VLÁKNA a TEXTIL

2

Volume 28.
June
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 (2) 2021
Vlákna a textil (2) 2021
June 2021

Content

METHODS FOR IMPROVING THE QUALITATIVE INDICATORS OF FABRIC ON THE BASIS OF HEMP COTONINE FOR THE TOP OF FOOTWEAR

Galina Boyko[1], Tetiana Holovenko[2], Svitlana Yageluk[2], Olena Dombrovskaya[1], Tetyana Kuzmina[1] and Valentina Evtushenko[1]

[1]Kherson National Technical University, Berislavskoe shosse 24, 75008 Kherson, Ukraine
[2]Lutsk National Technical University, Lvivska str. 75, 43018 Lutsk, Ukraine
tanyushkagolovenko@ukr.net

Abstract: *Every year there is a growing interest in the use of technical hemp in light industry, not only abroad, but also in Ukraine. Many native entrepreneurs in the production of textiles use natural, environmentally friendly hemp fibers. This is due to the high quality properties of the fibers of this culture. Hemp fiber has great wear resistance and strength, even when compared to linen or cotton fibers. Hemp fibers have high hygroscopic properties Due to the porous structure of hemp fiber, the fabric obtained from it is able to absorb moisture up to five hundred percent of its weight. Also, these fibers are hypoallergenic. But, with such quality indicators, hemp fiber has a high breaking elongation; this negatively affects the performance properties of footwear. This article analyzes all the factors that negatively affect the shape stability of the shoe upper fabric, based on technical hemp fibers: high relative breaking elongation of hemp cottonin - 17.2%; fibrous and percentage composition of warp and weft threads in shoe upper fabrics and the weave of the shoe upper fabric. Based on the above experimental studies, a number of scientific hypotheses have been proposed that will help solve the negative impact of the above factors on the performance properties of industrial hemp footwear. The implementation of these hypotheses will improve the quality of native products made from industrial hemp and make them competitive in the domestic and European markets.*

Keywords: *steaming, hemp cottonin, physical and mechanical properties, shoe products.*

1 INTRODUCTION

At present, the efficiency of Ukrainian light industry enterprises is rather low, the goods produced by enterprises in this industry are significantly inferior in quality and quantity of products of developed countries [1]. The lack of domestic raw materials leads to overpricing and encourages the sale of products made of synthetic and chemical fibers of poor quality. The increase in prices for natural foreign raw materials leads to an increase in the cost of finished products even at the initial stage of their manufacture. Given the global economic instability, not all segments of the population can afford to consume high-quality products from natural raw materials, since there is a pattern: an increase in product quality leads to an increase in its cost.

To create environmentally friendly goods with high consumer characteristics at an affordable price, it is necessary to have high quality domestic raw materials. Industrial hemp is an additional source of raw materials for Ukraine. Hemp fibers are very strong and have high antiseptic and hygienic properties, which have a beneficial effect on the human body [2].

Today Ukraine has potential opportunities for the development of the hemp processing industry. These are, first of all, favorable natural and climatic conditions for growing industrial hemp and obtaining high yields of fiber and seeds, the presence, albeit of an outdated material and technical base. Also, in Ukraine, highly productive varieties of hemp have been created, which are not inferior, but on the contrary, surpass varieties of another traditional culture for Ukraine - flax in all yield indicators.

The number of Ukrainian enterprises processing hemp is increasing every year. The needs of the modern consumer for environmentally friendly products stimulate entrepreneurs to produce more and more new products from hemp fiber raw materials. Clothes and footwear made from hemp fibers are in great demand because products, made of hemp fibers, have high sanitary and hygienic properties, which provide regular heat exchange and have a positive effect on the spine and musculoskeletal system of the human body [2]. Hemp fabrics have high air permeability, which contributes to the retention of oxygen in the structure of textiles, excluding the development of anaerobic bacteria and the possibility of their reproduction inside various types of clothing, knitwear, shoes, etc. But along with the positive aspects of hemp fiber in textiles, problems arose with some of the properties of the fibers in the products during their use - this is the loss of dimensional stability. This moment is especially strongly reflected in footwear, thus, with the high needs of the modern consumer in textile products from domestic natural raw materials.

2 LITERATURE REVIEW

Hemp is known to contain ultra-strong and long fibers. The use of such fiber in the yarn, without modification, does not impart the softness of a cotton fiber to textiles. The leading manufacturers of hemp fiber textiles in the world have solved this problem long ago and widely use modified hemp cottonin. Modern equipment for processing hemp fiber into a modified one is produced by the companies "Laroche" (France), "Temafa" (Germany), "HempFlex" Romania, as well as the technology of the Institute of Agricultural Engineering named after V.I. Leibniz (Germany) [3]. The essence of the fiber modification process consists in special processing of bast fibers to transform them into a material similar in structure to cotton, in order to obtain the possibility of processing it using cotton technology [4]. When preparing bast fibers for spinning, attempts are made to remove cellulose satellite substances from them, which can have a negative effect on the spinning process and yarn properties. For example, fats and waxes have a positive effect in the spinning process, the influence of proteins, ash and pentosan can be neglected, but the encrusting substances must be removed. The task of modern technologies for cottonization of hemp fiber is to obtain cottonin with an insignificant degree of contamination, the linear density of which is close to the linear density of the fibers, intended for mixing or for obtaining multicomponent yarns [5]. Known methods of cottonization are: mechanical, chemical, biological and physical.

At Ukrainian enterprises for the production of clothing and footwear, hemp cotonin of mechanical processing is used. But products made from it, especially shoes, have some disadvantages. After few time of usage, footwear loses its dimensional stability [6]. Therefore, the scientists of the Kherson National Technical University were tasked with identifying the causes of this defect and finding ways to eliminate it.

Scientific research on improving the quality properties of footwear was highlighted in the works of domestic and foreign scientists Baidakova L., Dudla I., Konoval V., Libi V., Nesterov V., Polovnikov I., Rybalchenko V., in general or specific aspects. Basically, these studies are devoted to the anthropo-morphological features of the feet of the population, materials science (leather, or imitation leather), the design and technology of footwear production [7-9]. But the study of the characteristics of the fiber, the study of hemp fiber upper fabrics and the occurrence of negative factors during operation for dimensional stability have not yet been considered. Therefore, the determination of ways to eliminate negative factors on the performance properties of footwear made of technical hemp is relevant for the solution.

3 RESEARCH METHODOLOGY

The tasks were solved using the methods and means of theoretical and experimental research, which make it possible to get a complete picture of the physical and mechanical structure of hemp fibers and make it possible to formulate practical conclusions and recommendations for changing their properties for the further introduction of this raw material into textile production.

Experimental studies were carried out on the basis of the research laboratory for the processing of natural fibers of the Department of Commodity Science, Standardization and Certification and the Laboratory of Textile Materials Science of the Department of Expertise, Technology and Textile Design of the Kherson National Technical University.

One of the objectives of this scientific work is the study of cottonized hemp fiber (*Gljana variety*). This grade is characterized by high fiber performance. Under the conditions of the Lyutinsky hemp plant, from this variety of industrial hemp, hemp cottonin was obtained by the traditional method of mechanical modification, which is the only source of domestic products for obtaining textiles.

The first stage of research was aimed at determining the physical and mechanical properties of the resulting fiber [10]. Due to the lack of standard methods for assessing the quality of hemp cotton, methods for assessing the quality of fibers used for cottonized flax and cotton were used to determine the main physical and mechanical parameters.

4 RESULTS AND DISCUSSION

First, the length of the hemp cottonin was determined. Since cottonized hemp fiber has significant unevenness in length, the characteristics of fiber groups were used to assess its unevenness: maximum, average and minimum length. Results of studies are given in Table 1.

Table1 Hemp cottonin fiber length groups

Maximum length 120-90 mm	Average length 80-60 mm	Minimum length 50-1 mm
30%	55%	15%

Based on the results of the main groups of fiber lengths, hemp cottonin has an average length of about 70 mm, which is greater than the staple length of medium staple cotton. This indicator does not allow using the obtained cottonin for the production of yarn using the cotton spinning system. At the same time, the percentage of short fibers and down is 15%, spun fibers - 75%, with a length of more than 10 mm - about 7%, which corresponds to the normative indicators for spinning using the short flax technology.

In addition to the analysis of the length, studies were carried out on the strength and linear density of hemp cottonin. Due to the fact that hemp cottonin has a high strength due to the content of a high percentage of lignin (up to 8%), more than that of other bast crops, and also has a large elongation, due to the high fat content of 3%, therefore, determine it according to the regulatory documentation for hemp fiber, it makes no sense. All tests were carried out in accordance with the cotton regulations. The test results are shown in Table 2.

Table 2 Qualitative indicators of hemp cottonin

№	Indicator	Indicator value
1.	Breaking load of one fiber [gf]	42.0
2.	Absolute breaking elongation [mm]	10.6
3.	Relative breaking elongation [%]	17.2
4.	Linear density [tex]	6.8

It is known that on the equipment of cotton processing enterprises using a carded spinning system, fibers with a linear density of 0.16-0.33 tex with a cross-sectional size of 15-19 microns are used. The resulting cottonin fiber has a linear density of 6.8 tex, which is 20 times higher than the standard cotton fineness. So, the hemp cottonin obtained using this cottonization technology does not correspond to the indicators of medium staple cotton in terms of thickness and cannot be used to obtain thin and soft yarn.

Analyzing the strength of hemp cottonin fiber, which is one of the most important indicators of its quality, from the data in Table 2, it can be concluded that the breaking load of cottonin is 39.5 gf greater than the maximum breaking load of medium-staple cotton fibers. So, hemp cotton fibers exceed cotton fibers by 95% in breaking load. Also, the elongation at break of hemp cotton is 17.2% with such an indicator 100 percent use of this raw material in yarn for form-stable products is not recommended. It is possible to select blends with other fibers or use various treatments of cottonized fiber to reduce this indicator.

It is also possible to use long hemp fiber for shoe upper fabrics, since the relative breaking elongation of the fibers is 5-9%, but as you know, the linear density of such fiber is 25-50 tex, which means that these fibers will be coarse and yarn from they will differ in their thickness. Thus, the use of this fiber in the upper yarn will spoil the appearance and comfort of the product. Compared to cottonin, which has a linear density of 6.8 tex, long hemp fibers are much inferior to hemp cottonin in terms of aesthetics and comfort for textiles. Thus, the use of long fibers in the upper yarn is possible, but not effective. Therefore, hemp cottonin was used for further research.

For this purpose, the scientists carried out the steaming of raw materials in a laboratory autoclave. At this stage of the experiment, in addition to steaming, the operations of boiling and washing hemp raw materials were added. The material was steamed under the following conditions:

- pressure: heating, cooking 1.2-7.1 kgf/cm^2, steaming 1.8-2.3 kgf/cm^2, washing 0 kgf/ cm^2;
- temperature: heating, cooking 90-160°C, steaming 140-121°C, washing 40°C;
- operation duration: heating, boiling for 30 minutes, steaming for 20 minutes, washing for 10 minutes.

After steaming, repeated tests were carried out physical and mechanical parameters of hemp cottonin fiber. The results of quality indicators of fiber after steaming hemp cottonin are shown in Table 3.

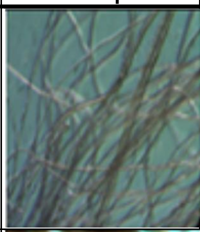
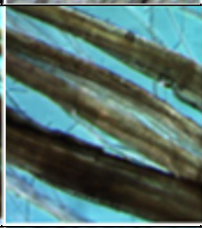
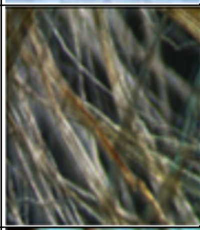
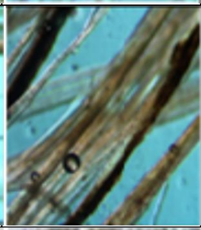
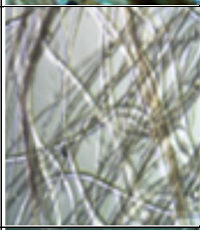
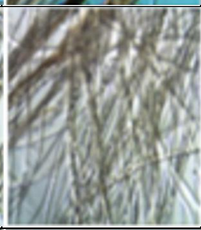
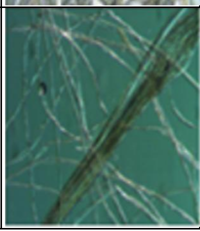
Table 3 Qualitative indicators of hemp cottonin after fiber steaming

№	Indicator	Indicator value
1.	Breaking load of one fiber [gf]	34.01
2.	Absolute breaking elongation [mm]	5.3
3.	Relative breaking elongation [%]	9.3
4.	Linear density [tex]	5.5

Studies have shown a significant decrease in the elongation at break, by almost half. This is due to a decrease in the fat wax up to 1% in the chemical composition. Also, the linear density has decreased, which also has a positive effect on the quality of the final textile product. A small reduction in breaking load does not have a large impact on the quality of the resulting fiber. From which it follows that steaming hemp cottonin changes the chemical composition with the redistribution of the molecular bonds of the fiber, which has a positive effect on the physical and mechanical properties of the hemp fiber.

After improving the properties of hemp fiber, the next stage of research was aimed at determining the fibrous composition of samples of fabrics for shoe uppers based on hemp cottonin and their weave, imported to Ukrainian shoe enterprises. For a more detailed determination of the basic composition of tissues, the method of light microscopy was chosen. Research data are highlighted in Table 4.

Table 4 Fibrous composition and weaving of imported fabric samples

№	Sample	Weave type	Photo of fiber microstructure		Fibrous composition [%]
			Warp	Weft	
1.		The two-faced weave is formed from three systems of threads; of two warp yarn systems and one weft yarn system			On the warp cotton 60%, hemp 40% On the weft cotton 60%, hemp 40%
2.		Plain weave in which the warp and weft threads overlap each other in every two successive overlaps			On the warp hemp is harsh 100% On the weft hemp is harsh 100%
3.		Two-faced weave is formed from three systems of threads: from one system of warp threads and two systems of weft threads			Based on hemp 100% The weft is 100% cotton
4.		Plain weave in which the warp and weft threads overlap each other in every two consecutive overlaps			Based on hemp 100% The weft is 100% hemp
5.		The reverse twill, in contrast to the base twill, has a scar direction from right up to left.			On the warp hemp 70%, wool 30% On the weft hemp 70%, wool 30%
6.		Plain weave in which the warp threads overlap each other in each successive overlap			Based on cotton 70%, hemp 30% On the weft cotton 70%, hemp 30%

Based on the results of previous studies of experimental wearing of shoes made of these hemp-based fabrics, a change in the dimensional stability of finished products was revealed. This is due to the high rate of elongation at break of hemp cottonin 17.2%. To reduce this indicator, mixtures with other fibers are used, but in this case, the above proposed mixtures do not have a positive effect on the dimensional stability of finished products.

The next stage of research was to determine the linear density of the threads in the fabrics along the warp and weft. The research results are shown in Table 5. The tissue samples in the Table 5 are numbered from the previous Table 4.

As can be seen from Table 5, only the sixth sample has a small linear density, which indicates the thinness and softness of this shoe upper fabric, the rest of the samples will look rough on the finished product. The manufacturers of these fabric samples decided to reduce its elongation by increasing the linear density of the yarn, but due to the high content of hemp cottonin in the mixtures without steaming, this indicator did not decrease, and the aesthetic characteristics deteriorated. Thus, the imported fabrics based on hemp fibers, which are currently used at the enterprises of the footwear industry in Ukraine, lead to a decrease in the competitiveness of domestic footwear made from environmentally friendly raw materials.

Table 5 Determination of linear density of tissue samples

Fabric samples	Linear density [tex]	
	On the basis	Weft
1 sample	102	104
2 sample	720	744
3 sample	184	60
4 sample	324	340
5 sample	248	260
6 sample	48	52

5 CONCLUSIONS

Based on the results of the studies, by steaming the fiber in the above modes, hemp cottonin fiber with an improved tensile elongation index was obtained. The indicators of this characteristic have halved from 17.2% to 9.3%, but this indicator is still large. The use of this fiber in a mixture with other fibers will make it possible to improve the dimensional stability index in future products.

Based on the studies carried out, the following working hypotheses were proposed to increase the form stability index of hemp fabric for the upper of shoes:

- into the mixture of hemp cottonin it is proposed to introduce lavsan fiber in various percentage compositions up to 40%. This percentage of synthetic fibers will reduce yarn elongation and will not interfere with the natural characteristics of the finished fabric;
- it is proposed to take cotton threads on the warp of the weave report and on the weft above the proposed hemp-lavsan mixture. The introduction of cotton fiber into the composition along the base will provide the fabrics for the upper of the shoe with a more uniform weave pattern, the fabric will be softer and more elastic, which will have a positive effect on the appearance of the product during operation;
- the use of twill weave in various variations (classic, reinforced) to determine the most relevant, in order to increase the dimensional stability. After all, as you know, twill weave is the most durable and form-stable, therefore it is usually used in the production of denim.

The implementation of these scientific hypotheses will solve the problems with the operation of shoes made of hemp fabrics. After all, the main factors of negative impact on the fabric of the upper of the shoe will be solved by a mixture of hemp with synthetic fibers and twill weave.

On the warp of the conducted scientific work, it was found that due to the steaming of hemp cottonin of the mechanical modification method, under certain conditions; it is possible to improve the physical and mechanical characteristics of fibers. Applying this fiber treatment in practice, it is possible to improve the dimensional stability of future products.

Also, while the analysis of the studies carried out on samples of imported fabric for the upper of footwear based on technical hemp has established that the reason for the low dimensional stability of finished footwear depends on many factors. The main problem is the low relative breaking load of hemp cottonin. In addition, the percentage composition of the warp and weft threads and the type of weave has a negative effect on dimensional stability. Therefore, to solve these problems on the basis of experimental studies, a number of scientific hypotheses have been proposed, the implementation of which will contribute to an increase in the operational life of the shoe without changing the appearance and its size. Based on this, we can conclude that the use of hemp cottonin in a mixture with lavsan fiber in the shoe industry.

