batik Figa community in Rejomulyo Village. In addition, we also would like to thank to the Research Institute at Universitas Negeri Semarang for funding this study by using the DIPA UNNES funding scheme of 2021.*

5 REFERENCES

1. 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
2. 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, https://doi.org/10.1177/2158244019846686
3. Pujiyanto: The Phenomenon of Surakarta and Yogyakarta Batik Designs, Gelar: Jurnal Seni Budaya 11(1), 2013, pp. 68-86, (in Indonesian), https://doi.org/10.33153/glr.v11i1.1439
4. Sobandi B., Triyanto, Rohidi T.R., Syakir: The use of clove leaves (Syzygium aromaticum L.) as natural dye for batik production in Kasumedangan batik industry, Indonesia, Vlákna a textil (Fibres Textiles) 28(1), 2021, pp. 86-94
5. Fadlia A.: Women and batik Rifa'iyah, in 2nd International Conference on History Education 2018, pp. 31-35
6. Syamwil R., Sugiarto E., Rohidi T.R., Nurrohmah S.: Weeds as a source of development idea on batik motive, Vlakna a textil (Fibres Textiles) 26(2), 2019, pp. 71-75
7. 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
8. Tjahjaningsih E., Handayani, Santosa A.B., Utomo A.P.: Creative techniques of contemporary batik motifs, International Journal of Organizational Innovation 12(3), 2020, pp. 248-254
9. Hunga A.I.R.: Protecting women's domestic area & environment: Study on eco-friendly batik, Indonesian Feminist Journal 2(2), 2019, pp. 82-105
10. Kim S.Y.: Tradition and transformation of batik in Indonesia, Journal of the Korean Society of Clothing and Textiles 37(5), 2013, pp. 676-690, http://dx.doi.org/10.5850/JKSCT.2013.37.5.676 (in Korean)
11. Pramono S., Sabana S., Haldani A.: Batik transformation and globalization (Transformasi Batik dan Globalisasi), Dimensi 15(1), 2018, pp. 55-62 (in Indonesian)
12. Triyanto, Mujiyono, Sugiarto E.: Aesthetic adaptation as a culture strategy in preserving the local creative potentials, Komunitas: International Journal of Indonesian Society and Culture 9(2), 2017, pp. 255-266,
13. Lokaprasidha P.: The history of batik and the development of kampung batik kauman as a local to international tourism destination, Journal of Tourism and Creativity 1(1), 2017, pp. 39-48, https://jurnal.unej.ac.id/index.php/tourismjournal/article/view/13796
14. Saddhono K., Widodo S.T., Al-makmun M.T., Tozu M.: The Study of philosophical meaning of batik and kimono motifs to foster the study of philosophical meaning of batik and kimono motifs to foster collaborative creative industry, Asian Social Science 10(9), 2014, pp 71-80, DOI:10.5539/ass.v10n9p52
15. [Taman K., Sidoarjo K.: A study of the form, function, and symbolic meaning of the gurda motif on the Yogyakarta larangan batik (Kajian Bentuk, Fungsi, dan Makna Simbolik Motif Gurda pada Batik Larangan Yogyakarta), INVENSI 5(30), 2020, pp. 65-80 (in Indonesian)
16. Cahyati D.N., Affanti T.B.: A Development of potential of creative industries-based contemporary batik design in Indonesia (Pengembangan Desain Batik Kontemporer Berbasis PotensI Industri Kreatif di Indonesia), J. Sosioteknologi 17(3), 2019, pp. 391-402 (in Indonesian)
17. Sugiarto E., Othman A.N., Triyanto, Febriani M.: Regional icon motifs: recent trends in indonesia's batik fabric development, Vlakna a textil (Fibres and Textiles) 27(1), 2020. pp. 93-98
18. Denzim N.K., Lincoln Y.S.: Entering the field of qualitative research, Sage Publisher, 1997, ISBN: 0-8039-4679-1
19. Yin R.K.: Case Study Research: Design and Methods. Thausand Oaks, CA: Sage, 2003
20. Rohidi T.R.: Arts Research Methodology (Metodologi Penelitian Seni), Semarang: Cipta Prima Nusantara, 2014, ISBN: 978-602-8054-40-9 (in Indonesian)

21. Sugiarto E. Lestari W.: The collaboration of visual property and Semarangan dance: a case study of student creativity in ‘generation Z', International Journal of Innovation, Creativity and Change 10(12), 2020, pp. 100-110
22. Miles M.B., Huberman A.M.: Qualitative Data Analysis, Arizona State University, USA, 1984
23. Jurriëns E.: The countryside in Indonesian contemporary art and media. From distant horizons to traversing drones, Journal of the Humanities and Social Sciences of Southeast Asia 175(4), 2019, pp. 446-473, https://doi.org/10.1163/22134379-17502023
24. Suardana I.W., Susanto M.R., Setiawati S.W., Barriyah I.Q., Aditya M., Ganika A.: Indonesian contemporary art : a local genius learning perspective, International Journal of Scientific & Technology Research 8(9), 2019, pp. 1282-1284
25. Chistyakova O.: Postmodern philosophy and contemporary art, in 4th International Conference on Arts, Design and Contemporary Education ICADCE 2018, pp. 131-136, https://doi.org/10.2991/icadce-18.2018.26
26. Smith T.: Currents of world-making in contemporary art, World Art 1(2), 2011, pp. 171-188, https://doi.org/10.1080/21500894.2011.602712
27. Nurhayati T., Wahida A.: Strategic Industry of sadewa batik in developing batik images viewed from corporate and product image, Vlakna a textil (Fibres and Textiles) 28(1), 2021, pp. 63-69
28. Yunari N.: Classification of types of written and non-written batik based on texture features of batik image by using learning vector quantization (Klasifikasi Jenis Batik Tulis dan Non Tulis Berdasarkan Fitur Tekstur Citra Batik Menggunakan Learning Vector Quantization), Institut Teknologi Sepuluh Nopember, 2017 (in Indonesian)
29. Tresnadi C., 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, https://doi.org/10.18533/journal.v4i8.797
30. [Steelyana E.: Batik, a beautiful cultural heritage that preserve culture and support economic development in Indonesia, BINUS Business Review 3(1), 2012, pp. 116-130, https://doi.org/10.21512/bbr.v3i1.1288
31. Rohidi T.R.: Arts in culture perspective (Kesenian dalam Pendekatan Kebudayaan), STISI Press, Bandung, 2002, ISBN 978-602-8054-86-7 (in Indonesian)
32. Widodo C.E.: The use of fractals as an Indonesian batik, International Research Journal of Computer Science 6(11), 2019, pp. 694-699
33. Ratuannisa T., Santosa I., Kahdar K., Syarief A.: Shifting of batik clothing style as response to fashion trends in Indonesia, Mudra Jurnal Seni Budaya 35(2), 2020, pp. 127-132, https://doi.org/10.31091/mudra.v35i2.1044
34. Niccholls M.B.: Examining Adaptation Studies in and through the Decadent aesthetics of J. - K. Huysmans' à Rebours, Doctoral thesis, University of West London, 2018, http://repository.uwl.ac.uk/id/eprint/6858
35. Frownfelter A.: Flower Symbolism as Female Sexual Metaphor, Senior Honors Thesis, Eastern Michigan University, 2010, https://commons.emich.edu/honors/238
36. Chicago J., Lucie-Smith E.: Women and Art: Contested Territory, Watson-Guptill Publications, 1999, 192 p., ISBN: 0823058525
37. Widayanti S.: The philosophical meaning of the 'Kembar Mayang' in the life of the Javanese Society (Makna Filosofis Kembar Mayang dalam Kehidupan Masyarakat Jawa), J. Filsafat 18(2), 2008, pp. 115-129 (in Indonesian)
38. [Anggraini T., Utami S., Murningsih: An ethnobotany study of plants used inJavanese traditional wedding ceremonies around the Kasunanan Surakarta hadiningrat palace (Kajian Etnobotani Tumbuhan yang Digunakan Pada Upacara Pernikahan Adat Jawa di Sekitar Keraton Kasunanan Surakarta Hadiningrat), J. Biolologi 7(3), 2018, pp. 13-20, (in Indonesian)
39. Susanti E.: Marginalization and subordination of women workers at the home-based batik industry in East Java, OPCIN 35(22), 2019, pp. 2899-2921, https://produccioncientificaluz.org/index.php/opcion/article/view/30856 (in Spanish)
40. Kusumasari D., Rahmi A.N.: Business preservation of batik Indonesia (heritage), challenges and the solution, Jurnal Ilmu Manajemen & Ekonomika 12(1), 2019, pp. 9-14, http://dx.doi.org/10.35384/jime.v12i1.151
41. Mawaddah H., Suyitno, Suhita R.: Javanese women's efforts to face patriarchal culture in the novel 'Para Priyayi' by Umar Kayam, International Journal of Multicultural and Multireligious Understanding 8(1), 2021, pp. 100-110, http://dx.doi.org/10.18415/ijmmu.v8i1.2267
42. Selamet J.: Indonesian Batik Translation: a Case Study, The International Journal of Visual Design 12(3), 2018, pp. 11-17, https://doi.org/10.18848/2325-1581/CGP/v12i03/11-17

PREPARATION, CHARACTERIZATION AND COLOR PERFORMANCE OF PLA PHOTOLUMINESCENT FIBRES

Z. Tomčíková, Š. Krivoš, F. Hrbáľ and D. Rerková

Research Institute for Man-Made Fibres a.s., Štúrova 2, 05921 Svit, Slovak Republic
tomcikova@vuchv.sk

Abstract: *Polylactic acid (PLA) is one of the fastest growing biodegradable polymers on the market. Consumers' preference of environmentally friendly products from biodegradable polymers but higher costs and lower quality of products may prevent their greater use compared to synthetic products. Therefore, there is an effort to modified PLA properties via different methods like using modifiers, blending, copolymerization and physical treatments. This article presents the preparation process of modified PLA fibres by an organic photoluminescent pigment as well as the preparation of knitted fabrics where the color efficiency of the pigment was detected by UV lamp illumination. For comparison, an unmodified PLA fibre and knitted fabric were prepared in the same manner as modified PLA fibres. To determine the supermolecular structure parameters of the fibres the methods of birefringence, sound velocity in fibres and crystallinity were used. The basic mechanical properties of the modified PLA fibres were expressed through the tenacity and elongation at break. Also, the overall fineness of the fibres has been determined. Results confirmed that the PLA can be used as a carrier of organic protective photoluminescent pigment without any impact on the structure and mechanical properties modified PLA fibres.*

Keywords: *PLA fibres, photoluminescent pigment, structure, mechanical properties, color performance.*

1 INTRODUCTION

Polylactic acid (PLA) is the first viable thermoplastic that can be produced from a plant-based feedstock such as corn or sugar cane, and be processed by the conventional melt processing technologies. Production of PLA requires 25-55% less fossil energy and 20-50% less fossil fuel resources than the production of petroleum-based polymers. PLA polymer is compostable, as it easily degrades by simple hydrolysis under the appropriate conditions (around 60°C and 90% relative humidity) [1]. Therefore PLA successfully bridges the gap between synthetic and natural fibres and finds a wide range of uses. Applications of PLA fibres are mainly in fibrefill (pillows, comforters, mattresses and duvets), nonwoven applications (agricultural and geo textiles, hygiene products, wipes) and less in apparel (sport, active, underwear and fashion wear) [2]. From other areas PLA finds use in the packaging, agriculture, medicine, electronics, construction and also automotive industries [3-6]. The simplicity of melt processing, unique property spectrum, renewable source of origin and of composting and recycling at the end of its useful life lead to growing interest in PLA. At the same time, polylactic acid is produced at the largest industrial scale of all biodegradable polymers (hundreds of thousand tons of PLA per year) [2].