6 REFERENCES

1. Boyko G., Tikhosova G., Kutasov A.: Technical hemp: prospects of development in Ukraine, Commodities and Markets No.1, 2018, pp. 110-120 (in Ukrainian)
2. Boyko G., Mandra O., Tikhosova A.: Unique consumer properties of technical hemp, Perfect Publishing, Vancouver, Canada, 2020 (in Ukrainian)
3. Kruglyj D., Boyko G., Klevtsov K.: Development of innovative technologies scientific foundations for producing best fibers for special purposes, INMATEH-Agricultural Engineering 54(1), 2018, pp. 147-152
4. Holovenko T. Yanyuk T., Boyko G., et al.: Promising methods and systems of quality control of innovative bast raw material, Science and Innovation 15(3), 2019, pp. 91-104, DOI: 10.15407/scine15.03.091
5. Boyko G., Chursina L., Kutasov A.: Development of Ukrainian light industry through the use of hemp raw materials, The scientific heritage, Ugorshchina, 2017, pp. 68-70, http://tsh-journal.com/wp-content/uploads/2017/03/VOL-1-No-9-9-2017.pdf
6. Boyko G., Chursina L., Kuzmina T.: Production of ecological, safe shoe and textile goods from hemp fibers: Bulletin of the Kiev National University of Technology and Design, Series: Technical Sciences 114(5), 2017, pp. 173-178, http://nbuv.gov.ua/UJRN/Vknutd_2017_5_24 (in Ukrainian)

7. Konoval V., Ribalchenko V. Hamster M.: Natural and artificial materials for shoes, Kiev, KNUDT, 2005, 218 p. (in Ukrainian)
8. Polovnikov I., Andrushchak V., Bednarchuk M.: Research technologies in the production of special footwear, (monograph), Lviv, Publishing house Lviv Commercial Academy, 2014, 368 p. (in Ukrainian)
9. Baydakova L.: Methods for assessing the quality of shoes and leather for shoe uppers: Measuring and computing equipment in technological processes, 2009, pp. 134-137 (in Ukrainian)
10. Boyko G., Kutasov A.: Determination of the properties of hemp cottonin and their change under steaming: Herald of Khmelnytsky National University, Technical sciences 255(6), 2017, pp. 263-266, ISSN: 2307-5732 (in Ukrainian)

EVALUATION OF ECONOMIC POTENTIAL OF TEXTILE INDUSTRY ENTERPRISES

Aktam Burkhanov[1] and Begalova Durdona Bakhodirovna[2]

[1]Finance and Accounting Faculty, Tashkent State University of Economics, Tashkent city, I. Karimov Street 49, 100003 Tashkent, Republic of Uzbekistan,
[2]Tashkent State University of Economics, Tashkent city, I. Karimov Street 49, 100003 Tashkent, Republic of Uzbekistan
burkhanov.a.u@yandex.ru

Abstract: *In this article has been proposed a new methodology for assessing the economic potential of textile enterprises. As a result of the analysis of foreign literature, the marginal values of the economic potential of the enterprise were determined. By the author have been proposed formulas for calculating indicators such as own working capital ratio, return on assets, return on long-term capital, etc. The level of financial security of textile enterprises operating in Uzbekistan has also been assessed and analyzed, and scientific proposals and practical recommendations have been developed to ensure their financial security. Proposed methods were implemented on private enterprise "OSBORN TEXTILE" and Joint-Venture "UZTEX TASHKENT" operating in Uzbekistan. Based on secondary accounting data of enterprises, the financial security situation of enterprises was analyzed and proposals for staving off threats were elaborated. This technique can be applied in all textile enterprises operating in the world.*

Keywords: *Financial security, textile enterprise, liquidity, financial resources, capital, net profit.*

1 INTRODUCTION

The current state of the global textile market shows that the rapid penetration into the textile markets of developed countries is carried out mainly by national companies integrated into the global textile industry. Also, the importance of providing the domestic market in the global textile industry trend is growing [1]. In particular, in 2016, world exports of textile products amounted to a total of 286.5 billion US dollars, in which the role of Asia remains high [2]. However, in 2016, the share of Uzbek textile exports in the top 10 textile exporters in the world was only 0.37%. This requires accelerating their integration into the global textile industry by creating national textile clusters.

The steady growth of the world's population in recent years and the continuation of this trend in the future will lead to improved living conditions and increased solvency, further increase in demand for finished and semi-finished textile products. This, in turn, requires modern research based on reducing the cost of production, as well as expanding the range and improving the quality of products in the light industry of the country, in particular, the textile industry. The study of scientific, methodological and practical aspects of this issue in terms of increasing the economic potential of enterprises of the national textile industry on the basis of innovative approaches is relevant today. At the current stage of rapid economic reforms in Uzbekistan, it is important to improve the mechanisms for increasing the economic potential of textile enterprises, including monitoring the level of economic potential of enterprises, accelerating receivables and developing a strategy for modernization of enterprises.

2 LITERATURE REVIEW

The textile industry is the basis for sustainable economic growth, increasing export earnings, prioritizing the development of small business and private entrepreneurship, as well as social crisis, i.e. providing employment, increasing incomes and ultimately improving living standards. Today, the textile industry is characterized not only as a rapidly developing industry, but also as a stable increase in exports, attracting foreign investment and modernization and radical technical and technological renewal of production processes.

It is known that today a lot of research has been conducted on the concept of economic potential of industrial enterprises, its components and its evaluation indicators. However, there is almost no research on the concept of economic potential of the sector enterprises, its assessment indicators and economic capacity building, which fully covers the specific development characteristics of the real sector of the economy.

In our opinion, it is expedient to scientifically formulate and disclose the economic nature of the indicators for its evaluation, taking into account the organizational and economic nature, composition, specific features of the development of textile enterprises.

There are many famous researches dedicated to textile industry, as well as Gereffi [1], Heymann [2], Tokatli [3] and Zhang [4]. In their scientific works have been investigated issues of industrial upgrading in the apparel commodity chain, manufacturing garments for ready-to-wear to designing collections for fast fashion in Turkey, profitability and productivity of the Chinese textile industry and etc.

In the 1990s, the economic security of an enterprise was interpreted as providing the conditions for maintaining these trade secrets. Economic security was later understood as a system that provides resistance to negative external economic factors.

In addition, economists discussed issues such as minimizing losses, ensuring control over property, ensuring information and legal security, and ensuring the economic security of the enterprise. Senchagov [5] defines the economic security of an enterprise as a set of measures that include a combination of these factors, not only dependent on the internal situation, the external environmental impact of the enterprise and the economic threats of the enterprise. Gaponenko [6] emphasizes that economic security is the timely response to changes in the external environment, which ensures that the enterprise adapts to existing conditions. According to Goncharenko [7], the economic security of an enterprise is interpreted as a state of efficient use of resources to prevent these threats and ensure the sustainable operation of the enterprise. The economic security of the enterprise is characterized by a combination of qualitative and quantitative indicators. Glyumov and Kiselitsy [8] noted that the economic security of the enterprise is characterized by a set of indicators of qualitative and quantitative economic security, the main of which is determined by assessing the state of use of enterprise resources on the criteria of economic security. They emphasize that the economic security of the enterprise is characterized by a set of qualitative and quantitative indicators, the main of which is to determine the level of economic security of the enterprise by assessing the state of use of enterprise resources on economic security criteria. From the point of view of Ivanov [9], the economic security of an enterprise is defined as economically safe if it has advantages over competing enterprises due to its material, financial, personnel, technological capabilities and compliance with the strategic goals and objectives of the organizational structure. Gaponenko, Bespalko and Vlaskov [6] defined the economic security of enterprises as the state of the enterprise, which is characterized by the ability to function normally to achieve their goals in the current external conditions and their change within certain limits. Manokhina [10] is very similar to the opinion of other scholars, who define the economic security of an enterprise as the existence of competitive advantages due to the material, financial, human, technical and technological capabilities of the enterprise and the conformity of its organizational structure to strategic goals and objectives. Proponent of a systemic approach, according to Bulanov [11], economic security includes "organizational, industrial, legal, material and intellectual relations, resource sustainability, financial and commercial success, and resources that ensure the consistent scientific and technological development of the real sector" and a situational approach to managing the economic security of an enterprise has become widespread. According to Glazyev [12], economic security is the state of the economy, socio-economic development and maintenance of the necessary competitiveness that ensures the stability of the enterprise itself. Schultz [13] emphasizes this approach that an economic security system based on the security of any social life is a flexibility based on strategic management, political analysis, and other rational activities related to the study of the past and present. Proponents of the functional approach and Oleinikov [14] argue that they consider the economic security of the enterprise as a broad concept that includes only the financial, intellectual, personnel, political and legal, environmental, information and energy sectors. According to Ermolaev [15] and Goncharenko [7], the economic security of the enterprise is, in turn, an integral part of the business security system, along with technological, environmental, information, psychological, physical, scientific and other things. It has been scientifically proven that the result of an enterprise's economic security is the result of properly established processes. The process of financial and economic activity itself is a set of different types of activities of enterprises, which use several resources at the beginning of the process ("input") and as a result ("input") produce valuable products for the consumer.

Functional and systemic approaches are very broad, so while trying to cover all functional areas of activity and system units, the enterprise develops its own concept of economic security and faces specific challenges. At the same time, the share of subjectivity of those who manage the economic security of the enterprise is high. In addition, careful development and monitoring of the economic security of enterprises makes it difficult to implement these two approaches in practice.

According to Belkin [16], the imperfection of the functional approach is manifested in the fact that the decision made in one division of the enterprise is often a problem for another, i.e. there is no consistency between units. According to the process approach, economic security covers all levels of the organizational structure of the enterprise. The existing business processes in the enterprise and their impact on the economic security of the enterprise were studied. At the same time, each process will be focused on achieving results that ensure the economic security of economic activity with its own “exit”. However, it is also not advisable to be limited to strategic economic security management processes, as resources are not important as a necessary condition for the implementation of different processes, "input" and "output", individuals working between processes, i.e. actions performed, as well as process disruption potential counterparties need to be considered. In this regard, the advantage of using a process approach is the innovative (cyclic) use in the formation of strategic economic security of the existing enterprise. This approach, according to Krasnoshek [17], is based on the existence of long, medium and short waves of economic development and is based on the application of the theory of economic cycles. At the same time, measures to eliminate threats to economic security need to be taken and implemented in the form of transition to a new cycle of economic development or in the form of leading the competition. In other words, we can talk about the presence of bifurcation points in the process of operation of the enterprise, which determine that its development does not change during the life cycle. Therefore, the application of this approach is necessary for practical application in the process ofmonitoring the safe development of the enterprise, but the life cycle curve, in addition, the identification of defining components of strategic economic security requires the development of enterprises and their evaluation methods. Thus, in our opinion, the formation of the strategic economic security of the enterprise can be achieved through the path of sustainable development based on its long-term performance. Thus, the economic security of an enterprise is characterized by its many types and approaches to detection. In this regard, it is necessary to systematize the approaches discussed above to form a complete definition of strategic economic security. To do this, we use the classification features proposed by Blank [18]:

- level of economic activity;
- functional type of economic activity;
- the nature of the threats to economic interests;
- source of threat to economic interests;
- the essence of mechanisms for the protection of economic interests;
- the direction of the mechanisms for the protection of economic interests;
- time period;
- level of management;
- level of protection of economic interests;
- stability of parameters that protect economic interests;
- legitimacy of the methods used to protect economic interests.

Scientists of our country have hardly studied this issue. Only one chapter of the textbook is devoted to the economic security and trade secrets of enterprises [19]. It is also clear that the issue of economic security of enterprises, as noted above, is one of the most pressing issues in today's economic liberalization. The fact that the subject is still unresolved, on the one hand, and its objective necessity on the other hand, became the basis for our attempt to study this topic, to solve its theoretical and practical problems.

In our view, the economic literature generally focuses on the economic security of the national economy, states, individual regions and enterprises. However, issues related to ensuring the economic security of enterprises, especially those operating industrial enterprises, have not been comprehensively studied. Accordingly, this topic is poorly covered in the economic literature. Their theoretical and practical solutions are still insufficiently developed. Scientists of our country have hardly studied this issue. Only one chapter of the textbook is devoted to the economic security and trade secrets of enterprises. It is also clear that the issue of economic security of enterprises, as noted above, is one of the most pressing issues in today's liberalized economy.

3 METHODOLOGY

One of the main methodological tasks of research on economic potential is the selection of its evaluation methods. Scientific and economic substantiation of methods and indicators of economic potential plays an important role in the development of strategies to ensure the economic potential of enterprises and increase it in the future. In particular, the assessment of economic potential:

- identification of existing opportunities of enterprises;
- assessment of the level of effective use of economic potential;
- identification of key areas for improving the efficiency of economic potential use;
- determine the level of use of its individual elements to find backup and unused opportunities;
- allows to determine the directions of development of economic potential of enterprises [7, 8].

Today, economists do not have a single methodology for assessing the economic potential of textile enterprises. In this context, the study of existing scientific views and methods for assessing the economic potential of enterprises is of scientific importance. Also, in many economic literatures [19-23] there are methods of rating the economic potential of enterprises. The economic significance of these methods is as follows:

- analysis of financial and economic activity of enterprises on the basis of many indicators describing the financial condition and results of the enterprise;
- calculation of the results of the rating based on the comparison of the results of the enterprises.

Most economists [24-28] propose an approach to assessing the economic potential of enterprises based on methods that typically evaluate the financial performance of enterprises. In this case, the economic potential of the enterprise is analyzed in terms of assessing the financial condition and property potential of the enterprise. It also uses a variety of methods to assess the financial and property aspects of capacity; the application of certain sets of enterprise performance and financial ratios is scientifically and economically justified.

The method proposed by Stepanova and Rogozhina [29] to assess the economic potential of enterprises in the textile industry is very interesting and important for our research. In particular, they assess the economic potential of textile enterprises as follows: financial; property; personnel; material; information; proposed a combination of innovative and energy potentials.

Assessment of economic potential is an important part of the internal management system of the enterprise, as it allows you to obtain information about the results of the enterprise, identify reserves, assess and forecast opportunities to improve the efficiency of the enterprise, as well as form organizational and managerial decisions.

The economic potential of enterprises cannot be assessed without the use of quantitative and qualitative methods. Such methods include:

- matrix method;
- scoring method;
- method of value assessment by value;
- index method;
- linear optimization model method;
- regressive methods can be introduced.

Based on various methods and techniques of assessing the economic potential of enterprises, the economic potential of textile enterprises is summarized, taking into account the specifics of the textile industry of Uzbekistan, as well as the importance of resources and reserves in the textile industry and the rapid inflow of investors and propose an improved methodology of evaluation based on index indicators, broken down into long-term potentials.

The proposed methodology can be economically justified as follows, i.e. the economic potential of textile enterprises should be considered as a separate system of independent development. They consist of indicators such as resources, reserves and potential reserves, which allow to ensure the growth of indicators of inter-dependence, i.e. the performance of the enterprise. Consequently, resources, reserves and potential reserves are sources of realization of economic potential. In this case:

- resources of textile enterprises - fixed assets, working capital and labor resources;
- reserves - total material resources that are not temporarily used for the intended purpose of the enterprise, but can also be used in production activities;
- potential reserves - we can include total material resources that are currently economically difficult to implement, but are available for future use.

Our substantiation of the economic potential of textile enterprises as resources, reserves and potential reserves allowed to classify it by the composition of the sources of its implementation (Figure 1).

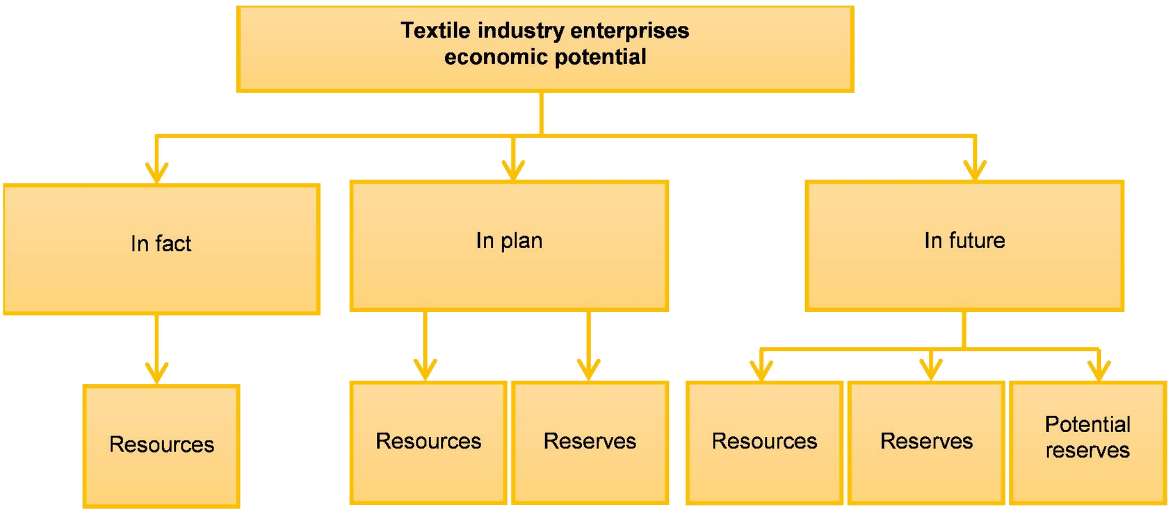


Figure 1 Classification of enterprises of the textile industry by types of economic potential and sources of their implementation

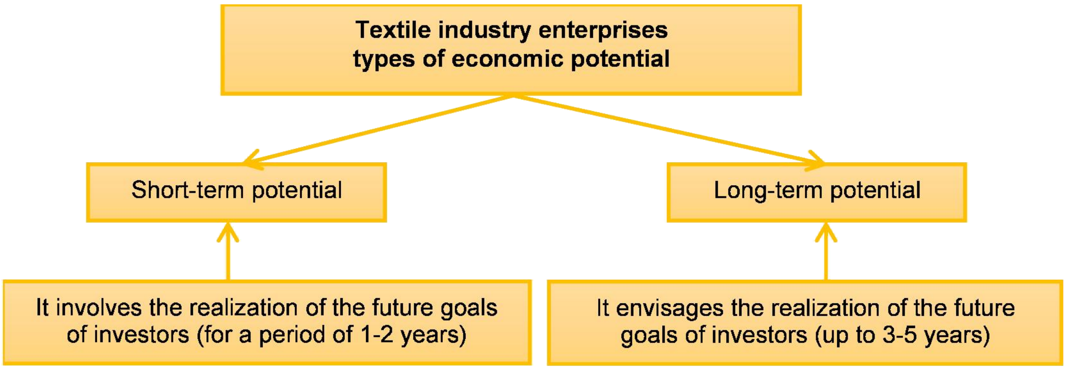


Figure 2 Classification of medium and long-term economic potential of textile enterprises

In particular, the real economic potential is the availability of resources and financial stability in the enterprise. The use of available resources and the calculation of the results of the enterprise, taking into account the reserves in the conditions of financial stability of the enterprise, determine the existing economic potential. Calculating the results of the activities of enterprises, involving existing resources, reserves and potential reserves, determines the future economic potential. Any of the above types of economic potential can be considered, but any investor looking to invest in the textile industry will focus more on assessing the future economic potential of textile enterprises. As the investor sets different goals when investing in enterprises, including that one investor wants to get economic benefits faster than the invested investment (1-2 years) and the other in the future (3-5 years). In this regard, we propose to classify the economic potential of textile enterprises by dividing them into short-term and long-term potentials (Figure 2). As mentioned above, based on the methodology for assessing the economic potential of enterprises in the textile industry, it is proposed to calculate on the basis of index indicators that reflect the activities of the enterprise and the results of its implementation. In this case, the economic significance of the index-based assessment methodology is that the current and future economic potential of textile enterprises is compared with the actual economic potential, i.e. the index is determined by dividing the current and future economic potential of enterprises by the actual economic potential. Key indicators for assessing the short-term economic potential of textile enterprises:

1. Own working capital ratio (OWC_r):

$$OWC_r = \frac{SOF_f + LTL - LTA}{A_j} \quad (1)$$

where: SOF_f - sources of own funds, thousand UZS; LTL - long-term liabilities, thousand UZS; LTA - long-term assets, thousand UZS; A_j - current assets, thousand UZS.