Phenomena that involve energy absorption and subsequent light emission are generally classified as luminescence. Depending on the method of excitation, there are several types of luminescence [7, 8]. Particularly interesting for fibres are photoluminescent pigments, which exist in organic and inorganic form [9-11]. The increasing interest in luminescent waveguides, applied as light concentrators, sensing elements, or decorative illuminating systems, is fostering efforts to further expand their functionality. By varying the concentration of luminophores can be tailored the overall color of yarn and fabric composition [12].

Smart textiles are defined as materials with responsiveness ability to an external stimulus such as light, electricity, chemicals, pH, solvent polarity and temperature [11]. In our work one from smart materials specifically PLA fibres were tried to prepare. Our fibres react to UV light as an effect of photoluminescent pigment content. As the first PLA masterbatch was prepared. The modified PLA fibres with protective photoluminescent pigment were prepared by the discontinuous process of spinning and drawing. The supermolecular structure and mechanical properties drawn modified PLA fibres were compared with drawn unmodified PLA fibre prepared under the same technological conditions. At the end, from modified and unmodified fibre the knitted fabric was prepared. The photoluminescent effect of the organic protective pigment was also observed in the knitted fabric.

2 EXPERIMENTAL AND METHODS

2.1 Materials

Polylactide acid (PLA) produced by Total Corbion PLA B.V with MFI=8.9 g/10 min (210°C/2.16 kg) and organic protective photoluminescent pigment (OP) from Biesterfeld Company were used. PLA masterbatch with content 3.0 wt.% OP and MFI=10.91 g/10 min (210°C/2.16 kg) developed by Research Institute for Man-Made Fibres, a. s. Svit was used during fibres preparation process.

2.2 Preparation of PLA masterbatch

Before preparation of masterbatch the premix has been prepared. The premix consisted of a PLA carrier and organic protective photoluminescent pigment. The polymer and the pigment were milled and dried at 85°C for 4 hours before preparing of the premixes.

The PLA masterbatch was prepared on a Werner-Pfleiderer ZDSK 28 laboratory line with a twin-screw extruder (a screw diameter of 28 mm) and a vacuum zone. The preparation process of masterbatch had been carried out at a constant screws rotation speed 270 min^{-1} and constant extrusion temperature of 210°C. The output was 3% masterbatch of OP.

2.3 Fibre preparation

The modified PLA/OP fibres, with organic protective photoluminescent pigment of a content from 0.1 and 0.3 wt.%, were prepared from mechanical mixture of PLA granulated polymer and PLA masterbatch using the classical discontinuous process of spinning and drawing. The laboratory discontinuous line had an extruder with diameter of D=32.0 mm, with a discontinuous one-step drawing process. The processing conditions were: the spinning temperature of 216°C, spinning die 25 holes with diameter 0.3 mm, final spinning process speed of 1500 $m.min^{-1}$, the drawing ratio λ=1.5, the drawing temperature of 80°C and final drawing process speed of 100 $m.min^{-1}$. The PLA fibre without OP under the same processing conditions was prepared for comparison.

2.4 Preparation of knitted fabric

From drawn unmodified PLA fibre and modified PLA/OP fibres the knitted fabrics of one meter length on a laboratory circular knitting machine were prepared. The principle of knitting was as follows: the needles move individually one after the other in the grooves of the cylinder, which rotates during work. The feet of the needles are gripped by a fixed lock, into the curved channel to which they fit. In this way, the needles move up and down, the supplied thread is caught by the needle head, forms an eyelet and threads them through the finished part of the knit.

2.5 Methods used

<u>Application properties of PLA/OP masterbatch</u>

The Melt Mass-Flow Rate (MFR), Melt Volume-Flow Rate (MVR) and viscosity (η) of PLA/OP masterbatch and PLA were measured on capillary rheoviscosimeter Dynisco Kayness using conditions: temperature of 210°C; load of 2.16 kg; detention time of 5 min; nozzle diameter of 2.095 mm; nozzle length of 8.00 mm and shear stress of 19.5 kPa. Samples have been dried before measurement for 4 hours at 85°C.

<u>Thermal analysis of PLA/OP masterbatch</u>

Evaluation of basic thermal properties of PLA/OP masterbatch was done by DSC technique using DSC-Q20 equipment from TA Instruments. In this procedure, the non-isothermal process of analysis was performed. PLA/OP masterbatch was heated at a rate of 16°$C.min^{-1}$ from 20 to 220°C, after tempering for 6 minutes the masterbatch was cooled again to a temperature of 20°C. All measurements were carried out in a nitrogen atmosphere. The masterbatch sample was not dried or treated by heat.

TGA analysis was performed using TGA-6 equipment from Perkin Elmer at isothermal temperatures 200°C, 240°C and 280°C. PLA/OP masterbatch was heated at the rate of 50°$C.min^{-1}$ from 25 to 50°C, the next was heating from 50°C to 200-280°C by rate 20°C/min with detaining time max. 20 min at the temperature required. All measurements were carried out in a nitrogen atmosphere.

By the same procedures, DSC and TGA analysis of the PLA polymer and the organic photoluminescent pigment were performed but OP by DSC technique was heated to a temperature 320°C. The DSC and TGA analysis were determined according to EN ISO 11 357-1: 2016 and EN ISO 11 358, respectively.

<u>Orientation of fibre (the fibre´s birefringence)</u>

The orientation of macromolecular chains segments in fibre expresses the level of anisotropy of oriented polymer system (fibre). The total orientation of prepared modified PLA fibres was evaluated using a DNP 714BI polarization microscope, where the refractive indexes of light in the fibre axis ($n_{\parallel}$) and in the perpendicular direction of the fibre ($n_{\perp}$) were identified. The fibre's birefringence (Δn) was calculated from these values using equation 1:

$$\Delta n = n_{\parallel} - n_{\perp} \quad (1)$$

<u>The sound velocity in fibres</u>

The sound velocity in fibres is given as the ratio of fibre length to the time needed for the transfer of acoustic nodes along that length (expressed in $km.s^{-1}$). It is dependent on the internal structure arrangement of fibres (expressed by a supermolecular structure parameter) and may serve as a measure of fibre anisotropy. The sound velocity in fibres was measured using a PPMSR Dynamic Modulus Tester (USA).

Crystallinity of fibres

Crystallinity β represents the crystalline portion of fibre which may be evaluated using various methods. In this work DSC-Q20 apparatus from TA Instruments was used for the evaluation of thermal properties of unmodified PLA fibre and modified PLA fibres. The non-isothermal process of analysis was performed. All samples of PLA fibres were heated by rate of 10°C.min^{-1} from 60 to 200°C under nitrogen flow. From melting endotherm of 1st heating of PLA fibres the melting enthalpy (ΔH_m) was determined. The crystallinity β of PLA fibres was calculated according to the following equation:

$$\beta = \frac{\Delta H_m - \Delta H_{cc}}{\Delta H_{m,0}} \cdot 100\% \qquad (2)$$

where: ΔH_{cc} is the cold crystallization enthalpy of PLA fibres obtained during heating scan and $\Delta H_{m,0}$ is the melting enthalpy of 100% crystalline PLA (93.6 kJ.kg^{-1}) [13].

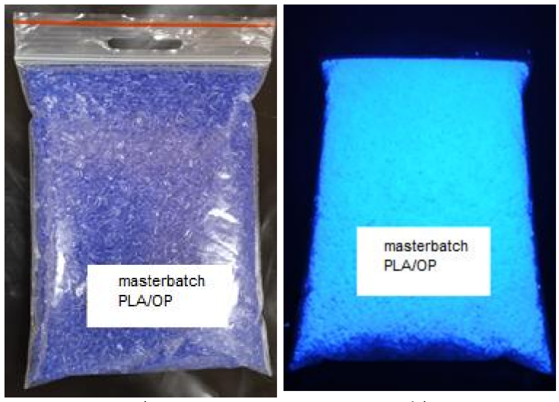
Mechanical properties of fibres

The basic mechanical characteristics (tenacity at break, and elongation at break) of unmodified PLA fibre and modified PLA fibres were measured using Instron 3345 equipment with a gauge length of 500 mm and clamping rate of 500 mm/min. An average of a least 10 individual measurements was used for each fibre. The mechanical characteristics and fineness were determined according to EN ISO 2062 and EN ISO 2060, respectively.

3 RESULTS AND DISCUSSION

For spinning and drawing technology research tests the masterbatch containing 3 wt.% OP was prepared. The illuminated PLA/OP masterbatch by daylight and under UV light is shown in Figure 1. It was shown, that PLA masterbatch has a photoluminescent effect under UV light.

The composition of PLA masterbatch and its application properties are given in Table 1 together with the PLA polymer used. By evaluating the application properties of the PLA/OP masterbatch (Table 1), it was found that the masterbatch of organic photoluminescent pigment has higher flow indexes and a reciprocal decrease in melt viscosity compared to the PLA polymer used. Values of application properties of PLA and PLA/OP masterbatch: MFR about 10 g/10 min and viscosity about 1000 Pa.s are suitable for achieving higher photoluminescent fibre tenacity.



a) b)

Figure 1 PLA/OP masterbatch with a content 0.30 wt.% of organic protective photoluminescent pigment illuminated by a) daylight D65 and b) UV lamp

The thermal properties of the PLA/OP masterbatch were evaluated by DSC thermal analysis where the following values were obtained: temperature of the cold crystallization - T_{cc}; enthalpy of the cold crystallization - ΔH_{cc}; melting temperature of the sample - T_m; melting enthalpy of the sample - ΔH_m; crystallinity - β; crystallization temperature - T_c and crystallization enthalpy - ΔH_c. The results of PLA/OP masterbatch heating are given in Table 2 and results of PLA/OP masterbatch cooling are given in Table 3. Values of PLA and organic photoluminescent pigment are given in tables for comparison.

The measured melting temperatures of the PLA/OP masterbatch and the melting enthalpy values determined during the first and second heating (Table 2) correspond to the PLA polymer matrix and take into account the thermal history of the masterbatch. The relatively rapid cooling of the PLA/OP masterbatch melt and the presence of OP cause the cold crystallization of the sample, which was measured during the first heating. The difference between the first and second heating of the PLA/OP masterbatch is significant, because due to the defined heating and cooling, the cold crystallization completely disappears, the temperature and the melting enthalpy slightly decrease with the simultaneous increase of crystallinity from 0.221 to 0.451. The organic pigment which does not have a melting and crystallization temperature in the temperature range examined; may act as a nucleating agent in the PLA/OP masterbatch. As the melt cools after the first and second heats, the temperature and enthalpy of crystallization of the PLA/OP masterbatch decrease, as can be seen in Table 3.

Table 1 Application properties of PLA/OP masterbatch

Sample	MFR [g/10 min]	MVR [cm/10 min]	CV_{MFR} [%]	η [Pa.s]	CVη [%]
PLA	8.90	8.04	6.6	1295.1	6.6
97 wt.% PLA / 3 wt.% OP	10.91	9.96	12.80	1076.8	13.6

Table 2 Results of DSC analysis (heating) of PLA, OP and PLA/OP masterbatch

Sample	HEATING	Cold crystallization		Melting of samples		Crystallinity
	Parameter	T_{cc} [°C]	ΔH_{cc} [kJ/kg]	T_m [°C]	ΔH_m [kJ/kg]	β
PLA/OP masterbatch	1st heating	99.7	24.8	179.8	45.5	0.221
	2nd heating	not determined	not determined	178.5	42.2	0.451
PLA	1st heating	not determined	not determined	175.5	52.5	0.561
	2nd heating	not determined	not determined	172.2	5.1	0.054
OP	1st heating	not determined	not determined	not determined	not determined	not determined
	2nd heating	not determined	not determined	not determined	not determined	not determined

Table 3 Results of DSC analysis (cooling) of PLA, OP and PLA/OP masterbatch

Sample	COOLING	Crystallization	
	Parameter	T_c [°C]	ΔH_c [kJ/kg]
PLA/OP masterbatch	1st cooling	104.8	34.1
	2nd cooling	92.4	15.6
PLA	1st cooling	not determined	not determined
	2nd cooling	not determined	not determined
OP	1st cooling	not determined	not determined
	2nd cooling	not determined	not determined

Table 4 Results of TGA analysis of PLA, OP and PLA/OP masterbatch

Heat load time [min]	Weight loss at isothermal temperatures [wt.%]								
	PLA/OP masterbatch			PLA			OP		
	200°C	240°C	280°C	200°C	240°C	280°C	200°C	240°C	280°C
0	0.01	0.12	0.31	0.08	0.32	0.48	0.00	0.00	0.01
5	0.04	0.18	0.36	0.16	0.38	0.52	0.00	0.00	0.07
10	0.06	0.24	0.42	0.21	0.42	0.57	0.00	0.00	0.12
15	0.09	0.26	0.49	0.25	0.47	0.62	0.00	0.01	0.16
20	0.12	0.29	0.56	0.31	0.52	0.67	0.00	0.01	0.18

Table 5 Supermolecular structure parameters of drawn PLA fibre and PLA/OP fibres

Content of OP [wt.%]	$\Delta n.10^3$	$CV_{\Delta n}$ [%]	c [km/s]	CV_c [%]	β
-	24.59	1.52	2.09	4.13	0.502
0.10	27.94	1.03	2.26	3.12	0.533
0.30	27.77	1.39	2.22	3.41	0.502

Table 6 Mechanical properties of drawn PLA fibre and PLA/OP fibres

Content of OP [wt.%]	Fineness [dtex]	CV_F [%]	Tenacity [cN/dtex]	CV_T [%]	Elongation [%]	CV_E [%]
-	147.4	0.6	2.97	4.9	18.5	5.2
0.10	147.6	0.5	3.06	2.4	19.8	4.7
0.30	147.3	1.6	3.01	1.8	21.0	4.6

TGA analysis of PLA/OP masterbatch, PLA granulate and OP in the temperature range of 200-280°C showed high thermal stability samples (Table 4). From the above, we can assume that in the working area of spinning 210°C, both – PLA/OP masterbatch and PLA polymer will have sufficient thermal stability.

From the mechanical mixture of PLA/OP masterbatch and from PLA granulate, PLA fibres containing 0.1 and 0.3 wt.% OP were prepared by spinning and discontinuous drawing to a drawing ratio of 1.5. For comparison, an unmodified PLA fibre was prepared in the same manner. From each type of fibre, the supermolecular structure and mechanical properties were evaluated (Tables 5 and 6). It is clear from Table 5 that due to the photoluminescent pigment, the orientation of the macromolecular chains segments (birefringence) increased slightly, up to 14% while the difference in the orientation of the macro-molecular chains segments of the unmodified fibre and the modified fibres in the surface layers (sound velocity) as well as the crystallinity did not change significantly.

The basic mechanical properties of PLA/OP fibres compared to unmodified PLA fibre (Table 6) also did not change significantly. A positive finding is that the tenacity of PLA/OP fibres reaches a value above 3 cN/dtex.

As the OP content increases, the elongation increases moderately. It follows from the above that OP slightly affects the supermolecular structure and mechanical properties of the fibres and does not negatively influence studied properties.

The last evaluated parameter was color performance investigated under UV lamp of modified PLA fibres (Figure 2) and of the knitted fabric (Figure 3). From Figures 2 and 3 it can be clearly seen the color expression of the organic photoluminescent pigment under the UV lamp in modified PLA fibres and the knitted fabric. Both concentrations of OP 0.10 and 0.30 wt.% have the same color intensity under UV light when observed with the naked eye. The standard fibre does not shine and remains dark.

Figure 2 The influence of organic protective photoluminescent pigment with content 0.10 and 0.30 wt.% on the color performance of drawn PLA fibre under a UV lamp

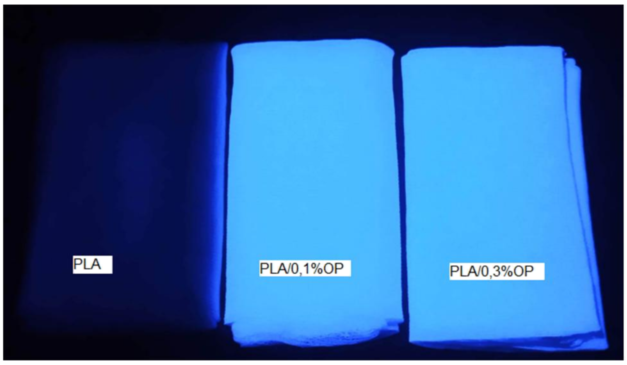
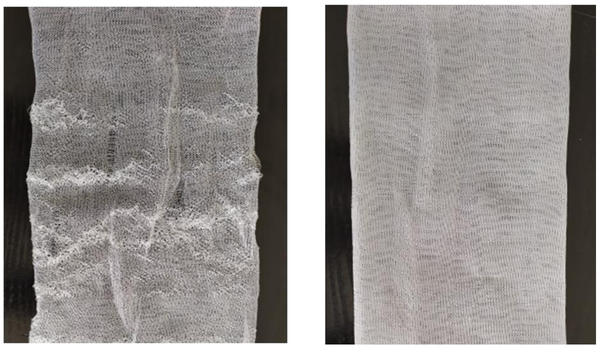


Figure 3 The influence of organic protective photoluminescent pigment with content 0.10 and 0.30 wt.% on the color performance of knitted fabric prepared from two drawn PLA fibres under a UV lamp

As can be seen from Figure 4a), during the formation of the sleeve from one fibre (with a total fineness of 147 dtex) the holes were formed and the loops were not uniform during knitting. Therefore two drawn PLA fibres were used, from which a sleeve with an even arrangement of loops was prepared (Figure 4b).



a) b)

Figure 4 For comparison: the knitted fabric prepared from a) one drawn fibre and b) from two drawn fibres

4 CONCLUSION

- Preparation of PLA/OP masterbatch with a content 0.30 wt.% of organic protective photoluminescent pigment was smooth;
- The PLA/OP masterbatch has a satisfactory coloristic performance under UV light and suitable application properties therefore can be used in a mixture with PLA granulate for the preparation of modified PLA fibres;
- The PLA/OP masterbatch has high thermal stability up to 280°C;
- The studied polymer system: PLA/OP masterbatch and PLA granulated polymer is fibre-forming and the spinning process is stable for the studied concentrations of 0.1 and 0.3 wt.% of organic protective photoluminescent pigment;
- The significant effect of the organic protective photoluminescent pigment on the supramolecular structure and mechanical properties of PLA fibres with a total fineness of about 147.5 dtex has not been demonstrated;
- From each sample, a knitted fabric by combining two the same fibres was prepared;
- The masterbatch, fibres and knitted fabrics show strong blue-white radiation under a UV lamp, observable with the naked eye.

ACKNOWLEDGEMENT: *This work was supported by the Slovak Research and Development Agency under the contract No. APVV-18-0187.*

5 REFERENCES

1. Avinc O., Khoddami A.: Overview of poly(lactic acid) (PLA) fibre, Fibre Chemistry 41(6), 2009, pp. 391-401, https://doi.org/10.1007/s10692-010-9213-z
2. Sin L.T.: Polylactid acid, 1st ed., PLA Biopolymer Technology and Applications, 2012, 352 p., ISBN 9781437744606
3. Schaefer Ch.: PLA films for packaging, bioplastics Magazine 15(06), 2020, pp. 20-21, ISSN 1862-5258
4. Suanprasert N.: PLA branches into agriculture, bioplastics Magazine 12, 2017, pp. 24-25, ISSN 1862-5258