2. Current liquidity ratio ($\mathrm{L_j}$):

$$L_j = \frac{A_j}{STL} \quad (2)$$

where: A_j - current assets, thousand UZS; STL - short-term liabilities, thousand UZS.

3. Net asset value (NAV_v):

$$NAV_v = A_v - L \quad (3)$$

where: A_v - average annual value of assets, thousand UZS; L - liabilities, thousand UZS.

Key indicators for assessing the long-term economic potential of textile enterprises:

1. Own working capital ratio ($\mathrm{O'AM_t}$):

$$OWC_r = \frac{O'M_m + UMM - UMA}{A_j} \quad (4)$$

where: $O'M_m$- sources of own funds, thousand UZS; LTL - long-term liabilities, thousand UZS; LTA - long-term assets, thousand UZS; A_j - current assets, thousand UZS.

2. Return on assets ($\mathrm{A_r}$):

$$A_r = \frac{F_s}{A_q} \quad (5)$$

where: F_s - net profit, thousand UZS; A_q - average annual value of assets, thousand UZS.

3. Long-term return on capital ($\mathrm{LTR_c}$):

$$\mathrm{LTR_c} = \frac{N_p}{LTA} \quad (6)$$

where: N_p - net profit, thousand UZS; LTA - long-term assets, thousand UZS.

The scientific significance of the proposed methodology is that it is a new approach to assessing the economic potential of textile enterprises, i.e. the use of "assessment of potential reserves" and its application on the basis of indices. Based on the above, we propose to use the following indicators in assessing the economic potential of textile enterprises (Table 1).

Table 1 Classification of final index indicators for assessing short-term and long-term economic potential of textile enterprises

Short-term economic potential		Long-term economic potential	
$i_{mt}^{OWC} = \frac{OWC_{r_{fact}}}{OWC_{r_{plan}}}$	Self-sufficiency of the enterprise.	$i_{lt}^{OWCr} = \frac{OWC_{r_{fact}}}{OWC_{r_{forecast}}}$	The fact that the enterprise is self-financed.
$i_{mt}^{CFCe} = \frac{CFC_{e_{fact}}}{CFC_{e_{plan}}}$	Current financial condition of the enterprise.	$i_{lt}^{A_r} = \frac{A_{r_{fact}}}{A_{r_{forecast}}}$	Efficiency of use of enterprise assets.
$i_{mt}^{NAV_e} = \frac{NAV_{e_{fact}}}{NAV_{e_{plan}}}$	The volume of net assets of the enterprise.	$i_{lt}^{LTCf} = \frac{LTC_{fact}}{LTC_{forecast}}$	Efficiency of use of long-term capital of the enterprise.
$\overline{i_{mt}^{IS}} = \frac{OWC_{r_{fact}} + CFC_{e_{fact}} + NAV_{e_{fact}}}{OWC_{r_{plan}} + CFC_{e_{plan}} + NAV_{e_{plan}}}$	Short-term economic potential level	$\overline{i_{lt}^{IS}} = \frac{OWC_{r_{fact}} + A_{r_{fact}} + LTC_{fact}}{OWC_{r_{forecast}} + A_{r_{forecast}} + LTC_{forecast}}$	The level of long-term economic potential

It is the final index that shows the extent to which the economic potential has increased due to the involvement of reserves and potential reserves in the financial and economic activities of the enterprise.

In this case, any investor can invest in an enterprise that is convenient and efficient for him, that is, based on a high level of economic potential. The method of assessing the level of economic potential of enterprises in the textile industry has been improved on the basis of the classification of economic indicators of enterprises into short-term and long-term economic potential, and it is presented in Table 1.

The practical significance of the proposed methodology is based on the possibility of obtaining information on the economic potential of the enterprise at the stage of study as an object of investment, which reflects the factors affecting the future activities of the enterprise. Thus, the proposed methodology for assessing the economic potential of textile enterprises is based on the assessment of the final index of financial and economic activity of the enterprise. This methodology plays an important role in the preparation of analytical data on the rapid inflow of investors into the textile industry and the economic potential of national textile enterprises in the context of liberalization of the foreign exchange market in our country.

4 ANALYSIS AND RESULTS

Assessment and analysis of the economic potential of textile enterprises “BAYPAK TEXTILE” JV operating in Uchtepa district, Tashkent region, “OSBORN TEXTILE” FV operating in Bostanlyk district, Tashkent region, “UZTEX TASHKENT” JV operating in Sergeli district, Tashkent city, was carried out by “CHINOZ TEXTILE” LLC operating in Chinoz district (Table 2).

The analysis shows that the volume of production of cotton yarn at the enterprises of the textile industry, which is the object of research, decreased sharply at the enterprises of "BAYPAK TEXTILE" JV and "UZTEX TASHKENT" JV, but the cost of production increased.

In particular, the volume of production at “CHINOZ TEXTILE” LLC increased sharply, i.e. in 2014 it produced 3.9 thousand tons, in 2017 this figure almost doubled and reached 7.4 thousand tons.

Based on the proposed set of methods and indicators for assessing the economic potential of textile enterprises, we analyze the assessment of the level of economic potential of enterprises in the textile industry.

Table 2 The dynamics of production in the textile industry, which is the object of study

Name of enterprises	Unit of measurement	year				In 2020, compared to 2017 [%]
		2017	2018	2019	2020	
"BAYPAK TEXTILE" JV	thousand tons	2.8	2.3	2.5	2.6	94.8
	billion UZS	16.2	16.5	17.9	19.0	117.1
"OSBORN TEXTILE" FV	thousand tons	5.7	5.5	6.1	6.7	117.5
	billion UZS	94.5	94.7	104.7	116.0	122.8
"UZTEX TASHKENT" JV	thousand tons	5.2	3.8	4.1	4.5	86.6
	billion UZS	39.5	39.5	42.8	46.2	117.1
"CHINOZ TEXTILE" LLC	thousand tons	3.9	5.9	6.6	7.4	191.9
	billion UZS	28.1	32.6	36.6	41.3	147.0

In particular, we analyze the key indicators for assessing the short-term economic potential of enterprises in the textile industry under analysis.

1. *Coefficient of self-sufficiency of textile enterprises*

The ratio of the company's own working capital is based on the fact that the company has its own capital and the higher the figure, the higher the company's own capital. In particular, the low normative level of this indicator in the territory of the Republic of Uzbekistan is 0.2. If the indicator is less than 0.2, then the enterprise is considered unsecured [1].

The analysis shows that in all enterprises, except for "BAYPAK TEXTILE" JV, the coefficient of working capital is higher than the established norm. It can be seen that in “BAYPAK TEXTILE” JV this indicator has been low for many years, according to experts [23], such a situation is considered as an indirect sign of incorrect reporting (Figure 3).

The following key factors contributed to the increase in the level of working capital in the analyzed textile enterprises (Figure 3):

- growth of own working capital, in particular, in “OSBORN TEXTILE” JV in 2020 the amount of working capital increased by 18.0% and amounted to 15.9 billion, in “UZTEX TASHKENT” JV - 42.5% and 13.2 billion UZS, respectively, “CHINOZ TEXTILE” LLC - 16.6% and reached 12.3 billion UZS;
- decrease in the amount of current accounts payable, in particular, the amount of current accounts payable in "UZTEX TASHKENT" JV in 2014 was 19.8 billion UZS, this figure decreased by 22.3% in 2020 or amounted to 14.6 billion UZS;
- decrease in the share of receivables from current working capital, in particular, the share of receivables in "UZTEX TASHKENT" JV in 2014 was 38.2%, in 2020 this figure decreased by 11.1% and reached 27.1%;
-
- growth of financial stability of enterprises;
- increase in the number of solvent buyers.

The low level of working capital of the textile enterprises under analysis can be justified by the following main factors:

- “BAYPAK TEXTILE” JV does not have its own working capital, i.e. in 2017 the goods were operated on the basis of immobilization of suppliers and contractors for 2.5 billion UZS, by 2020 this figure decreased by 55.8% and amounted to 1.1 billion UZS.
- High amount of current accounts payable, in particular, increase in current accounts payable in "BAYPAK TEXTILE" JV, i.e. in 2017 the current accounts payable amounted to 5.4 billion UZS, an increase of 7.4% in 2020 or 5.8 billion UZS, respectively, "CHINOZ TEXTILE" LLC increased 5 times and amounted to 17.0 billion UZS;
- High share of receivables from current working capital, in particular, the share of receivables in "BAYPAK TEXTILE" JV in 2018 was 35.4%, in 2018 this figure increased to 16.3% and reached 51.7%. Respectively, the share of receivables in “CHINOZ TEXTILE” LLC increased from 28.2% (in 2014) to 51.1% in 2017 or 22.9% compared to 2017, in “CHINOZ TEXTILE” LLC in 2018 to 15.4% reached 61.6% in 2020 or increased by 46.2% compared to 2014.

2. *Current liquidity ratio of textile enterprises*

Liquidity indicator, which determines the financial condition of the enterprise, plays an important role in assessing the economic potential of enterprises in the textile industry. After all, the main purpose of the analysis of the financial condition of enterprises is to justify decisions about the unsatisfactory composition of the balance sheet or insolvency of the enterprise according to the system of criteria for determining the unsatisfactory composition of the balance of insolvent enterprises.

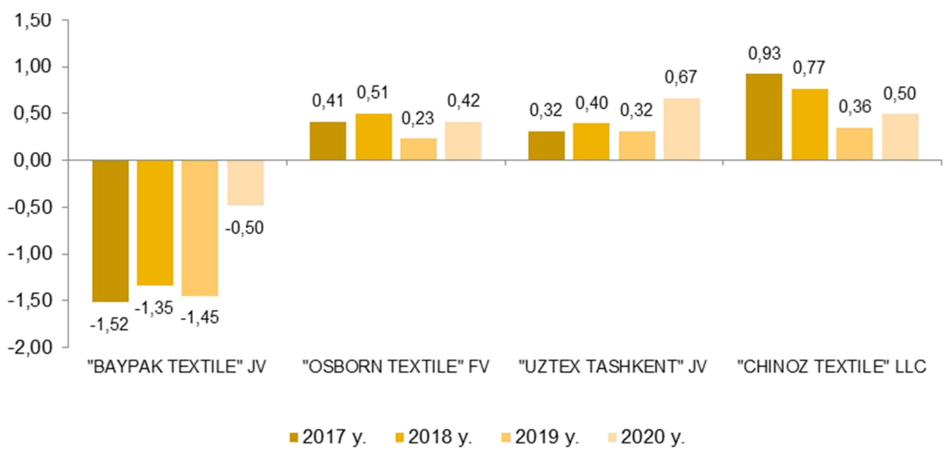


Figure 3 The dynamics of the coefficient of capital adequacy of enterprises in the textile industry

In particular, if the normative level of the current liquidity ratio in the territory of the Republic of Uzbekistan is lower than 1.25, then the enterprise is considered illiquid, i.e. insolvent [23]. During the years of analysis, the current liquidity ratio of "BAYPAK TEXTILE" JV was much lower than the norm. However, in other textile enterprises under analysis, this figure is high, on the one hand, it is considered a positive situation, on the other hand, it means that enterprises do not use working assets enough and there are barriers to obtaining short-term loans.

As can be seen from Figure 4, in 2020 compared to 2017, the solvency of “CHINOZ TEXTILE” LLC decreased sharply, which can be explained by an increase in short-term liabilities of the enterprise. The growth of the current liquidity ratio of the analyzed textile enterprises was influenced by the following key factors:

- growth of own funds of enterprises, in particular, in “OSBORN TEXTILE” FV in 2017 the amount of own funds was 62.0 billion UZS, this figure increased by 8.7% in 2020 or 67.4 billion UZS, respectively, “UZTEX TASHKENT” JV in – 2 times and 60.5 billion UZS, in "CHINOZ TEXTILE" LLC - increased by 2.2% and amounted to 42.7 billion UZS;
- decrease in the amount of short-term liabilities, in particular, the amount of short-term liabilities in "UZTEX TASHKENT" JV in 2017 amounted to 19.8 billion UZS, this figure decreased by 34.5% in 2020 or amounted to 13.0 billion UZS;
- increase in revenue from sales of products, in particular, in "OSBORN TEXTILE" FV in 2017 the revenue from sales of products amounted to 73.9 billion UZS, this figure increased by 52.2% in 2020 or 112.5 billion UZS, respectively, “CHINOZ TEXTILE” LLC - 40.2% and 36.6 billion UZS;
- collection of receivables, in particular, the amount of receivables in "UZTEX TASHKENT" JV in 2017 amounted to 11.1 billion UZS, while in 2020 this figure decreased by 47.9% or 5.8 billion UZS;

The decrease in the current liquidity ratio of the enterprises of the textile industry under analysis was influenced by the following main factors:

- high volume of finished products in warehouses, including above the norm, although the amount of finished products in the enterprises decreased in the analyzed years. In particular, in the warehouses of "OSBORN TEXTILE" FV in 2017 were not sold finished products worth 6.7 billion UZS, this figure decreased by 15.7% in 2020 or 5.6 billion UZS, respectively, in "UZTEX TASHKENT" JV – 62.1% and 1.3 billion UZS;
- increase in the amount of short-term liabilities, in particular, the amount of short-term liabilities in "BAYPAK TEXTILE" JV in 2017 amounted to 4.1 billion UZS, this figure increased by 27.4% in 2020 or 5.2 billion UZS, respectively, "OSBORN TEXTILE" FV - 57.6% and 30.0 billion UZS. The highest growth rate of short-term liabilities was observed in “CHINOZ TEXTILE” LLC, which in 2017 increased 19 times compared to 2017 and amounted to 15.2 billion UZS;
- decrease in income from sales of products, in particular, the amount of income from sales of products in "UZTEX TASHKENT" JV in 2017 amounted to 43.8 billion UZS, while in 2020 this figure decreased by 23.5% or 33.5 billion UZS.

3. *<u>The value of net assets of enterprises of the textile industry</u>*

The value of net assets of all textile enterprises under analysis is growing year by year, and its highest rate is observed in "OSBORN TEXTILE" FV and "UZTEX TASHKENT" JV (Figure 5).

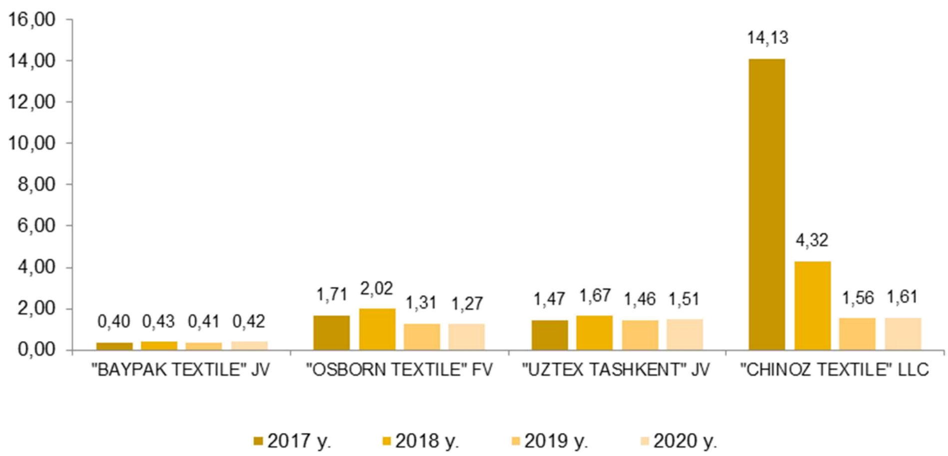


Figure 4 Dynamics of current liquidity ratio of textile enterprises

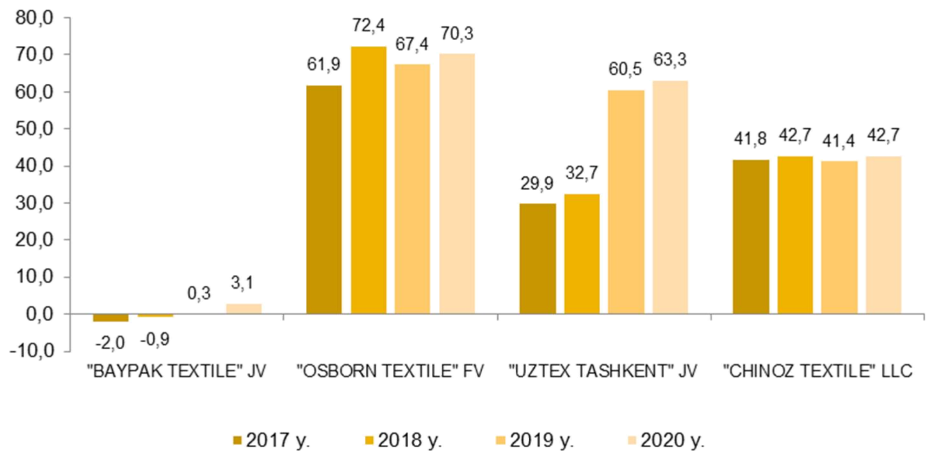


Figure 5 Textile industry enterprises net asset value dynamics

During 2017-2020, the value of net assets in "BAYPAK TEXTILE" JV was negative, which indicates the insolvency of the enterprise and the fact that the enterprise is dependent on creditors and does not have its own funds. The growth of the value of net assets of the analyzed textile enterprises was influenced by the following main factors:

- decrease in the amount of short-term liabilities, in particular, the amount of short-term liabilities in "UZTEX TASHKENT" JV in 2017 amounted to 19.8 billion UZS, this figure decreased by 34.5% in 2020 or amounted to 13.0 billion UZS;
- growth of net profit, in particular, net profit of "OSBORN TEXTILE" FV in 2020 amounted to 9.4 billion UZS, an increase of 16.7% compared to 2017. Thus, in 2020 alone, compared to the previous year, due to the proposal of "OSBORN TEXTILE" FV to accelerate the turnover of overdue receivables and payables in order to reduce the share of other operating expenses in current expenses, the share of other operating expenses in current expenses decreased by 35.8%, increased by 97 billion UZS.

The decrease in the value of net assets of the analyzed textile enterprises was due to the following main factors:

- growth of overdue receivables, in particular, overdue receivables in "BAYPAK TEXTILE" JV in 2020 increased by 2.5 times, in "OSBORN TEXTILE" JV - by 3.1 times and in "CHINOZ TEXTILE" LLC - by 15.5 times.
- decrease in net profit, in particular, net profit of “UZTEX TASHKENT” JV in 2017 was 680.2 million UZS, this figure decreased by 112.9 times or 6.1 million UZS in 2020, respectively, “CHINOZ TEXTILE” LLC – 82.6% and amounted to 0.2 billion UZS.

Based on the above indicators, we assess the level of short-term economic stability of textile enterprises.

The calculations are made on the principle of the ratio of the actual state of the absolute indicators to the planned indicators, which is the basis for the analyzed coefficients.

The results of the calculations show that during the analyzed years, the level of short-term economic potential of "OSBORN TEXTILE" FV and "CHINOZ TEXTILE" LLC is high (Figure 6). This indicates that investors have a high chance of making a profit by making short-term investments in these enterprises.

However, the results of the above analysis show that in addition to positive changes in all enterprises, negative trends, namely, creditor debts, chronic increase in overdue receivables, as well as a decrease in sales revenue and net profit can be observed.

It should be noted that the level of short-term economic potential of “BAYPAK TEXTILE” JV has been growing steadily over the years, but the current level is not positive for investors, so the company needs to develop the necessary economic support and mechanisms.

In the research we analyze the textile industry enterprises, which are the object of research, on the basis of the proposed key indicators to assess the long-term economic potential of enterprises. In particular, to assess the long-term economic potential, the coefficients of return on equity, assets and long-term capital of textile enterprises were determined.

1. Return on assets of textile enterprises

It is known that the change in the rate of return on assets of the enterprise is influenced by the following factors:

- -organizational and technical level of production;
- asset structure;
- intensive use of production resources;
- composition and volume of manufactured products;
- benefits by type of activity, etc.

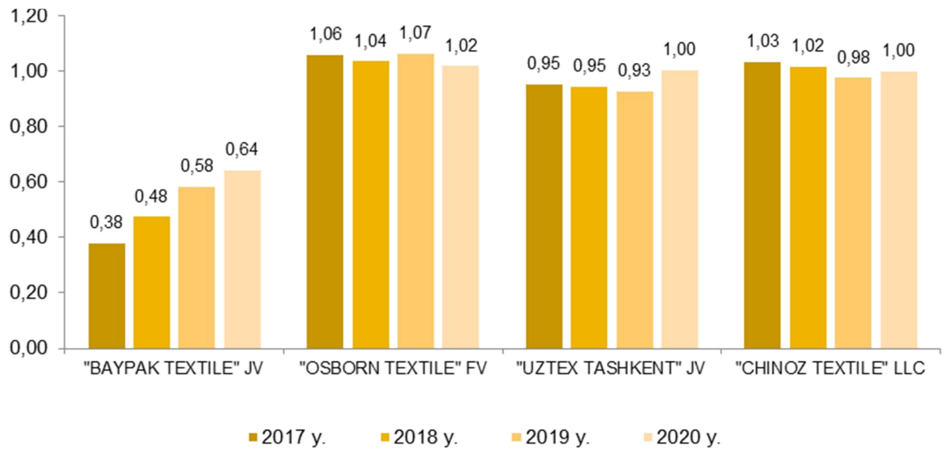


Figure 6 Dynamics of the level of short-term economic stability of textile enterprises

The analysis of the return on assets ratio of enterprises shows that in the enterprises of the textile industry under analysis, this figure was at different levels in different years. In particular, the return on assets is the analysis of the effective use of assets in the enterprise or interprets the financial result obtained from invested capital and is determined by the ratio of net profit to the average annual value of assets.

In particular, during the analyzed years, the return on assets is high in “BAYPAK TEXTILE” JV (2017-2020) and "OSBORN TEXTILE" FV (Figure 7).

In particular, in 2017, the assets of "BAYPAK TEXTILE" JV turned 7.2 times a year, but due to the high exchange rate differences (6.1 billion UZS); the return on assets of the company fell sharply to 0.10. In the remaining years, the turnover of assets decreased, but was much higher than in other enterprises and fluctuated in the range of 3.8-5.4 times in the analyzed years. Also, in the years analyzed at "OSBORN TEXTILE" FV, it fluctuated between 2.2 and 3.0 times.

In this case, in the "UZTEX TASHKENT" JV oscillated only 0.9-1.7 times, and in the "CHINOZ TEXTILE" LLC - 1.2-2.3 times. These enterprises also had high levels of production, operating costs and exchange rate differences. These factors are the basis for the negative return on assets in the textile industry enterprises under analysis.

However, in 2020 only, due to the proposal of “CHINOZ TEXTILE” LLC to develop a monetary policy for the timely payment of raw materials received in foreign currency, the company's "exchange rate difference costs" decreased by 26.9% and the economic potential of the company was 394.6. mil. UZS. Also, as a result of the proposal to accelerate the turnover of receivables, i.e. a letter to the tax authorities to collect tax debts from debtors and the decision of the Economic Court, the overdue receivables of “CHINOZ TEXTILE” LLC decreased by 10.2% and the economic potential of the enterprise 2 294.3 mil. UZS.

“UZTEX TASHKENT” JV in 2017 compared to the previous year, due to the proposal to develop a monetary policy for the timely payment of raw materials received in foreign currency, the "exchange rate difference costs" decreased by 22.4% and the economic potential of the enterprise amounted to 1 167.5 mil. UZS.

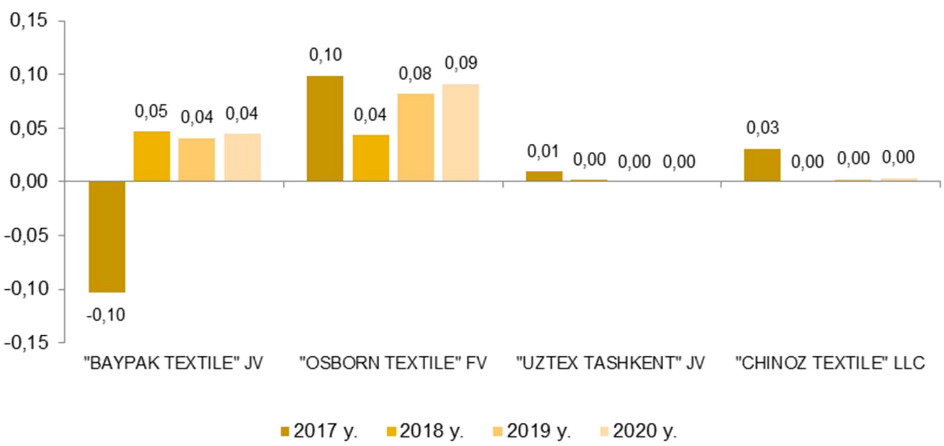


Figure 7 Dynamics of asset return ratio of textile enterprises

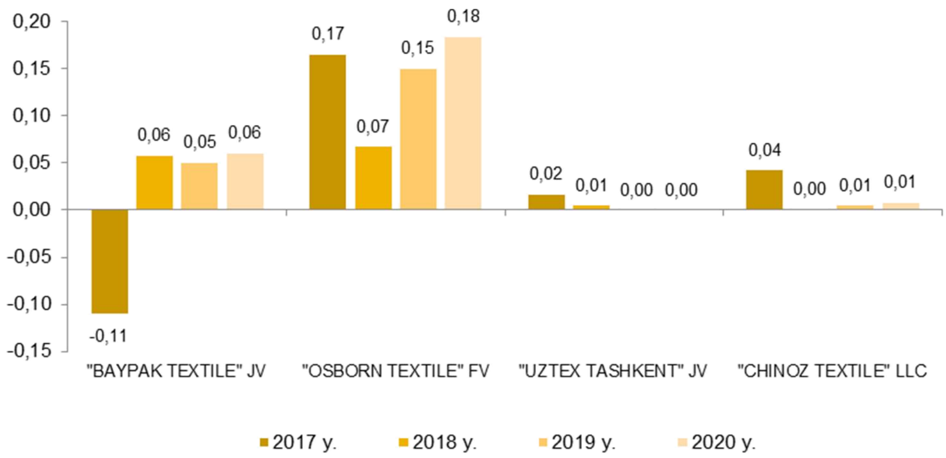


Figure 8 Dynamics of long-term asset return ratio of textile enterprises

2. *Coefficient of return on long-term assets of enterprises of the textile industry*

The long-term assets of the analyzed textile enterprises were as follows: in 2020, fixed assets (1.4%) and capital investments (98.6%) in “BAYPAK TEXTILE” JV, fixed assets in "OSBORN TEXTILE" FV (92,7%), equipment and devices (2.4%) and capital investments (4.9%), “UZTEX TASHKENT” JV fixed assets (96.2%), long-term receivables (3.6%) and capital investments (0.02%), “CHINOZ TEXTILE” LLC fixed assets (100%). In general, the long-term asset return ratio of the textile enterprises under analysis is directly related to the profit received. In this regard, in the analyzed years, “BAYPAK TEXTILE” JV and “OSBORN TEXTILE” FV also had a high rate of return on long-term assets due to higher profits than other enterprises (Figure 8). Also, taking into account the fact that 71.4% of fixed assets of "BAYPAK TEXTILE" JV are obsolete, as a result of the implementation of the proposal to develop a "policy of modernization of the enterprise" to update them, the economic potential of the enterprise in 2020 increased by 16.5%. The low return on long-term assets of “UZTEX TASHKENT” JV and “CHINOZ TEXTILE” LLC is explained by a sharp decline in profits due to high production, operating costs and exchange rate differences. In addition, new fixed assets purchased by enterprises for the purpose of modernization of production and its high price have also affected the return on long-term assets, and this is not a negative indicator.

Based on the results of the above indicators, we will assess the level of long-term economic stability of textile enterprises. The calculations are made on the principle of the ratio of the actual state of the absolute indicators to the forecast indicators, which is the basis for the coefficients being analyzed. From the results of the calculations it can be concluded that during the analyzed years, only the level of long-term economic potential of "OSBORN TEXTILE" FV was high and fluctuated between 0.66 and 1.06. It is usually sought by investors as an opportunity to make long-term profits by investing in businesses. In this regard, in our opinion, the level of long-term economic potential of "OSBORN TEXTILE" FV may be of interest to investors (Figure 9).

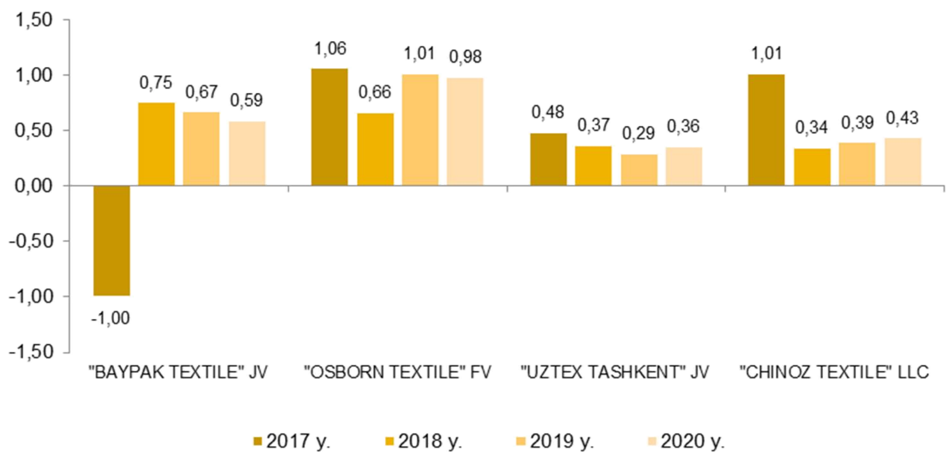


Figure 9 Dynamics of the level of long-term economic stability of enterprises in the textile industry

During the analyzed years, the level of long-term economic potential of other enterprises fluctuated, and in recent years there has been a moderate growth trend in "UZTEX TASHKENT" JV and "CHINOZ TEXTILE" LLC. The main reason for the low level of long-term economic potential in all textile enterprises, except for "OSBORN TEXTILE" FV, is the slow turnover of assets and the high level of production, operating costs and exchange rate differences.

5 CONCLUSIONS

It is known from world practice that any state seeks to ensure sustainable economic growth in the country by ensuring the economic security of enterprises in its economy and improving the living standards of the population. Despite the urgency of security issues, the economic security of enterprises and the system of its evaluation indicators are not sufficiently studied, and the extent to which its level meets modern requirements remains one of the most pressing issues. It is known that the essence of the level of economic security at the micro level is determined by appropriate criteria and indicators. The set of economic security criteria and their constituent indicators should be as accurate as possible to reflect the activities of the entity under study, all components that affect its economic situation, as well as to identify appropriate threats to economic security. Criteria for assessing economic security may include: the state of resource potential and its development potential, the efficient use of resources, capital, labor, the competitiveness of the economy, the ability to withstand external threats, social stability and the ability to resolve social conflicts.

In summary, the level of economic potential of the analyzed textile industry enterprises varies from year to year and is mainly influenced by the growth or decrease of net profit of enterprises, the amount of receivables and payables, slow turnover of assets, production, operating costs and exchange rate differences the amount is high.

In this regard, the development and implementation of modern methods, mechanisms and supports to increase the economic potential of textile enterprises in the future will create the basis for achieving the established economic efficiency.

6 REFERENCES

1. Gereffi G.: International trade and industrial upgrading in the apparel commodity chain, Journal of International Economics 48(1), 1999, pp. 37-70, https://doi.org/10.1016/S0022-1996(98)00075-0
2. Heymann E.: Textile and clothing industry: Innovation and internationalisation as success factors, Deutsche Bank Research, 2011. July 13, 12 p.
3. Tokatli N., Kizilgün Ö.: From manufacturing garments for ready-to-wear to designing collections for fast fashion: Evidence from Turkey, Environment and Planning A: Economy and Space 41(1), pp.146-162, https://doi.org/10.1068/a4081
4. Zhang Y., Wang T.: Profitability and productivity of the Chinese textile industry, China & World Economy 18(5), 2010, pp. 1-21, http://dx.doi.org/10.1111/j.1749-124X.2010.01209.x
5. Senchagov V.K. (Ed.): Russia's Economic Security. The General Course: A Textbook, 2005, 896 p. (in Russian)
6. Gaponenko V.F., Bespalko A.L., Vlaskov A.S.: Economic Security of Enterprises, Approaches and Principles, Izdatel'stvo «Os'-89», 2007, 208 p. (in Russian)
7. Goncharenko L.P.: The process of ensuring the economic security of the enterprise, Directory of the Economist 12, 2004, pp. 31-36 (in Russian)
8. Glumov, A., Kiselitsa P.: Formation of economic security of an enterprise, Academic Bulletin 4(26), 2013, pp. 85-90 (in Russian)
9. Ivanova L.K. Economic security of the enterprise, Bulletin of the Ufa State Aviation Technical University 17, 7(60), 2013, pp.30-33 (in Russian)
10. Manokhina N.V., Popov M.V., Kolyadin N.P., Zhadan I.E.: Economic security: Tutorial, INFRA-M, Moscow, 2014, 320p. (in Russian)
11. Bulanov S.Y. Socio-economic threats to the economic security of Russia and the European experience of their prevention, Yuto-Vostok-Service, Moscow, 2007, 92 p. (in Russian)
12. Glazyev S.Yu.: Economic security, Political encyclopedia, Moscow, 1999 (in Russian)
13. Shultz V.L., Tsyganov V.V., Idrisov R.F., Terekhova N.N.: Security of socio-economic systems, Center for Security Studies at the Russian Academy of Sciences, Moscow: Nauka, 2009, 272 p. (in Russian)
14. Olejnykova E. (Ed.): Fundamentals of Economic Security (State, Region, Enterprise, Personality): A Training Manual, ZAO "Byznes-shkola "YntelSyntez", Moscow, 288 p. (in Russian)
15. Ermolaev D.V.: Components of the economic security of an enterprise, Scientific notes of the Orlov State University. Series: Humanities and Social Sciences No. 4, 2012, pp.15-17 (in Russian)
16. Belkin D.V.: Basic approaches to the study of the economic security of enterprises, Vector of Science of Tolyatinsky State University, No. 4, 2011, pp. 183-186 (in Russian)
17. Krasnoshchek A.A.: Some aspects of analysis and evaluation of economic security, Bulletin of the Siberian State Aerospace University named after academician M.F. Reshetnev No. 3, 2011, pp. 214-218 (in Russian)
18. Blank I.L. Financial security management of the enterprise, 2nd ed., Elga, 2009, 776 p. (in Russian)
19. Abdukarimov B.A., et al.: Enterprise Economics, Textbook, Chapter 12, M.K. Pardaev (Ed.), Science, 2005 (in Russian)

20. Tursunov B.O.: Methodology for assessment the efficiency of production capacities management at textile enterprises, Vlakna a textil (Fibres and Textiles) 26(2), 2019, pp. 74-81, https://doi.org/10.5281/zenodo.3756262
21. Tursunov B.O.: Mechanism for determining optimal management of use of production capacity at the textile enterprises, Vlakna a textil (Fibres and Textiles) 27(1), 2020, pp. 99-106, https://doi.org/10.5281/zenodo.3787291
22. Burkhanov A.U.: Assessment of financial security of investment funds, Journal of Advanced Research in Dynamical and Control Systems 12(5), 2020, pp. 293-300, https://doi.org/10.5373/JARDCS/V12I5/20201717
23. Burkhanov A.U., Tursunov B.O.: Main indicators of textile enterprises` financial security assessment, Vlakna a textil (Fibres and Textiles) 27(3), 2020, pp. 35-40, http://vat.ft.tul.cz/Archive/VaT_2020_3.html
24. Grishchenko, O. V. Analysis and diagnostics of financial and economic activities of the enterprise: textbook, Taganrog: Publishing house of TRTU, 2000, 112 p. (in Russian)
25. Ershova I.V.: Enterprise property and finance: legal regulation, Educational and practical guide, 1999, 397 p. (in Russian)
26. Efimova O.V.: Financial analysis: modern tools for making economic decisions, Omega-L, 2009, 350 p. (in Russian)
27. Zhigunova O.A.: Theory and methodology of analysis and forecasting of the economic potential of an enterprise, monograph, Publishing House "Finance and Credit", 2010, 140 p. (in Russian)
28. Morozova L.E., Bortnik O.A., Kravchuk I.S.: Expert methods and technologies of comprehensive evaluation of economic and innovative potential of enterprises, educational contribution, Moscow, 2009, 81 p. (in Russian)
29. Stepanova S.M., Rogozhina N.N.: Management of the economic potential of a textile enterprise, Technology of the textile industry 332(3), 2011, pp. 7-12 (in Russian)