5. Mattana G., Briand D., Marette A., Vásquez Quintero A., de Rooij N.F.: Polylactic acid as a biodegradable material for all-solution-processed organic electronic devices, Organic Electronics 17, 2015, pp. 77-86, https://doi.org/10.1016/j.orgel.2014.11.010
6. Wu S., Lee H.: PLA foam sheet for tableware, bioplastics Magazine 14(01), 2019, p. 36, ISSN 1862-5258
7. Kitai A. (Ed.): Luminescent Materials and Application, John Wiley & Sons, Ltd, 2008, 292 p., ISBN: 978-0-470-05818-3
8. Krasovitskii B.M., Bolotin B.M.: Organic Luminescent Materials, Weinheim NY, VCH, 1988, 351 p., ISBN: 9783527267286
9. Bamfield P., Hutchings M.G.: Chromic Phenomena, Technological Applications of Colour Chemistry, 2nd ed., Royal Society of Chemistry, Cambridge, 2010, 584 p., ISBN 978-1-84755-868-8
10. Khattab T.A., Abd El-Aziz M., Abdelrahman M.S., El-Zawahry M., Kamel S.: Development of long-persistent photoluminescent epoxy resin immobilized with europium (II)-doped strontium aluminate, Luminescence 35(4), 2020, pp. 478-485, DOI: 10.1002/bio.3752
11. Alzahrani H.K., Munshi A.M., Aldawsari A.M., Keshk A.A., Asghar B.H., Osman H.E., El-Metwaly N.M.: Development of photoluminescent, superhydrophobic, and electrically conductive cotton fibres, Luminescence 36(4), 2021, pp. 964-976, https://doi.org/10.1002/bio.4024
12. Jakubowski K., Heuberger M., Hufenus R.: Melt-spun photoluminescent polymer optical fibers for color-tunable textile illumination, Materials 14(7), 2021, 1740, https://doi.org/10.3390/ma14071740
13. Cayuela D. et al.: Variation of microstructure of textured and fixed polylactide fibres with the texturing conditions, In: Book of Proceedings of the 5th International Textile, Clothing & Design Conference, Magic World of Textiles, Dubrovnik, Croatia, October 3-6, 2010, pp. 48-53

USAGE OF AUGMENTED REALITY TECHNOLOGIES IN THE LIGHT INDUSTRY

Iryna Zasornova[1], Oksana Zakharkevich[1], Alexander Zasornov[1], Svetlana Kuleshova[1], Julia Koshevko[1] and Tetiana Sharan[2]

[1] *Khmelnitskyi National University, 11, Instytutska str., Khmelnitskyi, Ukraine*
[2] *Russian School of Mathematics, 8299 161 st Avenue Northeast Suite 103, Redmond, WA 98052, USA*
izasornova@gmail.com; an8user@gmail.com

Abstract: *The article considers the use of augmented reality technologies. The analysis of directions of development of AR technologies in light industry is carried out. The dynamics of the development of augmented reality technologies in the garment industry and the fashion industry over the last decade is considered using the tools of Google Trends and SE Ranking. A study was conducted among women and men on awareness of the use of QR codes in light industry. The constructive-technological solution of a cuff of a sleeve of a women's jacket with use of AR technologies is offered. Men's pants are made using a QR-code on the label, which contains a link to the site TKSHV – Market.*

Keywords: *Augmented reality, QR-code, apparel, fashion industry, technology.*

1 INTRODUCTION

Today, more and more people use online services to make purchases and choose a potential product. In the process of technology development, the question of attracting and making the audience interested on the Internet is becoming more and more important. There are many different digital marketing tools that help companies understand the consumer better, collect statistics and understand the specifics of decision making. However, the means of influencing the consumer until recent times remained at the traditional level: banner advertising, video advertising, integrated messages in video and text materials, classic outdoor advertising and more. Now there is software that blocks advertising, such as AdBlock, which does not allow advertising materials to appear on web pages, which significantly reduces the effectiveness of this tool. A large number of people, using social networks and messengers, find the product directly on the pages of web stores, and pay attention to discounts and ads from them, use newsletters. Based on the current development of technology, companies are beginning to use augmented reality (AR), which helps to distinguish the product in both the real and virtual world. New integrations help to attract the consumer's attention, improve the use of technology, help to understand information, provide an idea of the product even if the consumer has not seen it. To a better extent, such issues are being studied in the United States and Western Europe. However, today there are no specific works on the use of augmented reality in retail.

AR is a new trend in marketing and sales strategy that allows brands to provide their customers with a unique experience with the convenience of connecting to their mobile devices [1]. In addition, it is possible to increase the level of interaction with the product anywhere, which gives the consumer a deeper knowledge of the product, and increases its rational and emotional motives for buying. One of the key elements to the success of applications and AR in general is to create an intuitive and simple interface that will not require much time to learn and get used to.

If in the industrial market, we strive for the most pragmatic and simple visual representation, for ease of operation and understanding by customers, then in the consumer market it is necessary to choose the functionality for a particular product. Therefore, it can be concluded that the design and interface of applications should be clear and simple to achieve the highest level of conversion and engagement.

2 DISCUSSION IDEAS

QR codes (Quick Response) are machine codes in the form and templates that can be scanned to view hidden information. They can be recognized using special scanners or smartphones. The reader decrypts the encoding and publishes information, which can be in the form of photos, text, links to the site, etc. [2].

A QR code can hold a large amount of information in a small image, the complexity of which depends on the amount of information. The maximum amount of information can be more than two printed pages. Modern devices for scanning QR-codes and the corresponding software allow to read the encoded data automatically [3, 4].

There are static and dynamic QR-codes. The static QR code contains the information specified when it was generated. Dynamic QR-code is multifunctional: it can be connected to additional functions that can be changed [5]. Dynamic QR codes are not tied to a specific data format. QR code viewers recognize encoded information and display to the user: text, graphics, information on web-pages, email, SMS, phone numbers, geographical coordinates, the ability to view 360° videos from the virtual store and other data. The type of information is specified when generating a QR-code [6]. To get the information directly to the screen of a mobile phone, just run the program to scan the code and point the camera lens at the code. The decoder program recognizes the type of information and performs the necessary actions, such as opening a web-page (in this case, you need to connect to the Internet) [5].

The use of AR technologies by industry giants, and their success, has prompted less known companies to implement similar technologies for consumers not only in the form of mobile applications, but also for websites and other platforms in the B2C and B2B areas. Thus, this tool becomes not only a new and powerful element in marketing, but also a trend for markets as a whole. The use of augmented reality greatly simplifies the spatial understanding and presentation of visual information for both employees and customers who want without special skills and in-depth knowledge to understand the process and principle of operation of certain devices or equipment [7]. It can also significantly reduce production costs by reducing the need for physical interfaces.

Thus, we can say that augmented reality with some time and increasing availability of technology will be able to conquer the market and significantly increase the effectiveness of digital marketing.

To get the most out of augmented reality economic activity, you need to develop the right and optimal software product that will be new to the market and supported by many platforms. With the current growth of global competition, this issue is becoming crucial to be able to compete in markets and have the opportunity to attract and interest most of the audience and attract new ones.

The pioneer in the use of AR in retail is the American brand of clothing and accessories American Apparel, which was able to reduce the burden on staff. Together with the technology giant Qualcomm, the retailer has developed a mobile application Vuforia, which provides information about any product in the range [7].

All you have to do is point the smartphone camera at the product label, and all the necessary information will appear on the screen: price, material, characteristics available in the store, colors and sizes, etc. You do not need to wait for the consultant to check for the required size or color, the client can find out for himself.

The app also shows product reviews from other users and their ratings. The buyer can immediately share his opinion, put the number of "stars" of the product and post a review on social networks.

"Smart mirrors" is the most famous application of augmented reality in fashion retail. This technology is used by many retailers and brands. For example, the Neiman Marcus luxury department store chain has installed 58 full-size MemoMi Labs "smart mirrors" in 34 stores. The devices use AR technology, artificial intelligence and gesture recognition software. A mirror such as a virtual locker room allows you to change the color of clothes in a matter of seconds and consider different combinations of outfits and accessories. The HD camera mounted on the mirror records eight-second videos - during this time the buyer has time to return in front of the mirror in all directions to get a full view of the 360°. The mirror interacts with the mobile application Neiman Marcus - the customer can send recorded videos to phone or share on social networks.

Platforms such as Google, Unity, Facebook or Snapchat also include AR web applications for ready-to-use fashion manufacturers and distributors. However, the problem of their use arises due to the different requirements for the format of 3D files, which has each of the respective platforms. To create and view augmented reality, existing digitally produced production files usually need to be first optimized and converted to meet the required conditions.

In general, it can be argued that from a technological point of view, the creation of 3D objects, as well as the visualization of AR embedded, static 3D clothing in physical spaces work quite well and can be used by brands and e-shops today. Dynamic fittings also work quite well in the segments of accessories and footwear, but are not yet perfect enough for clothing.

Industry experts emphasize the need to start experimenting with AR now that the technology is maturing and is expected to be fully operational within the next five years [8].

Three-dimensional visualizations have already reached a sufficient level that allows companies to digitally create garments that can hardly be distinguished from a photo of a real product. However, their large-scale production is still considered expensive and especially difficult to implement by small clothing companies. This is expected to change over the next few years, thanks to newly developed software tools and the inevitable digitization of design processes, paving the way for the wider spread of augmented reality technologies in the field of clothing distribution. Tools for visualizing models and virtual fittings will also be refined, achieving a high level of accuracy.

3 PRELIMINARY RESEARCHES

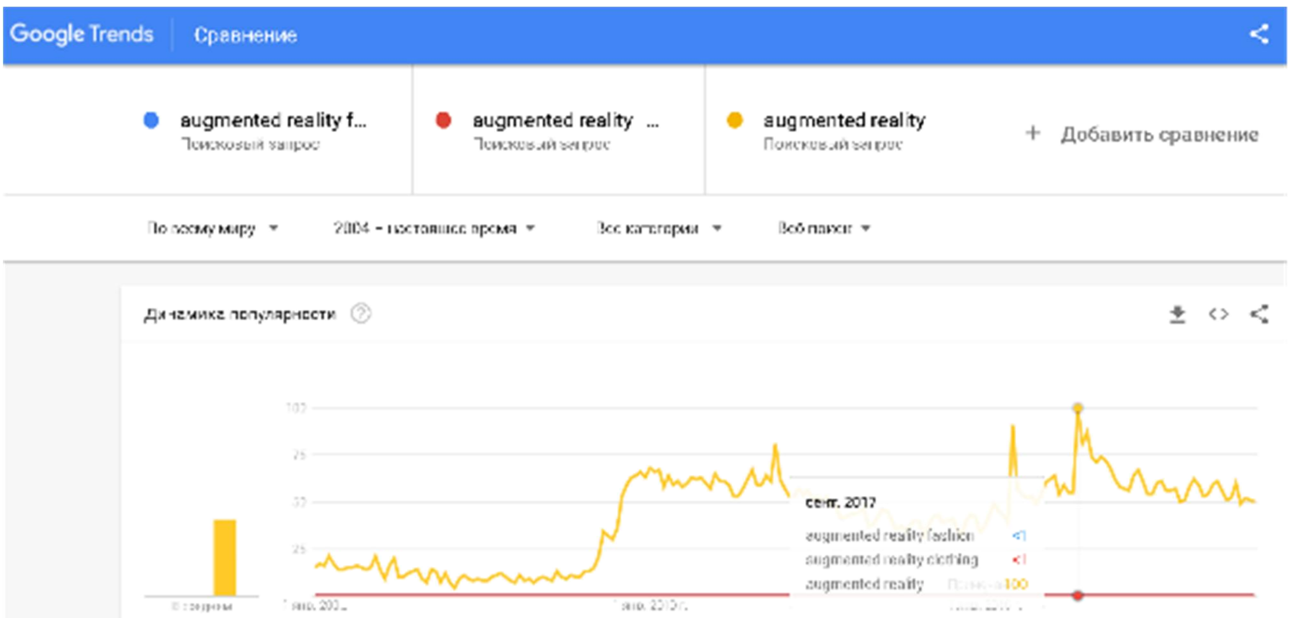
3.1 Research on the development of AR technologies

Studies of the development and popularity of augmented reality technologies using the tools of Google Trends and SE Ranking (Figure 1) found that the vast majority of potential consumers of such technologies do not associate them with clothing [9].