DEVELOPMENT OF THE ELASTIC LEATHER MATERIALS PRODUCTION TECHNOLOGY

Anatolii Danylkovych[1], Olga Sanginova[2], Viktor Lishchuk[1] and Serhii Bondarenko[2]

[1]*Kyiv National University of Technologies and Design, Nemirivicha-Danchenka Str. 2, Kyiv 01011*
[2]*Igor Sikorsky Kyiv Polytechnic Institute, Peremohy ave. 37, Kyiv 03056*
ag101@ukr.net; sanginova@xtf.kpi.ua

Abstract: *The filling-fatliquoring technology of chrome tanned semi-processed leather at the production of elastic leather materials from the raw bull hides with the use of the optimized fatliquor composition is developed. The influence of the fatliquor composition on the physical and chemical properties of elastic leather material is studied. The formula composition was optimized using the global criterion method, which allowed to reduce the problem of multicriteria optimization to single-criteria. A D-optimal plan is designed and implemented by the modified McLean-Anderson method and an adequate mathematical model of the filling-fatliquoring process is obtained. The main parameters of optimization of the constructed model were: yield of leather material, its strength limit and stiffness. A computing module was developed in Visual Basic for Application to automate the calculation; the module allows to determine the optimal process parameters and can be used to optimize similar technological processes. The optimised fatliquor composition provides highly elastic properties of leather material, which in terms of technological properties surpasses the material formed by production technology, respectively, elongation at a stress of 9.81 MPa greater by 21.0% and lower stiffness by 27.0%. A significant increase in the yield of the obtained material ensures the efficient use of raw hides and meets the requirements of DSTU 3115-95 "Garment leather. General technical conditions". The industrial testing results of the developed filling-fatliquoring processes suggest their effective use in new and improved technologies of elastic leather materials production from other types of raw hides and skins.*

Keywords: *semi-finished leather, filling-fatliquoring technology, elastic leather material, fatliquor composition, McLean-Anderson method, optimization, global criterion method.*

1 INTRODUCTION

Widening the variety of elastic leather materials requires the development of innovative technologies through the gradual improvement of chemical reagents or their compositions using new environmentally friendly materials [1, 2]. As a result of structural transformations in the filling and fatliquoring processes in the interaction of active chemical reagents with microfibrillar structural elements of the collagen is their dispersion and increase the mobility of the whole structure. It is essential to stabilize the collagen structure at the filling-fatliquoring stage. Collagen structure stability should be maintained after finishing drying and wetting processes and after processing stages of semi-processed leather products. Maintaining the above-mentioned effects is important for the next technological stages such as vacuum drying, pressing and others. At the same time, when improving a particular technological process, special attention should be paid to minimize the technogenic impact of both waste solutions and manufactured material on the environment [2]. In this regard, the issue of computer optimization of the composition and their effective use at all stages of the technological cycle of leather materials in the development of new technologies or the improvement of existing technologies is essential.

When filling and fatliquoring semi-processed leather materials, a wide range of chemical reagents and their composition of Ukrainian and imported production is suggested. Specifically, to increase the elasticity of leather for garment, the authors of [3] recommend the use of modified palm oil. For the same purpose, the company "TFL" recommends a plasticizing composition based on lecithin "Coripol ALF" for the manufacture of elastic leather materials [4]. Also, high stability of properties is provided, light and heat resistance of the received natural material increases.

The use of highly dispersed minerals, mainly in a modified form [5, 6] is a very promising direction in the process of filling in leather materials production. The increase of physical and mechanical properties and volume yield of leather materials when using modified montmorillonite is shown. The authors of [7] consider silica nanoparticles to be an effective filler of semi-processed leather products due to their high colloid-chemical properties. According to [8], the use of silica nanoparticles increases the physical and mechanical properties of leather, its ageing resistance and resistance to environmental effects. Modification of silica nanoparticles with polymethacrylic acid made it possible to use it also in the tanning process. Moreover, the colored silica nanoparticles are recommended by Ramalingam and co-authors [9] to be used to obtain a stable skin color. When filling the semi-processed leather product [10], natural aluminosilicate modified with acrylic polymer was used. Due to the effective compatibility of the modified highly dispersed montmorillonite with the collagen fibers [11], the process of structuring and filling-plasticization of the leather material takes place simultaneously. The obtained leather materials were characterized by increased strength, softness and volume yield. To determine the effect of synthetic polymers and plant extracts on the properties of white skins, a fluorocarbon compound was used [12]. The highest effect is achieved using tannins and a dispersing agent Inditan RS.

To increase the elastic properties of leather materials, fatliquoring reagents are added to the filling compositions. Thus, Manich and co-workers [13] study the impact of fatliquors based on triglycerides of colza oil and fish oil on the mechanism of water diffusion into the structure of the treated semi-processed product and its properties. Different aspects of sorption capacity in a semi-processed leather product depending on humidity are established. Thus, the vast majority of the selected papers are mainly empirical, in which the effective use of chemical reagents and compositions requires additional scientific research and optimization of their use in elastic leather materials production.

In this study, the development of the filling-fatliquoring process technology in elastic leather materials production is carried out by simulating the optimal composition of reagents. In the furtherance of this aim, the following problems are solved: filling and fatliquoring process conditions determination in the production technology of elastic leather materials; designing of experiments by the McLean-Anderson method; obtaining an adequate mathematical model of fatliquoring composition to technological properties; determining the optimal fatliquoring composition; testing of the developed technology in the field operating conditions.

2 EXPERIMENTAL

2.1 Materials and methods

The research object is the optimization process of the filling and fatliquoring composition and its effective use in the formation of highly elastic leather materials. For the study, a semi-processed product from the scalp area of the wet-salted and chromium tanned skins with a welding temperature of 107°C after splitting to a thickness of 1.4 mm was used. To optimize the composition are completed groups of samples of 5 pcs size 13×20 cm. The samples were prepared by the method of asymmetric fringe [14]. The control group of samples was processed according to the current technology [15].

The process of filling the semi-processed leather product is carried out after its neutralization [16] using reagents: acrylic polymer Retanal RCN-40 company "Cromogenia Units, S.A." (Spain), synthetic tanning agent Relugan D from BASF (Germany) and quebracho extract (China).

The following reagents were used to carry out the fatliquoring process:

- montmorillonite 85 % $(OH)_4Si_8Al_4O_{20}\cdot{}_nH_2O$ [14] modified with 5% sodium sulfite (x_1);
- technical cattle fat of light brown color with acid value of 51 mg of KOH/g, iodine value of 67 g of iodine/100 g of fat, and freezing point 13°C (x_2);
- unrefined sunflower oil with acid value of 6.0 mg of KOH/g, iodine value of 143 g of iodine/100 g of oil (x_3);
- nonionic surfactant SPK-50 TU 2488-014-22284955-99 / sodium alkylsulfonate $R\text{-}SO_2ONa$ C11–C18 TU 6-01-5763450-10 in the ratio 1:2 (x_4). The mass fraction of the basic substance in sodium alkylsulfonate is not less than 60%, and the pH of 1% aqueous solution is 8.1.

The effect of the fatliquoring composition on the process of forming the leather material is determined by the physico-chemical and technological properties of the obtained leather according to the methods [14]. Mineral substance is determined by the weight method by oxidizing the samples in air in porcelain crucibles at a temperature not exceeding 600°C until a constant mass is reached. The content of chromium compounds is determined by the iodometric titration and is expressed as a mass fraction of Cr_2O_3. A mixture of carbon tetrachloride and trichlorethylene in a ratio of 1:1 is used to establish substances that are extracted with organic solvents.

Physical and mechanical properties of the obtained material are determined after their preliminary conditioning at 20±2°C and humidity of 65±5% on the universal testing machine RT-250M (RF) at a deformation rate of 90 mm.min^{-1}. The hardness of leather is tested on the device PZhU-12M (RF), density - by pycnometric method. Adhesion of the coating is defined by using an 18% solution of polymethylacrylamide in alcohol and toluene 1:9. The leather area is measured on a Svit 07484/P1 machine (Czech Republic) after drying and conditioning processes.

2.2 A mathematical model development

All groups of samples were washed simultaneously, neutralized with a mixture of formate and sodium bicarbonate in a ratio of 1:1 to the pH 5.8-6.0 of the semi-processed product in a wooden drum with a volume of 18 dm^3 at a ratio of working solution: semi-processed product equal to 1:1 with liquid ratio (LR) is 1.0 at a temperature of 40-42°C and constant rotation at a speed of 18-20 min^{-1} for 60 min. After 10 min of washing, the semi-processed product is treated for 80 min with a filling composition with the consumption of ingredients, respectively, wt.% planed semi-processed product: acrylic polymer Retanal RCN-40, synthetic tanning agent Relugan D and Quebracho extract - 3, 5, 6. For fatliquoring, the samples are sorted into subgroups.

Based on previous studies, the variation limits of the fatliquoring composition ingredients are set (Table 1).

Table 1 Variation limits of the fatliquoring composition ingredients x_i

Ingredient number [x_i]	Constraints of the composition ingredients	
	low limit a_i	***upper limit b_i***
1	0.14	0.23
2	0.25	0.40
3	0.33	0.50
4	0.06	0.14

Note. Variation limits of the composition ingredients:

$$0 \leq a_i \leq x_i \leq b_i \leq 1 \quad (i = 1, 2,.., k) \qquad (1)$$

It should be noted that the following rationing condition should be maintained:

$$\sum_{i=1}^{k} x_i = 1 \qquad (2)$$

The effectiveness of the fatliquoring composition on the technological properties of the leather material is evaluated by the following variables: y_1 – the yield of the area of the leather material to the control group of samples [%]; y_2 – leather material strength limit [MPa]; y_3 – stiffness [cN].

According to the McLean-Anderson algorithm [17], 40 theoretical points were selected to obtain a plan for the experiment. To establish the experimental points, all theoretical points are sequentially sorted by the D-optimality criterion:

$$\det|D| \rightarrow \min \qquad (3)$$

where: $D=(F^T.F)^{-1}$ – dispersion matrix of the current plan; F – the plan of experiment matrix X obtained by the type of mathematical mode $\tilde{f}^T(\bar{x})$ of size n x l; l – the number of the model coefficients; n – number of selected points; T – matrix transposition operation.

In this paper, for the synthesis of the optimal plan of the experiment, all possible combinations of theoretical points are obtained, from which the best 10 are selected under condition (3).

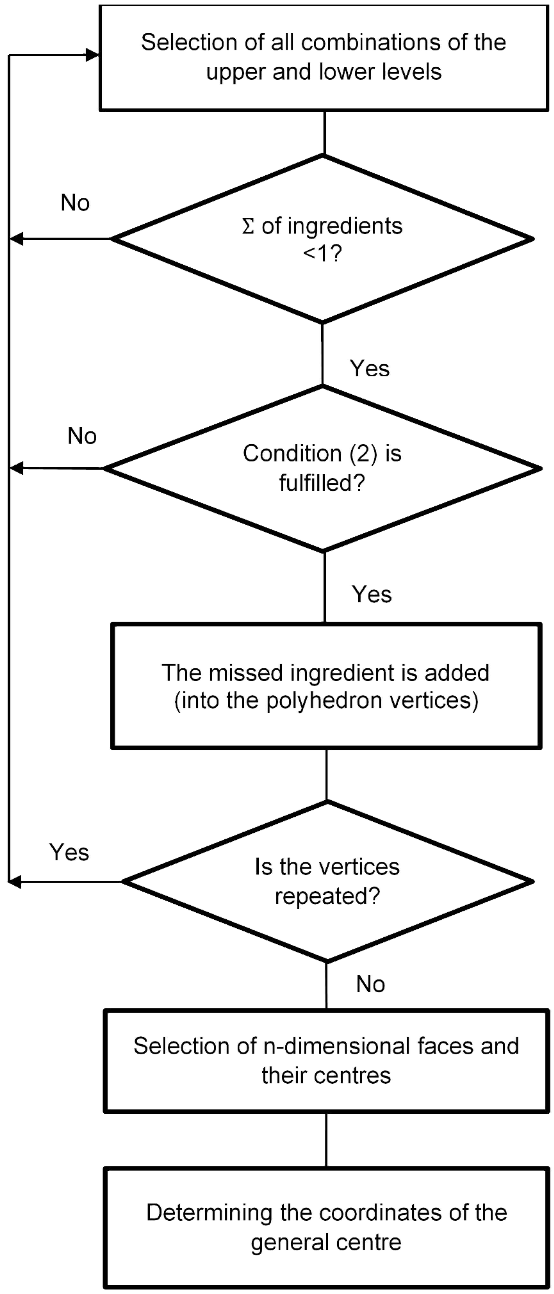


Figure 1 Experimental point selection algorithm by the modified McLean-Anderson method

According to the algorithm shown in Figure 1, the procedure for obtaining the optimal plan is as follows:

- for each ingredient of the composition, all possible combinations of lower and upper levels included in condition (1) are selected;
- from all combinations of ingredients, those are selected in which the sum of ingredients is less than 1 (according to condition 2) and the missed ingredient is added to them, but only if condition (2) is fulfilled. In this case, the combination with the added ingredient that also satisfies condition (1) is the coordinate of the vertices of the desired polyhedron;

- the condition for vertex repeatability is checked and repeated vertices are omitted; the dimension of the obtained polyhedron is always equal to k-1;
- the n-dimensional polyhedron faces are selected and the coordinates of the centres of all selected n-dimensional polyhedron faces are determined as the average values of the vertices coordinates that form the corresponding face;
- the coordinates of the general centre of a polyhedron are determined as the average value of the coordinates of all vertices of this polyhedron.

The presented algorithm is the basis of a software module implemented in the Visual Basic for Application (VBA). The obtained plan of the optimal experiment of the semi-processed product fatliquoring in a limited area of the simplex using the ingredient restrictions (Table 1) is shown in Table 2.

The fatliquoring process of the filled semi-processed product is carried out using a fatliquoring composition at a temperature of 52-55°C at LR 1.2 in a 10 dm^3 glass drum with constant rotation at a speed of 18-20 min^{-1}. The fatliquoring composition [18] is dosed into the drum according to the experimental point with a consumption of 7% by weight of the splitted semi-processed product at pH 8. After 40 min of rotation, alum in the amount of 04-0.5% and sodium formate in the amount of 0.3-0.4% is added to the process solution. Stirring is continued for another 20 min. The treatment is completed at pH 4.2. Further drying and wetting operations of the semi-processed product are performed according to the current technology. The defined properties of the filled-fat semi-processed product are shown in Table 3.

The coefficients of the four-component mathematical model of the fatliquoring composition are determined by the method of least squares in matrix form

$$B = (X^T X)^{-1}.XT^Y$$

where: B – vector of required coefficients; Y – vector-column of the dependent variables observed in the experiments.

Based on these experiments, the mathematical model is obtained for the above mentioned three technological indicators of the filled and fatliquored semi-processed product depending on the fatliquoring composition:

$$\begin{aligned} y_1 &= -180.197x_1 - 303.613x_2 - 341.419x_3 - 160.131x_4 - \\ &- 3.167x_1x_2 + 1.828x_1x_3 + 0.175x_1x_4 - \\ &- 0.444x_2x_3 + 0.743x_2x_4 - 0.1758x_3x_4 \\ y_2 &= -40.706x_1 - 68.008x_2 - 75.616x_3 - 35.966x_4 + \\ &+ 1.723x_1x_2 + 1.016x_1x_3 + 0.552x_1x_4 - \\ &- 0.161x_2x_3 + 1.152x_2x_4 + 0.613x_3x_4 \\ y_3 &= -41.911x_1 - 68.383x_2 - 78.833x_3 - 36.929x_4 - \\ &- 3.878x_1x_2 - 2.477x_1x_3 + 0.316x_1x_4 - \\ &- 0.557x_2x_3 - 1.51x_2x_4 - 0.2x_3x_4 \end{aligned} \quad (4)$$

To perform calculations on the obtained model, the ingredients are coded as follows:

$$\bar{x}_i = \frac{x_i - x_{0i}}{dx_i}, \; x_{0i} = \frac{a_i - b_i}{2}$$

where: a_i, b_i – the limits of the composition ingredients given in Table 1.

Experimental and statistical goodness of fit of the regression equations of the mathematical model by comparing the calculated values of the Fisher test with tabular at a p-value of 0.95 proved that the model adequately describes the studied process.

2.3 Optimization of the fatliquoring composition by the global criterion method

Determining the optimal fatliquoring composition using the obtained mathematical model based on the global criterion method. According to [17, 19], the method is used when it is possible to select one of the criteria as the main one. This method is quite simple and often used in solving technical and economic problems of optimization. In this case, the initial variables are subject to restrictions (Table 4), corresponding to the worst and best values of technological indicators.

Table 2 Plan of experiment

Ingredient	The composition formulation at the experimental point									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
x_1	0.23	0.14	0.14	0.23	0.23	0.14	0.14	0.23	0.23	0.14
x_2	0.30	0.39	0.30	0.38	0.25	0.25	0.40	0.25	0.28	0.35
x_3	0.33	0.33	0.50	0.33	0.38	0.47	0.40	0.46	0.36	0.45
x_4	0.14	0.14	0.06	0.06	0.14	0.14	0.06	0.06	0.14	0.06

Table 3 Technological properties of filled and fatliquored semi-processed leather product

Technological indicator	The value of technological properties of semi-processed leather products									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
y_1	101.5	100	98.7	100.2	102	95.6	100.8	99.5	98.3	100.4
y_2	24.5	21.3	18.4	22	24.8	18.9	24	22.5	21.2	22.5
y_3	21.2	25	27.4	24.5	21.5	29.7	22.6	23.2	25.6	23

Table 4 Technological indicators constraints of the filled-fatliquored semi-processed product

Indicator number y_i	Technological indicators constraints	
	min	***max***
1	102.0	103.0
2	21.0	23.0
3	21.2	25.0

Based on the economic and technological requirements for the technological process, the initial values of y_1 and y_2 should be maximized, and the value of y_3 should be minimized. The optimization of the composition for fattening a filled semi-processed leather product as a task of multicriteria optimization is estimated by the vector function of the form:

$$f(\overline{x}) = (f_1(\overline{x}), f_2(\overline{x}), \ldots f_k(\overline{x})) \quad (5)$$

components of which ($f(\overline{x})$ (i=1,2,…,k) are given functions of the vector $\overline{x} = (x_1, x_2, \ldots, x_n)$.

Constraints (Table 1) are imposed on variables x_i (i= 1,2,…,n). In this case, the vector $\overline{x}$ belongs to the set of possible values. It is necessary to find a point $\overline{x}^* \in X$ that will provide the optimal value of the functions $f_1(\overline{x}), f_2(\overline{x}), \ldots f_k(\overline{x})$.

One of the approaches to finding an optimal solution is to reduce it to the single-objective optimization problem. Therefore, according to the chosen global criterion method, one of the considered criteria $f_1(\overline{x})$ is chosen as the global one, and the other objective functions are replaced by constraints. Next, the single-objective optimization problem for the maximum (minimum) of the function $f_1(\overline{x})$ is solved, provided that other criteria will be greater than or equal to the specified control values of G_i:

$$\begin{aligned} &f_1(\overline{x}) \to \max \\ &f_i \geq G_i, \quad i = 2,3,\ldots k \end{aligned} \quad (6)$$

In this case, all values $\overline{x}$ must belong to an admissible set.

When solving the problem of finding the optimal fatliquoring composition, the global criterion for expert evaluation is the function y_1, which determines the yield of the area of leather material to the extruded semi-processed product [%], for which the maximization problem is solved.

To solve the above-mentioned optimization problem, a computational module in the VBA has been developed, which implements the global criterion method. The number of inputs and outputs of the applied model, limit values of parameters, coefficients of the corresponding equations of the mathematical model are used as initial data for the calculation of optimal fatliquoring composition.

The main window of the computing module with the entered initial data and the obtained results for the optimal fatliquoring composition are shown in Figure 2.

To perform calculations, the number of inputs and outputs (n and k respectively) in the appropriate cells should be indicated; also, the coefficients of the equations of the mathematical model in the pre-prepared cells for y_1, y_2, y_3 both with the limits of variables x_i, y_i should be entered.

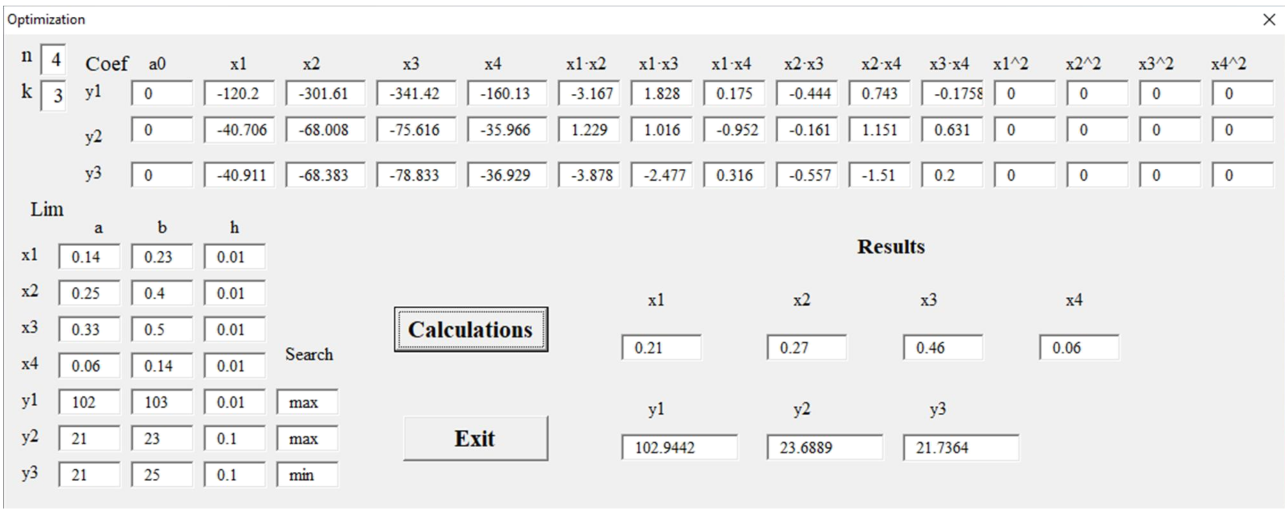


Figure 2 The main window of the computing module for calculating the optimal fatliquoring composition

After entering the required data and clicking the Calculations button, the results of calculations of the optimal composition will be displayed in the corresponding windows in the Results area. Pressing the Exit button ends the work with the program.

Thus, the optimal values of the fatliquoring composition ingredients for the technology of forming semi-processed elastic leather product were found. They are, wt.%: modified montmorillonite - 21, beef fat - 27, sunflower oil - 46, non-ionic surfactant SPK-50 - 6. The following technological indicators are achieved: the yield of the leather area to samples of control technology is 102.99%, the strength of leather material is 23.67 MPa and its stiffness 21.74 cN. All the results obtained are met the requirements on the input and output parameters, specified in Tables 1 and 4.

The use of a certain composition at the manufacturing of semi-processed leather products will improve the quality of the elastic leather material.

3 APPROBATION OF THE DEVELOPED TECHNOLOGY

The developed technology of filling and fatliquoring in the production of elastic leather materials was tested with optimal fatliquoring composition in the semi-production conditions of PJSC "Chinbar" (Ukraine). For this purpose, the wet-salted bull hides were used after soaking, deliming and tanning processes in the drum “Vulcan” of the Olcina Group (Spain) with a volume of 21.0 m^3, assembled in two batches by the method of alternating halves of 5 pcs each after splitting to a thickness of 1.4 mm [14]. The obtained semi-processed product was neutralized and filled similarly to test samples in a drum “Doze” (Germany) with a volume of 0.39 m^3.

The optimized fatliquoring composition with a consumption of 7% by weight of the semi-processed leather at pH 8.0 was dosed into the spent filling solution after raising the temperature from 40-42°C to 53-55°C by adding hot water to LR 1.2. The control halves set of the filled semi-processed product were fatliquored according to the current technology [15] using the emulsion of the FOSFOL L-1301 fatliquoring agent from Cromogenia Units, S.A. (Spain). Fixation of reagents in the structure of the semi-processed product was carried out with 10% formic acid with a consumption of 0.5% by weight of the semi-processed product to pH 4.0. Further processing of the fatliquored semi-processed product, including the application of the acrylic coating is performed according to the current technology.

The physical and chemical properties of the obtained leather materials are given in Table 5. The obtained leather materials according to the developed technology are characterized by an increased content of unbound fatty substances and a significant increase in elastic properties. Especially it concerns elongation at 9.81 MPa, skin stiffness and coating adhesion.

The determined physical and chemical properties of the leather obtained by the developed technology indicate a regular distribution of fat substances, which are fixed at the fibrillar level of the semi-processed product. The front layer of the leather has a non-oily surface. A significant increase in the yield of the leather material relative to the control sample is caused by the plasticization effect due to the use of an optimized fatliquoring composition.

Table 5 Physical and chemical properties of elastic leather material

Indicator	Leathers are obtained by the technology	
	Developed	***Proving***
The mass fraction [%] - Cr_2O_3 - mineral substances - substances extracted with organic solvents	 4.2±0.02 6.4±0.06 8.3±0.17	 4.3±0.03 5.6±0.04 7.7±0.15
Tensile strength [MPa]	23.0±1.2	19.3±1.3
Elongation at 9.81 MPa [%]	34.0±1.7	28.0±1.9
Elongation before break [%]	51.0±4	62.0±4.7
Stiffness [cN]	23.0±0.9	31.5±1.6
Coating adhesion [Н/м] - to dry leather - to wet leather	 390±2.5 196±3.9	 193±3.6 98±4.1
Density [g/cm^3]	0.616±0.02	0.659±0.03
Yield of leather material [%]	104.9 ±3.0	100.0 ±3.0

Note. The mass fraction of leather components are given in terms of solid matter.

4 CONCLUSIONS

The fatliquoring composition for chrome-tanned leather materials processing has been optimized. The optimization was carried out by the method of global criteria, which made it possible to reduce the problem of multicriteria optimization to the problem of single-criteria. An adequate mathematical model of the filling- fatliquoring process was obtained using the D-optimal plan, which was developed by the modified McLean-Anderson method. The optimal process parameters are calculated using the developed computational module in the Visual Basic for Application, which can be used to optimize similar technological processes.

A filling-fatliquoring technology has been developed to obtain a highly elastic leather material, which, in terms of technological properties, prevails over the material obtained by the existing technology and meets the requirements of DSTU 3115-95 "Sewing leather. General technical conditions". An improvement was achieved in the following parameters: the elongation at a stress of 9.81 MPa was 21.0% higher and the stiffness was 27.0% lower. The industrial test results of the developed filling-fatliquoring technology provide the basis for their effective use in new and improved technologies for the elastic leather production from other types of skins and hides.

5 REFERENCES

1. Wu J., Zhao L., Liu X., Chen W., Gu H.: Recent progress in cleaner preservation of hides and skins, Journal of Cleaner Production 148, 2017, pp. 158-173, https://doi.org/10.1016/j.jclepro.2017.01.113
2. Saravanabhavan S., Thanikaivelan P., Rao J.R., Nair B.U., Ramasami T.: Reversing the conventional leather processing sequence for cleaner leather production, Environ. Sci. Technol 40, 2006, pp. 1069-1075, https://doi.org/10.1021/es051385u
3. Wang C., Feng S., Wu J.: Preparation of organosilicone modified palm oil fatliquor, J. Amer. Leather Chem. Assoc. 106(5), 2011, pp. 161-169
4. New fatliquor for soft articles from TFL, World Leather 24(2), 2011, pp. 6
5. Bao Y., Ma J., Yan-Li W.: Preparation of acrylic resin/montmorillonite nanocomposite for leather tanning agent, JALCA 104(10), 2009, pp. 352-358
6. Mokrousova O., Volfkovich Yu.: Hide and Skin of Mammals. Structural Properties of Porous Materials and Powders Used in Different Fields of Science and Technology Part III : Chapter 12, Springer London Ltd, 2014, pp. 84-93
7. Ma J., Hu J., Zhang Z., Liu L.: The acrylic resin leather coating agent modified by nano-SiO_2, J. Compos. Mater 40, 2006, pp. 2189-2201, https://doi.org/10.1177%2F0021998306062314
8. Pan H., Li G.-L., Liu R.-Q., Wang S.-X., Wang X.-D.: Preparation, characterization and application of dispersible and spherical nano-SiO_2 copolymer nanocomposite in leather tanning, Appl. Surf. Sci. 426, 2017, pp. 376-385, https://doi.org/10.1016/j.apsusc.2017.07.106
9. Ramalingam S., Sreeram K.J., Raghava Rao J., Unni Nair B.: Organic nanocolorants: self-fixed, optothermal resistive, silica-supported dyes for sustainable dyeing of leather, ACS Sustain. Chem. Eng. 4, 2016, pp. 2706-2714, https://doi.org/10.1021/acssuschemeng.6b00218
10. Essomba Jean Serge, Jaya Prakash Alla, Placide Désiré Belibi Belibi, Ketcha Joseph Mbadcam, Nishter Nishad Fathima: Clay/polymer nanocomposites as filler materials for leather, Journal of Cleaner Production 237(10), 2019, 117837, https://doi.org/10.1016/j.jclepro.2019.117837
11. Bin Lv, Jianjing Gao, Jianzhong Ma, Dang-Ge Gao, Hongdi Wang, Xuewu Han: Nanocomposite based on erucic acid modified montmorillonite/sulfited rapeseed oil: Preparation and application in leather, Applied Clay Science 121, 2016, pp. 36-45, https://doi.org/10.1016/j.clay.2015.12.021
12. Silva V.F.M., Moncada M., Crispim A., Cruz T., Crispim F.: Studies on waterproofing wet-white leather, Leather and Footwear Journal 18(2), 2018, pp. 149-152, https://doi.org/10.24264/lfj.18.2.10
13. Manich A.M., Barenys J., Martínez L., Martí M., Carilla J., Marsal A.: Effect of fatliquoring and finishing on moisture absorption-desorption of leather, Vlákna a textil (Fibres and Textiles) 23(3), 2016, pp. 117-125
14. Danylkovych A.: Practical training on chemistry and technology of leather and fur: 2nd ed., revised and ext. Kyiv: Phoenix, 2006, 340 p. (in Ukrainian)
15. Technological methods of leathers production of various assortments for shoe uppers and shoe linings, haberdashery from cattle and horse skins. Kyiv: JSC Chinbar, 2003, 64 p. (in Ukrainian)
16. Danylkovych A., Romaniuk O.: Formation of hydrophobized leather of special purpose, Vlákna a textil (Fibres and Textiles) 27(2), 2020, pp. 24-31
17. Anderson V.L., McLean R.A.: Design of experiments: a realistic approach, Marcel Dekker, New York, Basel, Hong Kong, 1974, 418 p.
18. Danylkovych A.H., Mokrousova O.R.: Emulsion greasing of the semi-finished product using an emulsion emulsifier. In book: Effective Technologies for Forming Elastic Leather Materials, Kyiv: Phoenix, 2017, p. 228-242 (in Ukrainian)
19. Us S.A., Koriashkina L.S.: Models and methods of decision making, 2nd ed., Dnipro: NTU «DP», 2018, 300 p., http://ir.nmu.org.ua/handle/123456789/153995 (in Ukrainian)

THE EFFECT OF WASHING OPERATIONS ON THE ANTIBACTERIAL TREATMENT OF IHRAM CLOTHING USED IN HAJJ AND UMRAH

Rania Moustafa Kamel Abdulaal Debes

Faculty of Human Sciences and Design, King Abdulaziz University, Jeddah, Saudi Arabia
rdebes@kau.edu.sa

Abstract: *The Ihram is worn in Hajj and Umrah. It's woven with soft different weights and properties, and it also consists of two pieces. Makkah has a hot humid climate, and pilgrims wear Ihrams for a long time, which leads to the accumulation of components of sweat and skin fat due to the impact of the sun's burning and high humidity and dust with the multitude of gatherings, which is a good environment for the bacteria and microorganisms to grow on the Ihram and this affects the public health of the individual and makes it more susceptible to diseases. This research aims to measure the effect of washing operations on the antibacterial treatment of Ihram garments. The results reached showed that treating the Ihram's fabric against bacteria through nanosilver does not negatively affect the feeling of comfort when wearing it, and the ihram's appearance is not affected by the treatment processes. In addition to that, it resists bacteria and types of fungi with a strong degree, but this decreases through the number of washes so that it can be wearable, but the anti-bacterial effect is weakened.*

Keywords: *washing operations, antibacterial treatment, Ihram clothing.*

1 INTRODUCTION

Ihram clothing is popular in local markets throughout the year and achieves a high rate of sales as it is the legal dress for performing Hajj and Umrah rituals in Makkah. It is a soft woven cotton fabric (rings appear on one or both sides of the cloth), always white and consists of two unstitched white sheets. The first covers the lower part of the body (from the navel to the knee and is called Izar) and the second covers the upper part is called Ridaa [1]. Figure 1 shows the two parts of Ihram when it's wrapped up around the body.

Figure1 The upper and lower parts of Ihram clothing

1.1 How to wear Ihram

Ihram clothing is worn directly on the body without any other layers of clothing, so that it is wrapped up around the body and is fixed by a belt. Figure 2 shows the steps of wear the Ihram, three steps for wearing the upper part, and three steps for wearing the lower part.

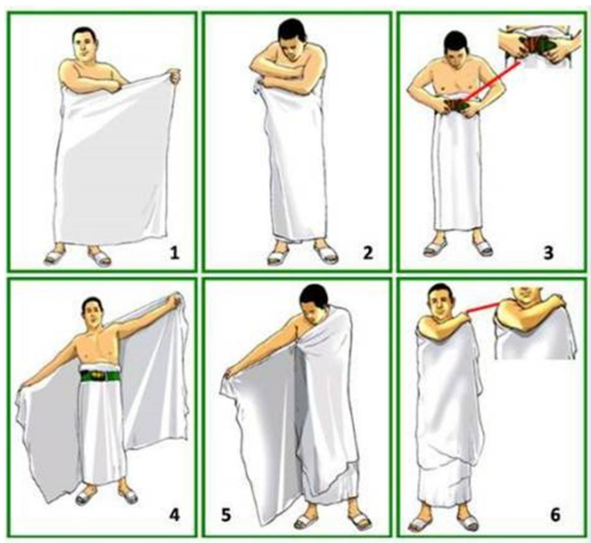


Figure2 How to wear Ihram around the body

If a Muslim wants to wear Ihram for Umrah or Hajj, he is obliged to do several things before that and among these things are his clothes' properties.

It is preferred that the Ihram is a white cotton and it must be free of decorations, manufacturing defects and any holes since it must be characterized by absorbing liquids and having the property of moisture, as they consist of two pieces, the dress and the buttons, of equal length and dimensions.

The Saudi Vision 2030 calls for the present vision of the future with 3 main divisions: a thriving economy, a vibrant society, and an ambitious nation. And its most prominent development goals are to increase the capacity to receive from 8 million to 30 million pilgrims and the Kingdom will work to empower more than 15 million pilgrims and Umrah performers annually [2].

Makkah Al-Mukarramah is located within the Tihama region to the west of the Arabian Peninsula which extends along the Red Sea, about 75 km from its coasts, in a site that is considered one of the most complex areas of geological formations and is dominated by the pattern of very hard rocks. The prevailing geography in this holy city imposed itself on the current climate. Its location in the tropical region, its low elevation above sea level, and its location relatively far from the Red Sea, making its climate a tropical desert in which there is a very hot summer and a warm winter.

1.2 Problems that faces Ihram

The climate of Makkah region, in the presence of massive numbers of pilgrims and Umrah performers, is a fertile climate for the growth of bacteria and fungi. The presence of microorganisms, such as bacteria and fungi, is everywhere around humans, in soil, water and air close to the surface of the earth. They are also found on natural fibers and their proliferation increases according to the surrounding conditions in terms of humidity, and the appropriate temperature for some species. Micro fungi, bacteria, tape bacteria and algae are distinguished by their ability to biodegrade (break down the fibers) and thus lead to the loss of some of the properties of these fibers such as tensile strength and elasticity, or color removal. It is good that, in some cases, the processing materials treated with the surface of the fibers may attack fungi and micro-organisms harmful to the fabric [3].

The consumer should be obliged to wash any material purchased from any sales centers, especially the kinds of cotton that confirmed that they contain a high fungal density which amounted to 1932 fungal colony/cm^2 [4].

Ministry of Health confirmed in its health article (Hajj 1436) that skin diseases are the most common diseases that affect arrivals for Hajj and Umrah due to the high temperature, high humidity and a large number of gatherings.

Preparation against biological activities (bacteria) is the treatment of textile products with substances that prevent the accumulation of various, microorganisms such as bacteria and fungi [4]. It is indicated that recently there has been an increasing demand for textile products treated against bacteria and fungi because of their utmost importance on the health of the consumer, who has become interested in the different and important properties of fabrics.