At the same time, even among the existing consumers and manufacturers who use augmented reality in clothing or related areas, there are no representatives of many countries. Among all the existing areas of augmented reality, its use in clothing is only 12% (Figures 2 and 3, Table 1).

Table 1 shows a fragment of the analysis of the directions of development of AR technologies in light industry [1, 10-18].

a)



b)

Figure 1 Analysis of the frequency of queries relevant to the phrase "augmented reality in clothing" using Google Trends

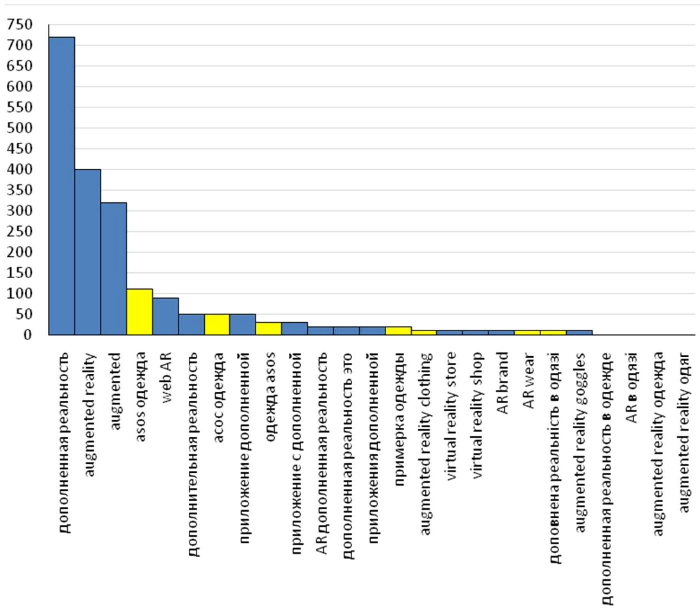


Figure 2 Analysis of the frequency of queries relevant to the phrase "augmented reality in clothing" using SE Ranking tools

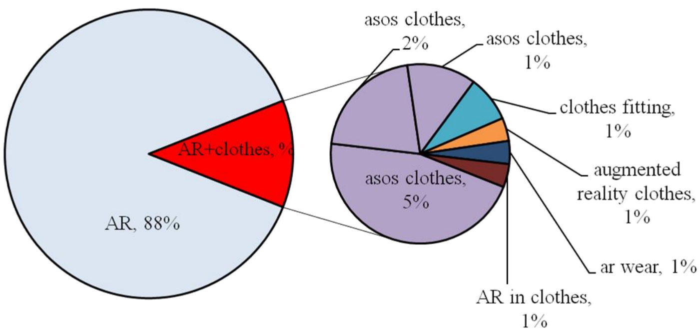


Figure 3 The ratio of the frequency of augmented reality queries in clothing to the total number of queries

Table 1 Analysis of directions of AR technologies development in light industry (fragment)

Brand (name of the application), year of issue	Brief description	Feature	Range
1	3	4	5
deKryptic (the Boosted Art Augmented Reality App), 2020	deKryptic's collection consists of various garments - from hoodies and tees to denim jackets and jeans. The subject matter for the brand's graphics is quite diverse and suitable for all ages. The AR clothing spotlights various beloved cartoons through playful collaborations, including one with Dexter's Laboratory and even Popeye. The garments come to life with the Boosted Art Augmented Reality App, boasting "beautiful 3D animations and rich sound effects to accompany that graphic." Wearers can share it across their social media channels, as well.	Animation of prints on clothes	T-shirts
GOAT, 2019	GOAT, which is recognized as a global destination for authentic sneakers, is now launching an AR sneaker Try-On feature to help its users virtually see rare and exclusive sneaker styles on their own feet. Prior to launching this feature, GOAT introduced an augmented reality feature to give sneakerheads a better way to get to know the materials and textures of sneakers. Already familiar with this technology, fans will appreciate being able to see some of the most coveted sneakers appear thanks to the magic of augmented reality before their eyes. Some of the styles that can be previewed virtually with GOAT's Try-On include designs from Nike and Air Jordan, as well as unreleased samples like the Air Jordan 4 Undefeated and Air Yeezy 1 Glow in the Dark Tour.	Virtual fitting	Sneakers

Carlings, 2019	Changing the image and text that appears on a shirt usually calls for purchasing a new style or making some kind of DIY modification but The Last Statement T-shirt by Carlings sets itself apart with a design that can be digitally updated. The t-shirt makes the most of a new feature on Instagram called Targeting Tracking, so that the plain white shirt can be enhanced with Instagram's augmented reality filters. Previously, AR effects and filters on Instagram have been limited to faces but the body and pieces of clothing can now be enhanced with augmented reality graphics as well. Pointing the Instagram camera at the logo on the t-shirt calls up a design that seems incredibly realistic and makes it easy for social media users to use a single shirt for photographing different looks.	Animation of prints on clothes	T-shirts
IKAR, CGTrader, 2019	At CommerceNext 2019, CGTrader - the world's largest source for licensable stock and custom 3D models - is introducing augmented reality innovations to shape the future of fashion, retail and customer experiences. CGTrader is working with IKAR to transform traditional 2D images and paper catalogs into 3D, AR experiences for the design and manufacturing company's lines of apparel and active wear. With these AR innovations, IKAR will be able to effortlessly show its seamless apparel styles on 3D fashion models without the cost or time investment of traditional photoshoots. Additionally, the technology will allow for a range of designs, colors and styles to be visualized without needing physical garments to be produced for meeting with customers in the fashion industry.	Virtual catalog	-
(The Apparel App), 2016	The Apparel app is a digital platform that allows consumers to customize their garments using augmented reality. Consumers can add geometric and modular patterns and shapes to their clothing using the app that move around and add dimension to the clothing. The app works in conjunction with a simple black shirt that when viewed through a camera on a smartphone with the Apparel app pulled up, can be altered with moving geometric shapes that shift and change on and around the shirt. The designs are visual translations of data from a Twitter feed, so the shapes change depending on the incoming interactions from the social media account. The connection between design, social media and fashion moves in real time against the black shirt for consumers to see	Clothing animation	T-shirts
FXMirror by FXGear Helps Users Virtually Try on Garments, 2018	Seoul-based augmented reality brand FXGear recently unveiled its FXMirror concept which acts as a virtual fitting room platform that aims to take retail technology and experiences to new and exciting heights. Already trialed inside Korea's Lotte Department Store, the AR mirror works by calculating a person's exact height and measurements to showcase the most precise image of what clothing looks like when worn. When describing FXGear's latest ventures, the company's CEO Choi Kwang-jin states that AR is one of its primary areas of focus. "In China, customers who purchase their garments online account more than 50% of all purchases. When purchasing clothes online, people want to know if it fits. I believe FXMirror's mobile version can help customers find this out," he said	A smart mirror	–
Ralph Lauren (Snapchat), 2020	With the help of Snap, Ralph Lauren is bringing its polo pony logo to life with augmented reality - meaning that the logo can be scanned from virtually any surface to start an AR experience. Scanning the Ralph Lauren logo starts an experience - at this time of year it's a festive one - that has the potential to lead app users to purchase	Logo animation	-
LKM Lab, 2020	LKM Lab is a brand that's behind virtual runway shows, designing incredibly unique backdrops for designers to choose from for their shows. The brand utilizes 3D animation alongside virtual reality technology to create a virtual environment that immerses and wows the viewer. What's more, is that these designs can change at any moment, creating a versatility and excitement that's exclusive to virtual shows	Virtual show	-
Neiman Marcus (Neiman Marcus), 2019	"Smart mirrors" - the most famous solidification of augmented reality in fashion retail	Virtual fitting	-

Also, AR technologies are used by other brands and firms that are not presented in Table 1: Gucci (2019), Puma's LQD Cell Origin (2019), Wannaby's 'Wanna Kicks' (2019), Adidas Ultraboost (2018), Gymboree (2018), aiia 'Teemoji' (2017), Virtuali-Tee (2016) and others [18].

According to Table 1, a diagram was constructed (Figure 4) which demonstrates the dynamics of the development of augmented reality technologies in the garment industry and the fashion industry over the past decade.

Analysis of the development of augmented reality technologies in the garment industry and fashion industry shows their rapid development over the past decade. The most common technologies that are now available to the general public are the application of printed images on T-shirts and other knitwear, which serve as augmented reality markers and are animated using special mobile applications (Table 2, Figures 5 and 6).