Several advanced materials have been developed for the bacterial resistance of textiles, such as phenols, halogen, organic metals, quaternary ammonium salts, metal salts, organic mercury compounds, copper compounds, organic zinc and tin compounds, silver salts, each of which has its own properties, as well as the process of providing fibers with cyanide groups. The method of vaccination of acrylonitrile polymers works to prevent them from being attacked by mold bacteria, the need to treat textiles against bacteria as they are the first thing that comes into contact with the human body [5].

The properties of the Ihram fabrics are affected by the difference between the type of fibers used, the height of the pile, the shape, direction, and density of the pile, as well as the need to achieve the properties of comfort, durability, care, appearance, and protection [6]. The researcher saw the importance of measuring the effect of washing operations on the treatment's properties. In addition to the appearance of the Ihram clothing treated against bacteria in an attempt to improve the Hajj environment in response to the points related to Hajj and Umrah in the Kingdom's 2030 vision. Although some researches dealt with treating cotton fabrics against bacteria and that the Ihram clothes are made of cotton fabrics, this is one of the few studies that deals with the Ihram clothes that are worn under special climatic conditions in addition to their direct contact with the body, so there is no insulation between them and the body, and wearing it for a period up to several consecutive days during the Hajj, and one of the few studies that deals which measure the effect of washing on the treatment of Ihram clothes against bacteria

The research was based on the fabrics from which the Ihram garments are made, where the Ihram clothes were used most widely in the local market and treated against bacteria with nanosilver technology, which is accessible to all pilgrims and Umrah performers, and the main goal was to ensure that the treatment with nanofiber technology did not affect the appearance of the Ihram clothes and achieve comfort for pilgrims. In addition, the stability of bacteria resistance with repeated washing was measured.

2 EXPERIMENTAL

<u>Research aims:</u>

- Measuring the effect of antibacterial treatment on the comfort properties of Ihram garments.

- To measure the effect of anti-bacterial treatment on the appearance of Ihram garments.
- Measuring the effect of washing operations on the antibacterial treatment of Ihram garments.

Research importance:

- Linking scientific research with the Ministry of Hajj and serving pilgrims.
- Contribute to raising the efficiency of services provided to pilgrims and Umrah performers, and preserving their health and performance of rituals.
- Contributing to activating the policy of the tenth development plan, which stipulates "Upgrading the level of services for pilgrims, Umrah performers, and visitors."
- Response to the Kingdom of Saudi Arabia's 2030 Vision, which is concerned with serving pilgrims and Umrah performers.

Research methodology:

The research follows the semi-experimental approach in terms of its suitability to study the research's objectives, through used Ihram which is treated against bacteria and making laboratory tests to measure the stability of treatment with washing, as well as measuring the appearance and comfort of the treated fabrics.

Research tools:

- Questionnaire to evaluate the treated Ihram garments.
- Lab data registration form.

Applied study:

The applied study went through steps that help in achieving the research objectives, as follows:

I. Used Ihram clothes, which are made of 100% cotton towelling "terry", and already treated against bacteria. The material used is a common material purchased on the Saudi market and that the antibacterial treatment was performed by the producer.

II. Conducting laboratory tests to measure the effect of washing operations on the treated Ihram clothes according to the household washing specification, this process done in "Bureau Veritas Saudi Arabia Testing Services - Textile" in Jeddah, Saudi Arabia using Standard specification for Dimensional Stability in Washing and Drying (ISO 5077 / BS EN ISO 6330 / ISO 3759 / AATCC 135 / AATCC 150).

III. Comparison between Ihram clothing resistance to bacteria (*Escherichia coli, Staphylococcus aureus*) and resistance to fungi (*Candida albicans, Aspergillus flavus*), before and after the washing process. The tests were done in Microanalytical Center, Faculty of Science, Cairo University, Egypt.

IV. Designing a questionnaire for users of Ihram clothing to evaluate the comfort and appearance of fabrics treated with nano-silver technology that resists bacteria. The questionnaire consisted of two axes; one of them, which was the comfort of the Ihram clothing, consisted of 8 items, as shown in Figure 3 and the other axis was about the appearance of the Ihram clothing and consisted of 7 items as shown in Figure 4. The questionnaire targets men during the Hajj and Umrah season. The questionnaire consists of three options and they are: yes, maybe, no. The questionnaire was distributed to 70 individuals through Hajj and Umrah trips in the Kingdom of Saudi Arabia in the Jeddah region.

3 RESEARCH RESULTS

Through the research tools and applied study steps, a set of results was reached:

3.1 Results related to the effect of treating fabrics with nanosilver technology (anti-bacterial treatment) on Ihram garments

<u>*A: The effect of treating fabrics with anti-bacteria on the comfort of the body*</u>

The following figure shows the opinions of the target group regarding the suitability of the treated fabrics during use, and the degree of feeling the requirements of comfort and function for the wearers of the Ihram clothing. Figure 3 shows the effect of treating fabrics with anti-bacteria on the comfort of body during wearing the Ihram in Umrah.

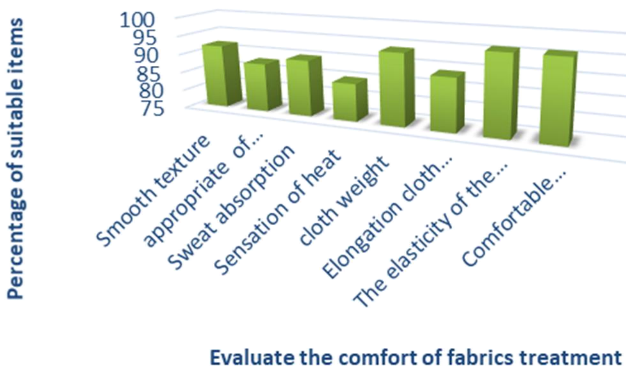


Figure 3 The effect of treating fabric with anti-bacteria on the body comfort

The previous figure shows that all of the percentages were concentrated between 85% and 96%, which indicates the high results of the items related to the feeling of the research sample of pilgrims and Umrah performers with the degree of comfort of the Ihram clothing after being treated with nano-silver technology (treatment against bacteria) so that the last item, which is the feeling of comfort, is generally 96%, which is satisfactory. No negative remarks were recorded on the part of the research sample as well.

***B:** The effect of antibacterial fabric treatment on the appearance of Ihram clothing fabrics*

The treatment procedure may affect the appearance of the fabrics as a result of the effect of the materials involved in the treatment. So the appearance of the fabrics was evaluated by specialists in the field of clothing and textiles, after completing their treatment with nano-silver technology (anti-bacterial treatment), and the following figure shows the results of the evaluation. Figure 4 shows the effect of treating fabrics with anti-bacteria on the fabric's appearance related to consumer opinion during Umrah.

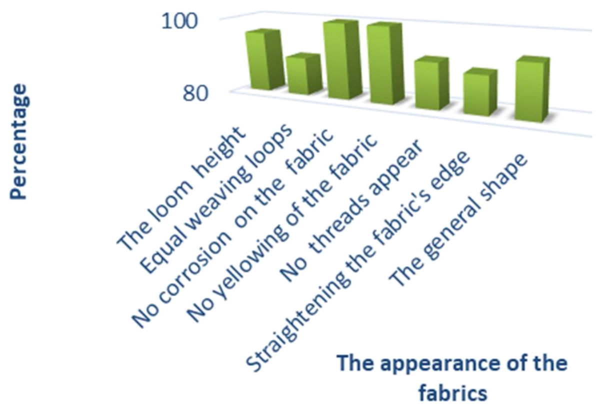


Figure 4 The effect of treating fabric with anti-bacteria on the fabric appearance

The previous figure shows that all of the percentages were concentrated between 90% and 100%, which indicates high results of the items related to the appearance of the fabrics after treating them with nano-silver technology (treated against bacteria), so that the last item, the general form, reached 94%, which is a satisfactory rate. No negative remarks were recorded on the part of the research sample.

Through the previous results related to the comfort and the appearance of the treated fabrics against bacteria, the suitability of the treated fabric was reached and there were no negative results related to the use.

3.2 Results related to the effect of washing operations on the antibacterial treatment of Ihram garment

Biological activity (Sensitivity tests): The antimicrobial activity of the tested samples was determined using a modified Kirby-Bauer disc diffusion method [7]. Isolated colonies of the organisms were tested using disc diffusion method. For the disc diffusion, the zone diameters were measured with the National Committee for Clinical Laboratory Standards [8]. Agar-based methods are simpler and faster than broth-based methods so they can be a good alternative [9, 10]. The tests were carried out before the washing process and after completing 5 washes, and the tests included a group of organisms. Table 1, shows the strains of microorganisms that tested its effect by the washing process, its divide in to two kinds of bacteria and two kinds of fungus.

Table 1 The strain type of microorganisms

Name	Gram reaction	ATCC
Escherichia coli	G-	11775
Staphylococcus aureus	G+	12600
Candida albicans	Fungus	7102
Aspergillus flavus	Fungus	9643

The laboratory results appeared as shown in the following Figures 5-8. The number (1) represents the resistance of the sample against the organism before washing and the number (2) represents the resistance of the sample to the organism after five washes. Figure 5 shows the resistance of the sample against *Aspergillus flavus* (fungus) before washing and after five washes. It was found that the resistance decrease after the fabric washing.

Figure5 The effect of washing on *Aspergillus flavus*

Figure 6 shows the resistance of the sample against *Candida albicans* (fungus) before washing and after five washes. It was found that the fabric still have resistance after the fabric washing.

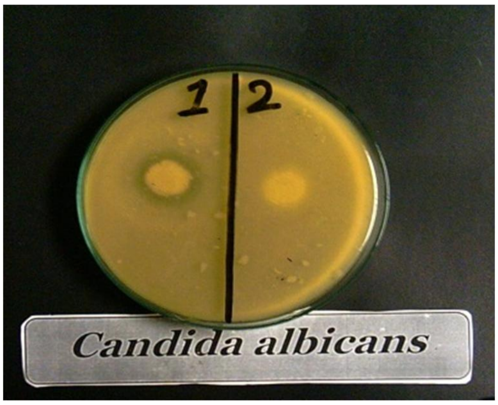


Figure6 The effect of washing on *Candida albicans*

Figure 7 shows the resistance of the sample against Staphylococcus aureus (bacteria) before washing and after five washes. It was found that the fabric still have resistance after the fabric washing but less than sample no. (1) – fabric before washing.

Figure7 The effect of washing on *Staphylococcus aureus*

Figure 8 shows the resistance of the sample against *Escherichia coli* (bacteria) before washing and after five washes. It was found that the fabric still have resistance after the fabric washing but less than sample no.(1) - fabric before washing.

Figure 8 The effect of washing on *Escherichia coli*

Table 2, shows the results of the microbiological analyzes of the resistance of the treated fabric samples against bacteria before washing and after five washes, and the number (1) refers to the samples before washing, while the number (2) refers to the samples after five washes.

4 CONCLUSION

Both tested samples have a resistant and anti-bacterial effect, but the sample (1) before washing is much better than the sample (2) as it has a stronger effect on the types of Gram-positive and Gram-negative bacteria in addition to having a resistive effect against the yeast type *Candida albicans*. For sample 2, which is the fabric after five washes, it was found that it has an anti-bacterial effect, but at a weak rate, and it does not affect the types of fungi or yeasts tested.

The treating the Ihram fabrics against bacteria through nanosilver do not have a negative effect on the feeling of comfort when wearing, and its appearance is not affected by the treatment processes. In addition to that, it resists bacteria and types of fungi with a strong degree, but this has become less through the number of washes so that it can be wearable, but the anti-bacterial effect is weakened

4.1 Recommendations:

- Treating fabrics used in Ihram clothing against other types of microorganisms that didn't exist in this research.
- Increasing areas of use anti-bacterial treatments in fabrics especially in functional clothes.
- Conducting more scientific research that is interested in the fabrics of Ihram clothing and their effect on direct sunlight and high temperatures.

ACKNOWLEDGEMENT: *This Project Was funded by the Deanship of Scientific Research (DSR) at King Abdulaziz University, Jeddah, under grant no. (G: 352-253-1441).The author, therefore, acknowledge with thanks DSR for technical and financial support.*

Table 2 Microbiological analyzes of samples treated against bacteria

Sample	Inhibition zone diameter [mm/1 cm of sample]			
	Bacteria		Fungi	
	Staphylococcus aureus **(G+)**	***Escherichia coli*** **(G-)**	***Candida albicans*** **(fungus)**	***Aspergillus flavus*** **(fungus)**
1 - before washing	29	27	17	0.0
2 - after five washes	12	13	0.0	0.0

5 REFERENCES

1. Abd al-Fattah L.: The possibility of implementing some of the men's Ihram fabrics to match the functional performance, Home Economics, Faculty of Specific Education, Tanta University, 2015 (in Arabic)
2. Ministry of Hajj and Umrah, https://www.haj.gov.sa/ar/News/Details/12374
3. Abu-Nasif G.: Treating the carpets of the Two Holy Mosques to resist dirt and microorganisms and their effect on some properties, PhD thesis, Faculty of Home Economics, King Abdulaziz University, Jeddah, 2011 (in Arabic)
4. Al-Shehri F.: Studies on the fungal flora associated with some textiles in Jeddah, Master thesis, Faculty of Science, King Abdulaziz University, Jeddah, 2004
5. Boryo D.E.A.: The effect of microbes on textile material: A review on the way-out so far, The International Journal of Engineering and Science (IJES) 2(8), 2013, pp. 9-13
6. Al-Andijani N., Eid Y.: Determining the standard for ihram fabrics in light of modern technological variables, published in the Eighteenth Scientific Forum, Faculty of Designs, Umm Al-Qura University, 1439 AH (in Arabic)
7. Bauer A., Kirby W., Sherris C., Turck M.: Antibiotic susceptibility testing by a standardized single disk method, American Journal of Clinical Pathology 45(4), 1966, pp. 493-496
8. Clinical and Laboratory Standards Institute: M07-A9 Methods for dilution antimicrobial susceptibility tests for bacteria that grow aerobically. Approved standard – 9th ed., Clinical and Laboratory Standards Institute, Vol. 32 No. 2, 2012, ISSN 2162-2914 (Electronic)
9. Liebowitz L., Ashbee H., Evans E., Chong Y., Mallatova N., Zaidi M., Gibbs D.:. A two year global evaluation of the susceptibility of *Candida species* to fluconazole by disk diffusion, Diagnostic Microbiology and Infectious Disease 40(1-2), 2001, pp. 27-33, https://doi.org/10.1016/S0732-8893(01)00243-7
10. Matar MJ.,Ostrosky-Zeichner L., Paetznick V.L., Rodriguez J.R., Chen E., Rex J.H.: Correlation between E-test, disk diffusion, and microdilution methods for antifungal susceptibility testing of fluconazole and voriconazole, Antimicrobial Agents and Chemotherapy 47(5), 2003, pp. 1647-1651, https://doi.org/10.1128/AAC.47.5.1647-1651.2003

6 ILLUSTRATIONS

Figure 1: The upper and lower parts of Ihram clothing, https://www.kanbkam.com/sa/en/religion-ihram-clothing-for-men-36872661

Figure 2: How to wear Ihram around the body, http://travelforumrah.co.uk/blog/wp-content/uploads/2017/07/How-Men-Wear-Ihram.jpg

IMPLEMENTATION OF STRATEGIC IMPERATIVES FOR STRENGTHENING THE ECONOMIC SECURITY OF TEXTILE ENTERPRISES THROUGH INTRODUCTION OF AGILE MANAGEMENT SYSTEM

Larysa Liubokhynets[1], Yevhenii Rudnichenko[2] and Nataliia Havlovska[2]

[1]Department of Economic Theory and Economic Security, Khmelnitsky National University, Khmelnitsky, Ukraine
[2]Department of Management, Administration and Hotel and Restaurant Business, Khmelnitsky National University, Khmelnitsky, Ukraine
e.m.rudnichenko@gmail.com

Abstract: *The article proposes a model of a probabilistic neural network in order to ensure a sufficient level of economic security through the introduction of agile enterprise management system. It is built on the basis of statistical classifiers highlighting the degree of threats to economic security of enterprise. An input matrix for a probabilistic neural network was developed and a target matrix of classes (states) was formed. A probabilistic neural network was built in the environment using the built-in Matlab-function «newpnn», based on the proposed matrices. A list of management decisions that is a response to determined degree of threat was identified for each degree of threat to economic security. Detailing of management decisions in terms of individual components allows managers to understand the response to the current threat from the standpoint of effective management. Also, availability of alternatives expands opportunities for managers to improve existing management system in various directions. Implementation of management decisions using a neural network can reduce the degree of threats to economic security of enterprise. The article forms a target matrix of lists of actions of company's management and a crucial probabilistic neural network is built in Matlab environment. The implementation of the proposed approach is tested on the example of a particular enterprise, which indicates its suitability for practical use and solution of applied practical problems. Accordingly, the proposals developed in the study on the use of neural network allow a management of enterprise to respond quickly to current threats and risks.*

Keywords: *economic security, threats, agile management, management decisions, modeling, neural network.*

1 INTRODUCTION

The dynamism of modern environment and the crisis of the world economy caused by the COVID-19 pandemic require companies to respond effectively and quickly to change. There are constant transformations of target markets, which in most cases worsen the situation for producers and industrial sector as a whole. Information on state of markets and changes that significantly affect demand is extremely useful and relevant for making strategic decisions and adjusting the overall strategy of enterprise development [1, 2]. This necessitates the introduction of flexible management tools to ensure sufficient level of its economic security. Agile management of the enterprise allows to quickly respond and withstand challenges and threats. And this «flexibility» should be applied when managing not only the enterprise, but also the economic security system [3, 4].

The results of assessing flexibility of management system of the studied industrial enterprises indicate the need for significant improvements in management processes, and in some cases, their new architecture. Standardized, mostly directive management methods, although they ensure the prompt execution of tasks, in many cases do not contain a sufficient level of flexibility. A special place in the formation of system of agile management is occupied by management decisions that directly implement reactions of enterprise management and ensure the functioning of such a system based on information about the internal and external environment of business entities.

2 REVIEW OF LITERATURE

There are a number of methodologies that have explored various aspects of agile management, including lean manufacturing methodologies [5-7], methodologies for building and operating agile organizations [8-10] and methodologies of agile software development in construction and operation of agile organizations [11, 12]. The introduction of agile management in enterprises practice in order to ensure a sufficient level of its economic security requires taking into account threats of its activities and making informed management decisions.

Accordingly, a significant number of scientists [13, 14] focus on threats, because they are more specific and targeted and to level them it is necessary to activate the enterprise economic security, or in its absence (or rather lack of formalized representation), such actions will be generated by the existing management system.