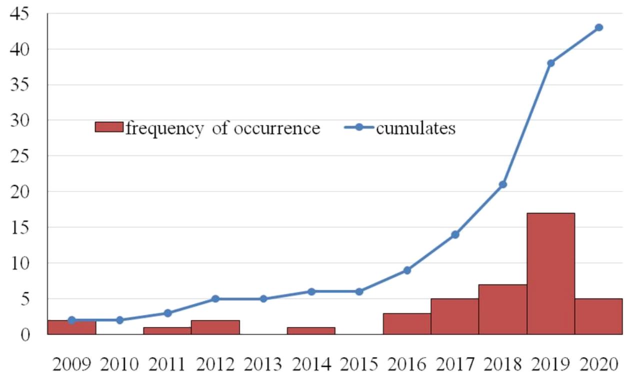


Figure 4 Dynamics of development of augmented reality technologies in the garment industry and fashion industry

Table 2 Frequency of usage of augmented reality applications in clothing and the garment industry in general

Direction of usage	Type of usage of AR	Frequency of occurrence [units]
Animation	Animation of prints on clothes	9
	Clothing animation	3
	Animation prints	1
	Logo animation	1
	Photo animation	1
Database	Database	1
Fitting	Virtual fitting	16
	Virtual show	4
	Smart mirror	1
Prototyping	Virtual prototyping, catalog	1
	Virtual prototyping	1
Catalog of virtual 3D models	Virtual catalog	5

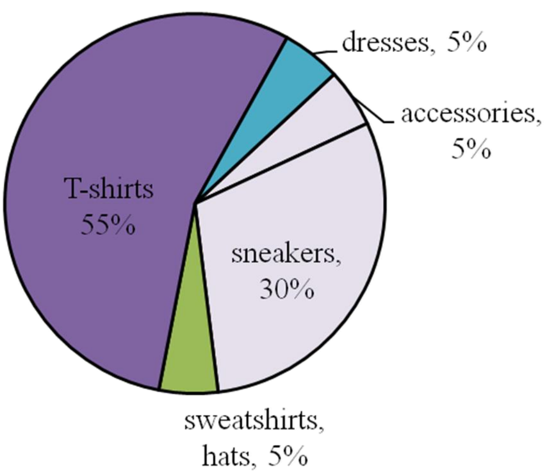


Figure 5 The range of clothing using AR-technologies

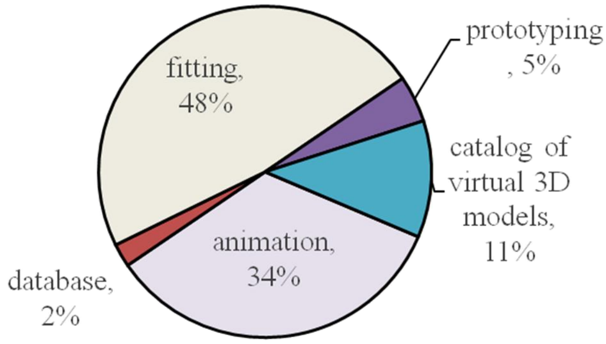


Figure 6 The ratio of AR usage in clothing

3.2 Research of consumer use of QR-codes in light industry products

To determine the awareness of QR-codes among consumers (separately for women and men), a study of the use of QR-codes in products was conducted. It was conducted by surveying people of different ages and genders of 10 respondents of each type, a total of 100 people.

Then, with the help of expert evaluation, the main ways of using the QR code were identified. Determining the most commonly used basic ways of using a QR code is possible only using the research methodology. To solve the tasks, the method of expert survey and expert assessments, mathematical statistics, experimental methods to determine the actual values of indicators were used.

The method of determining the most important ways to use the QR-code was performed in the following stages:

- conducting a survey among consumers of clothing;
- analysis of expert assessment;
- identification of the most significant ways to use the QR-code;
- chart construction.

For calculations and registration of work, the program Microsoft Office Excel and the program EXPERT are used. These programs are used during research at the Department of Garment Technologies and Design of Khmelnytskyi National University.

The use of QR codes in various fields is modern and progressive. If you apply them in the production process, you can improve several production issues. For example, tissue storage is a very large process in the production process of any enterprise. Tissue passports are confused, lost, you should always look for the necessary information in stacks of paper. But researchers at Istanbul University have found a way to use QR codes. They have developed a special program in which data about a particular fabric are entered: geometric data, balances, sellers. All you need to do is mark the rolls of fabric with QR codes and provide scanners or smartphones to your workers to read the information. This reduces the process of finding information in the warehouse [19].

Equipment manufacturers also do not lag behind progressive trends. In the Netherlands, a special machine was created to embroider QR codes on an industrial scale. LogoBorduurstudio (Barneveldi, the Netherlands) has allowed the use of a computer-controlled embroidery machine to make fabric consisting of QR codes. This allows you to embroider barcodes on clothing or other products [20, 21].

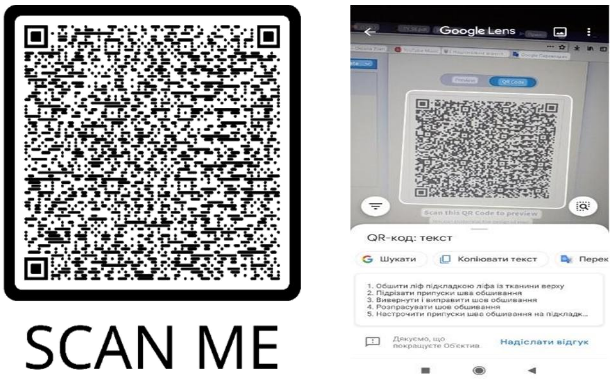
Siruba was one of the first manufacturers of sewing equipment to use QR codes on sewing equipment [22]. They apply a laser to the metal table serial number, model name and QR code. The operator brings the smartphone to the code, reads it and, when connected to the Internet, receives complete information about the model, series, operating instructions and more [23].

Unfortunately, today the least common is the use of QR-codes in production automation. Reading the codes would speed up the production process and reduce time.

Code generators are widely available online and do not require special knowledge to implement them. In addition, the introduction of such technology in enterprises does not require the purchase of any additional equipment, as it involves the use of employees' own mobile devices, which are provided to almost 100% of the population.

As an experimental technology, tools have been developed that can replace instruction cards in employees' workplaces. For example, these could be Instructional Technology Maps (TICs) for quality controllers. Such maps can present controlled indicators for each operation, written rules and methods for assessing the quality of basic operations on the main control indicators. The presence of the card "TIC quality control operation" reduces the risk of subjective assessment of the object of inspection by the controller, as it contains instructions that determine the sequence and method of checking the quality of the assessed area of the product. Therefore, similar tools using augmented reality can be developed for quality controllers in individual operations of the technological process. The generated codes allow: to obtain the sequence of processing the node (or the content of the organizational operation) in the form of plain text (Figure 7); get the sequence of processing the node (or the content of the organizational operation) in the form of a pdf-file, which additionally shows the assembly diagram of the section of the node; view a virtual 3D model of the site; watch a video showing the sequence and techniques of performing direct technological operations.

The Figure 8 shows dynamic codes that provide interaction with pdf-files and video-files Figure 9.



a) b)

Figure 7 The work of a static QR-code to obtain the technological sequence of processing the node in the form of simple text: a) QR-code; b) application of the code using Google Lens

Figure 8 Dynamic QR-codes

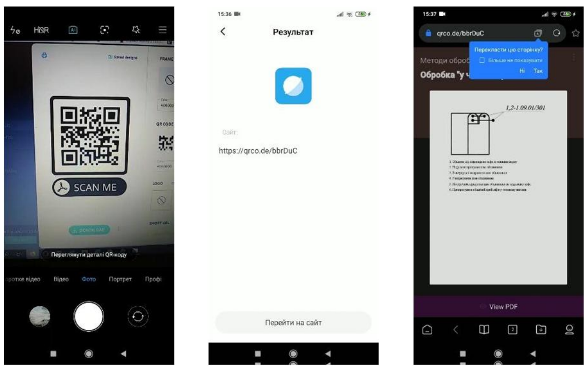


Figure 9 The process of obtaining information in the form of a pdf-file

Today, the development of virtual three-dimensional forms of garments in mass production has traditionally focused directly on products. Usually the algorithm for building a virtual model is based on the use as a basis of scanned with a body scanner typical representatives of each type of clothing. In this case, the default is the same type of technological processing of the virtual basis of the product and designed in a specific design situation. As a result, the virtual model is created only in the form of an external shell, without displaying complex functional units and without taking into account the allowances for technological processing.

To implement technologies of virtual representation of product forms directly into the manufacturing process in the form of an instruction card or additional manual for training beginners and high quality manufacturing, there is a need to present in three-dimensional space not the whole product, but only parts. Each node should reflect the operation / operations that are performed at a specific workplace in the sewing flow. For example, the selected node (finishing the top of the part "in the clean edge") is built using a universal graphics editor AutoCAD. The mentioned editor allows to execute both plane drawings, and to construct three-dimensional objects and to carry out their visualization.

The cross section of the node was constructed by Operation "Polyline". Conversion to a three-dimensional model is performed using the "Extrude" command. For clarity of the received model all details are painted in contrasting (Figure 10).

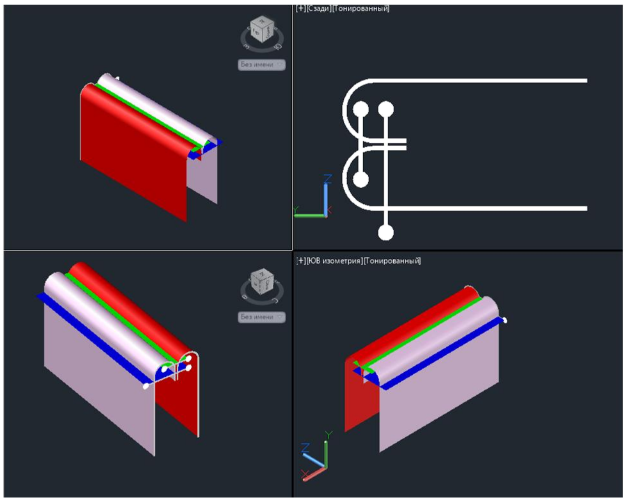


Figure 10 3D-model of node processing

3.3 Application of AR technologies in the manufacture of cuffs for women's jacket sleeves

For the practical application of augmented reality technologies, it was decided to make a women's costume, which is decorated with the effect of augmented reality "snow falls" and sounds "Shchedryk-Shchedryk" based on the works of artist Olena Golembovska.

The print is made on the overlay cuff of the sleeve of the women's jacket from the suit. The choice of such an augmented reality marker location is argumented by the fact that in this case, the augmented reality effect can be viewed directly by the clothing owner (when the woman is wearing a suit) and does not require outside help.

To apply prints on the fabric of women's costume as markers of augmented reality technology, the technology of sublimation printing was chosen. Sublimation printing is printing with ink, in which it passes from sublimation paper to textile material under the influence of high temperatures. The image is printed with sublimation inks using a printer on the appropriate sublimation paper, which is covered with a thin layer of special varnish [24].

The fabric is placed in a special thermos press machine, which is a two Teflon plates. One of the plates of the thermos press machine has a heating element. Paper with the finished image is placed on the fabric and clamped with a thermopress for a minute, giving a high temperature and pressure of several hundred kilograms. Under the action of temperature, the paint turns into a gaseous state, while separating from the carrier (paper) and immediately penetrating into the structure directly of the fabric (in this case, the cuff fabric). Among textile materials, it is better to prefer synthetic fabrics (a higher percentage of synthetics provides higher image quality and durability). It is not possible to print on already colored, colored or dark fabrics or products (the background, that is the base color should be light or white) [25], so a white gabardine was chosen to make a cuff with a print on it (Figure 11).

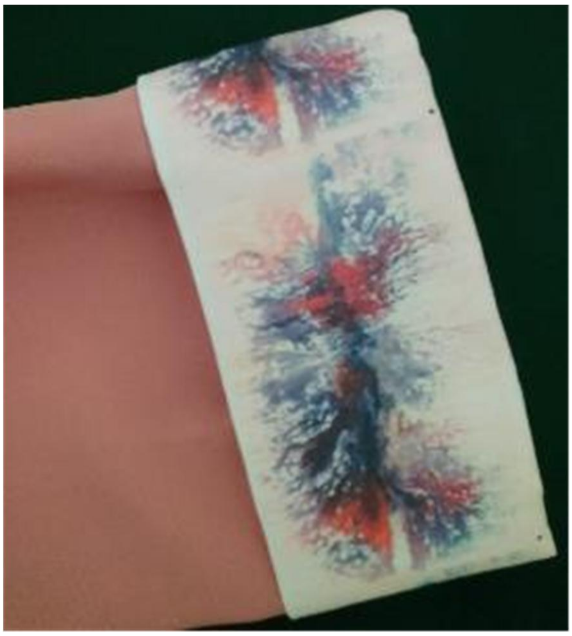


Figure 11 Technological solution of a cuff of a woman suit with use of print and AR technologies

4 EXPERIMENTAL

A separate study was conducted among women (W) and men (M) on the use of QR codes in garments. The analysis of the answers is given in the summary table of the survey of clothing consumers (Table 3). To improve the perception of the obtained results, on the basis of the processed data of Table 3 diagrams were constructed (Figures 12-14). This allowed us to evaluate them.

Table 3 Responses from clothing consumer surveys

Questions	Age	to 20		20-30		30-40		40-50		over 50	
	sex	W	M	W	M	W	M	W	M	W	M
Do you know what a QR code is?	yes	6	9	10	10	10	10	10	10	8	6
	no	-	1	-	-	-	-	-	-	2	4
Do you often come across a QR code in your life?	yes	8	4	9	4	8	6	6	4	4	3
	no	2	6	1	6	2	4	4	6	6	7
Do you use a QR code?	yes	9	4	9	4	8	6	7	3	2	3
	no	1	6	1	6	2	4	3	7	8	7
Did you come across the picture as a QR code on your clothes?	yes	8	5	7	4	5	5	4	2	2	-
	no	2	5	3	6	5	5	6	8	8	10
Have you come across an embroidered QR code?	yes	2	1	3	1	1	2	-	-	-	-
	no	8	9	7	9	9	8	10	10	10	10
Have you seen the applique in the form of a QR-code?	yes	-	-	2	-	1	-	-	-	-	-
	no	10	10	8	10	9	10	10	10	10	10
Did you see the QR code on the garment label?	yes	8	5	9	7	7	5	5	3	2	
	no	2	5	1	3	3	5	5	7	8	10

From the Figure 12, we can conclude that 96% of women know what a QR code is, and 70% have met it in their lives and used it. However, only 52% of women encountered pictures with a QR code on their clothes. Even fewer women saw the embroidered and appliqued QR code of 12% and 6% respectively. However, 62% of women saw the labels depicting him. The average percentage of awareness and use of the QR code among women of all ages reached 52.6%.

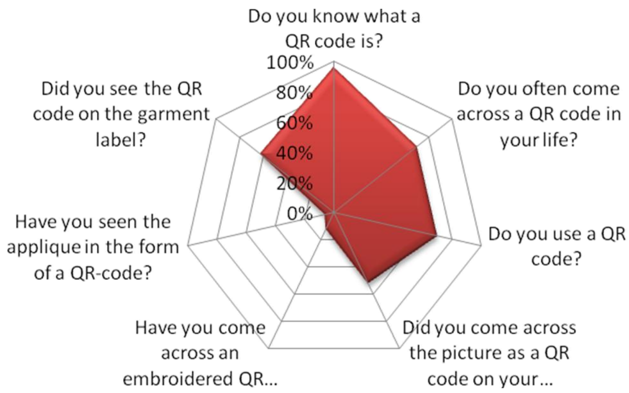


Figure 12 Diagram of a survey of ***women*** regarding the introduction of QR codes in the garment industry

From the survey chart of men in Figure 13 we can conclude that 90% of men know what a QR code is, but only 42% have met it in their lives, and used only 40%. Only 32% of men met pictures with a QR-code on their clothes. Even fewer of them saw the embroidered QR-code 8%, and made the application did not see. Only 40% of men saw labels with a QR code image on them. The average percentage of awareness and use of QR-code among men of all ages reached only 36.0%. This figure is much lower than for women by almost 17%.

From the women and men survey chart in Figure 14 can be seen that 93% of women and men know what a QR code is, 56% have encountered it in their lives, and 55% have used it. Only 42% saw images with a QR code on their clothes. Only 8% saw the embroidered QR-code, and only 3% made the application. Only 51% of respondents saw labels with the image of the QR-code. The average percentage of awareness and use of QR-code among respondents of all ages reached 44.3%, which shows a lack of awareness and use of QR-code by respondents.

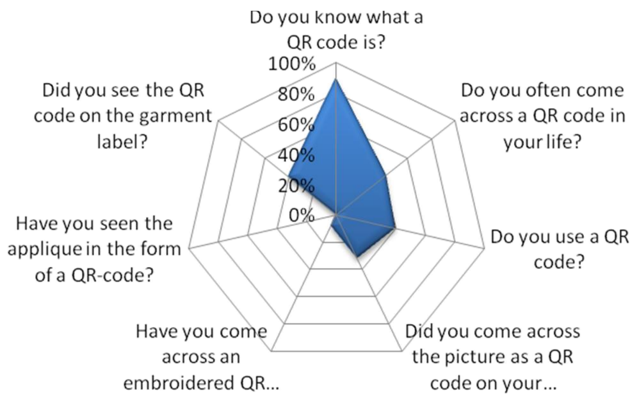


Figure 13 Diagram of a survey of ***men*** regarding the introduction of QR codes in the garment industry

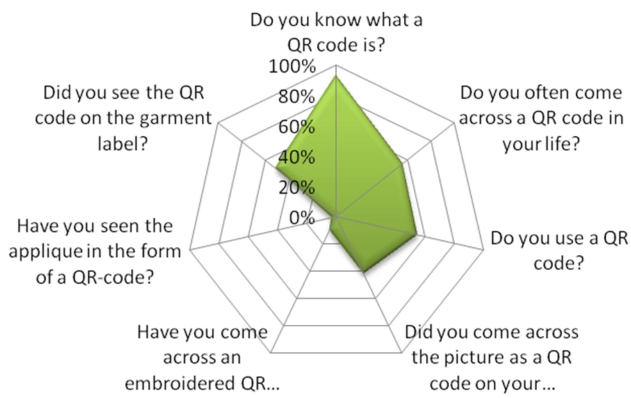


Figure 14 Diagram of a survey of ***women and men*** regarding the introduction of QR codes in the garment industry

Awareness and use of QR-code by respondents depending on age were studied separately.

From the diagram (Figure 15), the survey of women it is clear that the most knowledgeable and most often use the QR code of women under 40 years. Women over the age of 50 know and use them the least.

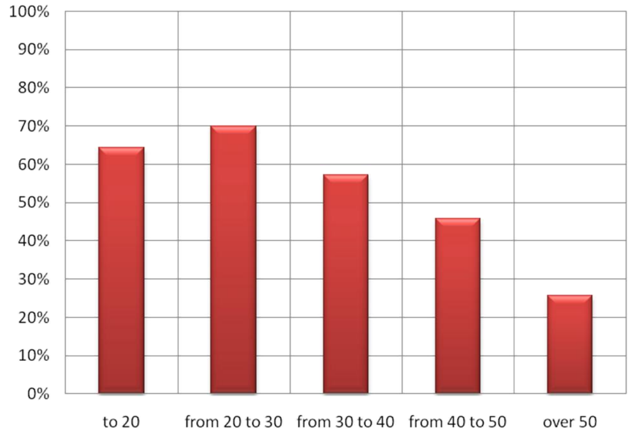


Figure 15 Diagram of a survey of ***women*** regarding the introduction of QR codes in the garment industry

From the diagram (Figure 16) a survey of men shows that the most knowledgeable and most often use of QR code by men, as well as women happens if they are under 40 years old. However, the peak of the chart is with men between the ages of 30 and 40, and with women between the ages of 20 and 30. This shows that men's interest in QR codes comes later. The least aware about QR-codes and least used they are by men over 50 years.

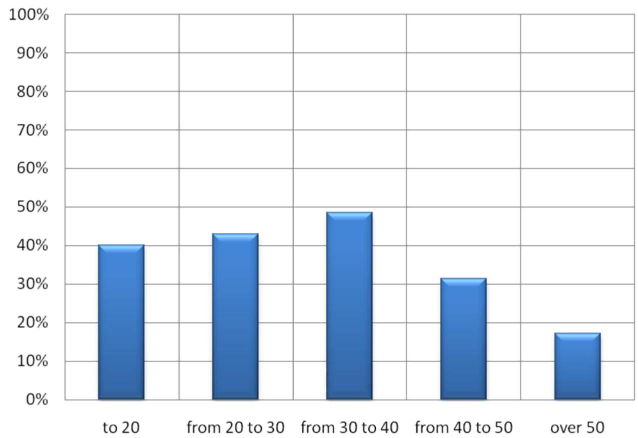


Figure 16 Diagram of a survey of ***men*** regarding the introduction of QR codes in the garment industry

From the diagram (Figure 17) a survey of women and men shows that the most aware and most often use the QR code consumers aged up to 40 years. However, the peak of the chart is between 20 and 30 years. Consumers over the age of 50 know and use them the least.

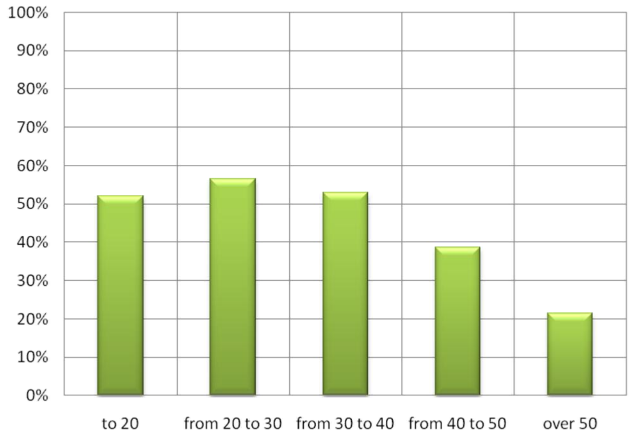


Figure 17 Diagram of a survey of ***women and men*** regarding the introduction of QR-codes in light industry

There are many paid services that provide tools for generating color or non-format codes. As part of the research, to perform a QR-code on the label of men's pants, it is proposed to use the free service QR Code Generator [26]. As a result, the service for generating a QR-code provides a link for placement on the site, ready code for embedding. The process of creating the code does not take much time - you only need to specify the source data for encryption and click "Generate".

5 RESULTS

The functioning of the generated dynamic QR-codes is presented in Figures 18 and 19.

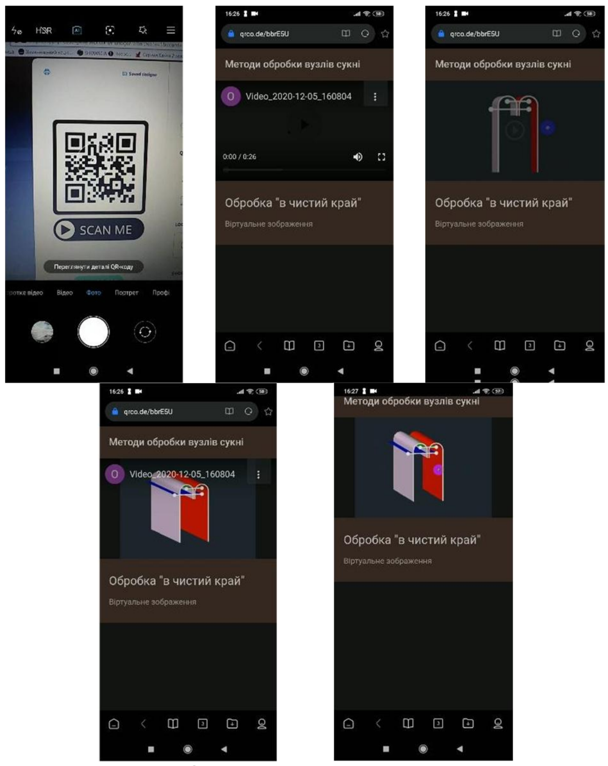


Figure 18 Use a QR code to view a 3D node processing model

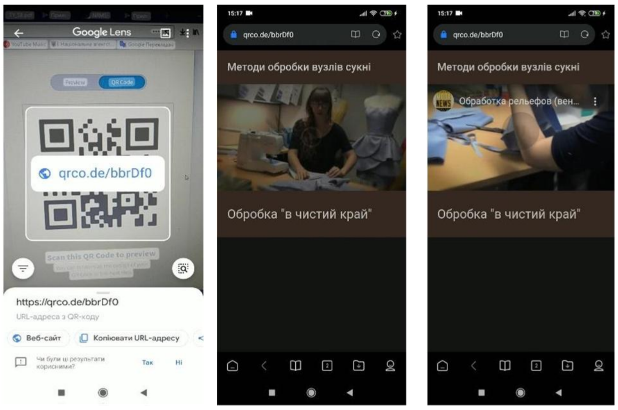


Figure 19 Use a QR code to view a video demonstration of node processing

The database of augmented reality images of the mobile application Artivive includes works by artist Olena Golembovska, who has been working in this direction for quite some time. The artist presents her works through her Instagram page, holds exhibitions and presentations. From the page of the artist (with the prior oral consent of the author) were selected several paintings that in their color content correspond to the color scheme of women's costume, which was designed at the Department of Garment Technologies and Design of Khmelnitsky National University (Figure 20).

Figure 20 Screenshot of the Artivive mobile application and the effect of augmented reality (snow falls and sounds "Shchedrik-Shchedrik")

Taking into account the results of the study, men's pants were also made using a QR-code on the label, which contains information about the product (size, material composition and link to the site TKSHV – Market). On the site there are only men's pants and information about them (size, material composition, operating conditions and other information). From the site you can go to the Telegram-channel, where it is convenient to ask additional questions about the product, see the process of creating a QR-code, etc. It is also planned to create other channels on social networks, such as Instagram, Facebook, Viber, etc. This will allow the consumer to use a more convenient social network.

The embroidery of the QR code on the label made using JANOME 350 E embroidery machine (Figure 21) [27].

Figure 21 Making a QR-code on the label of men's pants

The women's suit and men's trousers, which were made according to the research results, are shown in Figures 22 and 23.

Figure 22 Women's suit with usage of AR technology

Figure 23 Men's pants with usage of the QR code on the label

6 CONCLUSIONS

The results of the generated dynamic QR-codes will increase the awareness of garment specialists in the field of application of augmented reality technologies in the technological process and for training new workers, which in turn will increase the efficiency of production capabilities and ensure product competitiveness.

As a result of research on the development and popularity of augmented reality technologies using Google Trends tools and SE Ranking it was found that the vast majority of potential consumers of such technologies do not associate them with clothing. Among all the existing areas of augmented reality, its use in clothing is only 12%.

Analysis of the development of augmented reality technologies in the garment industry and fashion industry shows their rapid development over the past decade. The most common technologies that are now available to the general public are the application of printed images on T-shirts and other knitwear, which serve as markers of augmented reality and are animated using special mobile applications.

As a result of the research, a constructive-technological solution of the patch cuff of a women's jacket was proposed, on which a print-painting of the artist Olena Golembovska was applied, which was included in the image database with augmented reality of the Artivive mobile application.

It can also be concluded that the QR code is popular and developing and spreading in the world. Areas of application are increasing every day, so it is possible that the garment industry will use it more and more.

Studies have shown that the most aware and most commonly users of QR-codes are consumers under 40 years. However, the peak of the chart is between 20 and 30 years. The least aware about QR-codes are consumers over the age 50, regardless of gender. This shows that men's interest in QR-codes comes later, namely from 30 to 40 years.

It is also worth noting certain advantages of using QR-codes:

- a large amount of information. Information is recorded in two directions: vertical and horizontal. This approach can significantly increase the amount of stored information;
- easy scanning with digital devices. This makes it possible to easily and quickly transfer data to electronic form without manual typing;
- the presence of an error correction algorithm. It allows you to recognize damaged codes;
- the ability to read in motion. It is possible to read data from the window of a moving car;
- the opportunity to develop a QR-code for Facebook, Instagram, etc. There are special free applications for this.

Taking into account the results of the survey, men's pants were made using a QR-code on the label, which contains a link to the site TKSHV - Market. The site contains men's pants and information about them (size, material composition, operating conditions and other information). From the site it is possible to go to the Telegram-channel, which also contains all the necessary information about the product. In addition, it is possible to get feedback from the manufacturer, ask additional questions about the product and see the process of creating a QR-code and more.

7 REFFERENCES

1. Joan C.W.: Harvard Business Review, 2019, https://bit.ly/2IlRiJy
2. Lebedenko S.O.: The use of augmented reality technologies in trade and marketing, Effective economy, 10, 2019, pp. 7-10 (in Ukrainian)
3. How to use QR codes on clothing apparel and T-shirts? 2021, https://www.qrcode-tiger.com/how-to-use-qr-codes-on-clothing-and-t-shirts
4. Zasadna H.O.: QR-coding and alternative technologies, Financial Space, 2014, pp. 103-108 (in Ukrainian)
5. QR Codes in Fashion Retail: East versus West, 2019, https://fashionbi.com/newspa-per/qr-codes-in-fashion-retail-east-versus-west
6. Byoungho J., Kim G., Moore M., Rothenberg L.: Consumer store experience through virtual reality: its efect on emotional states and perceived store attractiveness, Fashion and Textiles, 2021, pp. 1-21, https://doi.org./10.1186/s40691-021-00256-7
7. QR code business ideas, 2020, https://www.qrcodechimp.com/article/qr-code-business-ideas/
8. Zak M.: Augmented Reality Try-On Adoption in the Online Clothing Industry: Understanding Key Challenges and Critical Success Factors, 2020, http://essay.utwente.nl/84375/1/Zak_MA_BMS.pdf
9. Google Trends, 2021, https://trends.google.com/trends/?geo=US
10. Zhylenko T.I., Kudryavtsev A.M., Zakharkevich O.V.: Mobile application to calculate the parameters of top wear basic design, Nauka innov. 15(3), 2019, pp. 2434, http://scinn.org.ua/sites/default/files/pdf/2019/N3/Zhylenko.pdf
11. Lego presented a clothing line through augmented reality - News: distribution (# 1068264), Fashion Network, 2019, https://ru.fashionnetwork.com/news/Lego-prezentoval-liniyu-odezhdy-cherez-dopolnennuyu-real%CA%B9nost%CA%B9,1068264.html
12. Ventana Research, Augmented reality in marketing and sales, 2018, https://bit.ly/2ne79Ci
13. L'Oreal. How L'Oreal is Using Augmented Reality & VR to Build In-Store Experiences, 2019, https://futurestores.wbresearch.com
14. The Ukrainian brand has created clothes with augmented reality. What does it look like and where to buy it? 2020, https://bit.ua/2020/06/gender-sexism/ (in Ukrainian)
15. Augmented reality on clothes Pikabu, 2019, https://pikabu.ru/story/dopolnennaya_realnost_na_odezhde_6824581
16. Augmented reality clothing, 2020, https://www.geyzerrr.com/blog/odezhda-dopolnennoj-realnosti
17. AR/VR | Application during COVID-19. DesignGlory, 2020, https://design-glory.com/4309/ar-vr-primenenie-vo-vremya-covid-19
18. Immersive AR Clothing Brands: AR clothing, TRENDHUNTER, [Online], 2021, https://www.trendhunter.com/trends/ar-clothing
19. Hryhorenko O., Zasornova I, Zasornov O.: Development of classificer for use of QR-codes in the garment industry, International Science Group, I International Science Conference on Interdisciplinary Research, January 19-21, 2021, Berlin, Germany, pp. 1008-1013, ISBN - 978-1-63684-352-0, DOI: 10.46299/ISG.2021.I.I
20. QR codes embroidering machine created in the Netherland. QR code Press, 2013, https://www.qrcodepress.com/qr-codes-embroidering-machine-created-in-the-netherlands/8517745/#:~:text=LogoBorduurstudio%2C%20a%20company%20based%20in,other%20types%20of%20soft%20items
21. Slavinskaya A., Syrotenko O., Zasornova I., Zasornov A.: Ethnic designer component of clothes' decoration techniques using, Vlakna a textil (Fibres and Textiles) 26(4), 2019, pp. 69-83
22. SIRUBA Product Trace: QR code & APP, 2017, https://www.youtube.com/watch?v=0uF6GEoxmkE&ab_channel=SiRUBAKAULIN
23. Ivanova A.: Technologies of virtual and augmented reality: opportunities and obstacles of application. Strategic decisions and risk management 3, 2018, pp. 108
24. Methods of printing on fabric, Allbest, 2021, https://knowledge.allbest.ru/manufacture/3c0a65635b2bd78a4d43b88421206d27_0.html
25. Sublimation printing, Printing portal, 2019, http://drukarstvo.com/sublimaciinyi-druk/
26. QR Code Generator, 2021, https://www.qr-code-generator.com/]
27. Zasornova I.: The research of technological parameters of the machine embroidery, made by cross elements, and practical recomendations for their application. Study of problems in modern science: new technologies in engineering, advanced management. Aficiency of social institutionsm Monograph, Shalapko Y., Wyszkowska Z., Musial J., Paraska O. (Eds.), Bydgoszcz, pp. 131-141, 2015

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