Among the publications of Ukrainian authors covering the topic of economic security, we can single out the researches by Havlovska [13], Illiashenko [15] Kozachenko [16], Rudnichenko [17], Vasyltsiv [18] et al. Foreign approaches to the functioning of the economic security system were studied in [19-21].

To meet management needs, taking into account the degree of threats and improve decision-making system, it is advisable to use intelligent data processing systems based on construction and use of neural networks. The use of neural networks is reflected in many scientific studies, and is associated with various scientific fields, including chemistry [22, 23], physics and biology [24], industry [25], medicine [26], pharmacy [27], etc. Approaches to the use of neural networks are found in scientific publications of economic profile, in particular in studies of innovation processes [28, 29], finance [30, 31], management decisions [32, 33], pricing [34, 35], etc.

3 METHODS

We will build a system of agile enterprise management to ensure a sufficient level of its economic security on a basis of statistical classifiers. First of all, we need to identify a list of factors influencing degree of threat. Let us denote by set of all such factors:

$$Z = \{z_i\}_{i=1}^{N} \tag{1}$$

where: Z_i is i-th factor or i-th indicator (in the terminology of statistical classifiers), which negatively affects the degree of threat (i.e., increases this degree), and N is a general number of such indicators.

For further consideration, the set (1) is represented as a combination of subsets of external and internal factors:

$$Z = \{z_i\}_{i=1}^{N} = Z_{\text{зов}} \bigcup Z_{\text{вн}} = \\ = \left\{ z_{i_1}^{(\text{зов})} \right\}_{i_1=1}^{N_{\text{зов}}} \bigcup \left\{ z_{i_2}^{(\text{вн})} \right\}_{i_2=1}^{N_{\text{вн}}} \tag{2}$$

where: $Z_{\text{зов}}$ and $Z_{\text{вн}}$ are subsets $N_{\text{зов}}$ of external and $N_{\text{вн}}$ internal factors, and $N= N_{\text{зов}}+ N_{\text{вн}}$.

Let us denote by a set of M degrees of threat to economic security of enterprise:

$$S = \{s_k\}_{k=1}^{M} \tag{3}$$

where: s_k is k-th degree (kind or type) of threat.

Thus, formally speaking, we face the task of not just reflecting a set of factors of influence Z into a set of degrees of threat S, but the task of classifying the degree of threat based on the study of N indicators in set Z. In other words, we need to make a choice (make a decision) according to which s^* is the most relevant threat level among all M levels:

$$s^* \in S = \{s_k\}_{k=1}^{M} \tag{4}$$

This can be done using a statistical classifier such as a probabilistic neural network.

A probabilistic neural network is very easy to build in a Matlab environment. To do this, it is necessary to form an input matrix [36]:

$$\mathbf{F} = \left[f_{ij} \right]_{N \times (mM)} \tag{5}$$

where: $m \in \{1,2,3,\ldots\}$, and the value of the element f_{ij} is a numerical estimate (fractional or integer,

as well as from an arbitrary, generally speaking, interval) of the sign z_i in the state (class) s_k for:

$$k = j - M \cdot \psi\left(\frac{j-1}{M}\right) \tag{6}$$

where auxiliary function ψ(x) returns an integer part of a number x.

Theoretically, the matrix (5) can be of N×M *size*, where m=1 and k=j according to the formula (6). In this case, each indicator in each state (degree of threat) will have only one assessment. This case is possible in calculations, but its implementation requires very reliable estimates (you need to provide $K \cdot M$ of such estimates).

Once an input matrix (7) for the probabilistic neural network is built, you only need to form the target matrix of classes (states):

$$\mathbf{T} = \left[t_{ij} \right]_{M \times (mM)} \tag{7}$$

which is a sequential horizontal concatenation of m unit matrices of size M×M, where $m \in \{1,2,3,\ldots\}$.

After the matrices (5) and (7) are prepared, the probabilistic neural network $\boldsymbol{n}_{pnn}(N,M)$ in the Matlab environment is built using the built-in Matlab function «newpnn», which accepts at the input of the matrix F and T together with the parameter of the scatter of radial basis functions («spread of radial basis functions») ρ:

$$\mathbf{n}_{pnn}(N, M) = \text{newpnn}(\mathbf{F}, \mathbf{T}, \rho) \tag{8}$$

By default, the parameter ρ = 0.1 (however, this value should not be considered the recommended value of the scatter parameter). If this parameter is close to 0, the probabilistic neural network acts as a classifier of the «nearest neighbor» type. If the parameter ρ is increased, the probabilistic neural network takes into account several close (in the sense of the corresponding Euclidean metric) vectors in the matrix (5).

It is very easy to use a ready-made probabilistic neural network (8). If $\boldsymbol{V}$ is a vector with N features, i.e.:

$$\mathbf{V} = \left[v_i \right]_{N \times 1} \in \mathbb{R}^N \quad (9)$$

Then in the Matlab environment with the help of the built-in Matlab-function «sim» we get:

$$\mathbf{A} = \mathrm{sim}\left(\mathbf{n}_{pnn}\left(N, M \right), \mathbf{V} \right) \quad (10)$$

where: $\mathbf{A}$ is an M-dimensional vector, where M–1 has a value of 0 and only one element has a value of 1.

The index of an element with a value of 1 corresponds to the state number that has the most relevant degree of threat among all M degrees.

A set of features in the second stage will consist of N_{BH}+1 element: N_{BH} of internal factors and a predicted condition or degree of threat s_{k^*}.

Let us denote this set as:

$$Z_{\text{BH}}^{(+1)} = \left\{ s_{k^*}, \left\{ z_{i_2}^{(\text{BH})} \right\}_{i_2=1}^{N_{\text{BH}}} \right\} = \left\{ \vartheta_{i_2} \right\}_{i_2=1}^{N_{\text{BH}}+1} \quad (11)$$

Let us denote by set of $J(s_{k^*})$ possible options for action (management decisions) of the company's management to eliminate the threat of economic security in a certain state s_{k^*}.

$$D\left(s_{k^*} \right) = \left\{ d_u\left(s_{k^*} \right) \right\}_{u=1}^{J(s_{k^*})} \quad (12)$$

Of course, this set depends on a degree of threat. Each element in it is a certain list of management decisions of an enterprise. Moreover, a list of actions of a company's management for, for example, a weak degree of threat will be smaller than for a strong or critical one.

Thus, there will be a total of M variants of the set (12). Each level of threat to economic security must have its own list of actions, which can be called a response to this level of threat. These lists in general will be used in our model.

Based on the sets (11) and (12), we again construct a probabilistic neural network. First, we form an input matrix of ($N_{BH}+1$) x ($m_2 J(s_{k^*})$ size similar to the construction of the matrix (5):

$$\mathbf{F}_2 = \left[g_{i_2 j} \right]_{\left(N_{\text{BH}}+1 \right) \times \left(m_2 J\left(s_{k^*} \right) \right)} \quad (13)$$

where: m_2 є {1,2,3,…}, and the value of the element g_{i2j} is a numerical estimate (fractional or integer, as well as from an arbitrary, generally speaking, interval) feature ϑ_{i2} in u-th action $d_u(s_{k^*})$ for:

$$u = j - J\left(s_{k^*} \right) \cdot \psi\left(\frac{j-1}{J\left(s_{k^*} \right)} \right) \quad (14)$$

similar to the transformation (6). Theoretically, the matrix (13) can have a ($N_{BH}+1$) x ($J(s_{k^*}$) size, where $m_2=1$ and $u=j$ by formula (14).

Once the input matrix (13) for a crucial probabilistic neural network is built, it is necessary to re-form the target matrix of company's management actions lists:

$$\mathbf{T}_2 = \left[t_{i_2 j} \right]_{J(s_{k^*}) \times (m_2 J(s_{k^*}))} \; (m_2 \in \{1,2,3,\ldots\}) \quad (15)$$

which is a sequential horizontal concatenation m_2 of unit matrices of $J(s_{k^*})$ x $J(s_{k^*})$ size.

Similar to the solution of problem (4) by the first neural network, the second (decisive) probabilistic neural network solves the problem that is, we need to find the most relevant list of management decisions that will be the most effective response to the degree of threat s_k^*.

$$d^* \in D\left(s_{k^*} \right) = \left\{ d_u\left(s_{k^*} \right) \right\}_{u=1}^{J(s_{k^*})} \quad (16)$$

After the matrices (13) and (15) are prepared, a decisive probabilistic neural network is built in the Matlab environment:

$$\mathbf{n}_{pnn}\left(N_{\text{BH}}+1, J(s_{k^*}) \right) = \mathrm{newpnn}\left(\mathbf{F}_2, \mathbf{T}_2, \rho \right) \quad (17)$$

where we use the same parameter of scatter of radial basis functions ρ as in the network (8). It is very easy to use a ready-made probabilistic neural network (8). If $\mathbf{V}_2$ is a vector with N_{BH}+1 indicator, i.e.:

$$\mathbf{V}_2 = \left[v_{i_2}^{(2)} \right]_{(N_{\text{BH}}+1) \times 1} \in \mathbb{R}^{N_{\text{BH}}+1} \quad (18)$$

then in the Matlab environment using the built-in Matlab-function «sim» we get:

$$\mathbf{A}_2 = \mathrm{sim}\left(\mathbf{n}_{pnn}\left(N_{\text{BH}}+1, J(s_{k^*}) \right), \mathbf{V}_2 \right) \quad (19)$$

where $\mathbf{A}_2$ is a $J(s_k^*)$-measurable vector, where $J(s_k^*)$–1 element has a value of 0 and only one element has a value of 1.

The index of an element with a value of 1 corresponds to the number of the list of management decisions that is most effective in counteracting economic threats with s_k^* degree. Thus, the response vector of the probabilistic neural network (17):

$$\mathbf{A}_2 = \left[a_u \right]_{J(s_{k^*}) \times 1} \text{ with } a_u \in \{0, 1\} \quad (20)$$

where:

$$a_u = 0 \text{ where } u \in \left\{ \overline{1, J(s_{k^*})} \right\} \setminus \left\{ u^* \right\} \text{ and } a_{u^*} = 1 \quad (21)$$

and $d^* = d_{u^*}(s_{k^*})$ is the required list of management decisions, which is the solution to problem (16).

The expert questionnaire for estimating the input matrix of the first probabilistic neural network has the general form shown in Table 1.

The estimate of the matrix $\mathbf{F}_2$ will be similar to $\mathbf{F}$, but we recall that there will be M matrices in total (each level of threat will have its own matrix). Therefore, experts should provide their opinions in M more questionnaires (Table 2).

Table 1 Expert questionnaire for estimates (from 0 to 1) of the matrix **F**

		Threat level				
		s_1	s_2	**...**	s_{M-1}	s_M
External factors	Z_1 – list number, an integer from 1 to $\sum_{k=1}^{M} J\,(s_k)$			**...**		
	z_2			**...**		
	⋮	⋮	⋮	⋮	⋮	⋮
	z_{N3OB-1}			**...**		
	z_{N3OB}			**...**		
Internal factors	z_{N3OB+1}			**...**		
	z_{N3OB+2}			**...**		
	⋮	⋮	⋮	⋮	⋮	⋮
	z_{N-1}			**...**		
	z_N			**...**		

Table 2 Expert questionnaire for assessments (from 0 to 1) of the $\mathbf{F}_2$ matrix for the s_k $(k = \overline{1, M})$ level threat

		Lists of management decisions to eliminate the s_k level threat				
		1	**2**	**...**	**$J(s_k)$-1**	**$J(s_k)$**
Level threat (defined at the previous stage)	$s_k(\vartheta_1)$					
Internal factors	$z_{N_{3OB}}+1(\vartheta_2)$			**...**		
	$z_{N_{3OB}}+2(\vartheta_3)$			**...**		
	⋮	⋮	⋮	⋮	⋮	⋮
	$z_{N-1}(\vartheta_{N_{BH}})$			**...**		
	$z_N(\vartheta_{N_{BH}+1})$			**...**		

Table 3 Expert questionnaire for estimates (from 0 to 1 in vector V) of the threat increase intensity

Signs (influencing factors)	**z_1 (list number, integer)**	z_2	**...**	z_{N3OB}**+1**	z_{N3OB}	z_{N3OB}	z_{N3OB}**+2**	**...**	z_{N-1}	z_N
Estimate (judgment)	* this rating is provided only before the system starts		**...**					**...**		

Table 4 Expert questionnaire for assessments (from 0 to 1 in the vector V2) of the feasibility of making a list of management decisions $d_u(s_{k^*})$ to eliminate s_{k^*} **level threat** (defined in the previous stage)

Signs	$z_{N_{3OB}+1}(\vartheta_2)$	$z_{N_{3OB}+2}(\vartheta_3)$	**...**	$Z_{N-1}(\vartheta_{N_{BH}})$	$Z_N(\vartheta_{N_{BH}+1})$
Estimate (judgment)			**...**		

After receiving all the matrices for the two neural networks, we run a flexible control system. In this system it will be necessary to evaluate vectors (9) and (18) monthly or quarterly (for a relatively short period of time) to supply them to the inputs of the first and second neural networks, respectively. Estimates of vectors **V** and $\mathbf{V}_2$ will also be obtained with the help of expert judgments (Table 3 and Table 4).

4 RESULTS

Let us consider specific examples of the implementation of the developed system on the example of PJSC «Lileia», which is a very powerful enterprise of light industry.

The management of this enterprise has established that objectively there are five levels of threats (from the lowest to the highest). The lowest degree of threat is such that has almost no effect on economic performance and development (stable support) of production. Signs of threats are given in Table 5.

In this case, the degree of threat has different lists of management decisions to eliminate (weaken) 2, 2, 3, 4, 6 respectively. The content of these lists is given in Table 6.

Table 5 Signs of threats to economic security of PJSC «Lileia»

<table>
<tr><th>Threat level</th><th>Weak</th><th>Slight</th><th>Moderate</th><th>Strong</th><th>Critical</th></tr>
<tr><td>List of management decisions that theoretically do not help eliminate this threat</td><td colspan="5">Integer from 1 to 17 (see Table 2)</td></tr>
<tr><td>External factors</td><td colspan="5">1) deepening economic crisis;
2) increasing competition;
3) acquisition by another company;
4) raiding;
5) unfavorable changes in relevant legislation;
6) exchange rate fluctuations;
7) changing fashion trends;
8) natural disasters;
9) pandemic and appropriate quarantine measures;
10) military action</td></tr>
<tr><td>Internal factors</td><td colspan="5">1) lack of resources;
2) low quality of resources;
3) obsolescence of equipment and technologies;
4) opportunistic behavior of employees;
5) conflicts between owners and management of enterprise;
6) loss of skilled workers;
7) absence or imperfection, poor (unsatisfactory, unstable) functioning of marketing system.</td></tr>
</table>

Table 6 Degrees of threats to the economic security of PJSC «Lileia» and the corresponding lists of management decisions for their mitigation

<table>
<tr><th>Threat level</th><th colspan="12">Lists of management decisions for threats mitigation</th></tr>
<tr><td>Weak</td><td colspan="6">1) introduction of minor incentives for employees, advertisement on social networks</td><td colspan="6">2) partial reduction of working hours, partial (minimum) rebranding, promotion of the best products with the help of loyal partner companies</td></tr>
<tr><td>Slight</td><td colspan="6">3) introduction of permanent incentives to employees on the basis of production indicators and sales, regular advertising on social networks</td><td colspan="6">4) partial reduction of working hours, partial (minimum) rebranding, regular advertising on social networks and «promotion» of YouTube channels</td></tr>
<tr><td>Moderate</td><td colspan="4">5) introduction of permanent incentives for employees on the basis of production indicators and sales, regular advertising on social networks, introduction of a trial (temporary) system of penalties for lateness, search for new (alternative) resource suppliers</td><td colspan="4">6) partial (minimal) rebranding, regular advertising on social networks and «promotion» of YouTube channels, search for new (alternative) resource providers abroad</td><td colspan="4">7) partial upgrade of equipment, introduction of a trial (temporary) system of penalties for lateness, creation of a new marketing department, promotion of the best products with the help of loyal partner companies</td></tr>
<tr><td>Strong</td><td colspan="3">8) regular advertising on social networks and «promotion» of YouTube channels, search for new (alternative) resource suppliers abroad, partial upgrade of equipment, search for grants</td><td colspan="3">9) reduction of expenses due to depreciation funds, search for grants, regular advertising on social networks and «promotion» of YouTube channels</td><td colspan="3">10) partial renewal of equipment at the expense of depreciation funds, introduction of permanent incentives to employees on the basis of production indicators and sales, moderate rebranding</td><td colspan="3">11) reduction of production, reduction of number of employees, production of new products at the expense of partial production wastes, reduction of expenses at the expense of depreciation funds</td></tr>
<tr><td>Critical</td><td colspan="2">12) introduction of a permanent system of penalties for lateness, reduction of the number of employees, increase in prices for the most popular products</td><td colspan="2">13) reduction of expenses at the expense of depreciation funds, introduction of permanent incentives to employees on the basis of production indicators and sales, reduction of prices</td><td colspan="2">14) partial sale of obsolete equipment, increase in prices for the most popular products, advertising on social networks and «promotion» of YouTube channels</td><td colspan="2">15) moderate rebranding, introduction of permanent incentives to employees on the basis of production indicators and sales, introduction of a permanent system of penalties for lateness without staff reductions</td><td colspan="2">16) moderate rebranding, significant reduction in staff, advertising on social networks and «promotion» of YouTube channels, introduction of permanent incentives to employees based on performance and sales</td><td colspan="2">17) full rebranding, reduction of employees, advertising on social networks and «promotion» of YouTube channels</td></tr>
</table>

A total of 29 experts were involved in PJSC «Lileia» study. This expert group mainly includes representatives of the management and leadership of this enterprise. As a result, the input matrix for the first probabilistic neural network (Table 7) was obtained after optimal clustering of expert judgments, it consisted of two submatrices (i.e., here m=2).

When evaluating the five $\mathbf{F}_2$ matrices, the expert judgments were clustered into three clusters and, therefore, m_2=2. These matrices for each state are given in Tables 8–12.

Table 7 Input Matrix F for PJSC «Lileia»

Threat level		Weak	Slight	Moderate	Strong	Critical	Weak	Slight	Moderate	Strong	Critical
normal list		0.130	0.071	0.424	0.478	0.915	0.133	0.290	0.218	0.723	0.758
External factors	1	0.130	0.169	0.305	0.617	0.712	0.080	0.179	0.265	0.586	0.688
	2	0.300	0.394	0.307	0.575	0.397	0.236	0.385	0.251	0.603	0.412
	3	0.098	0.410	0.485	0.699	0.955	0.074	0.381	0.476	0.756	0.840
	4	0.067	0.608	0.653	0.776	0.793	0.050	0.577	0.698	0.807	0.813
	5	0.325	0.428	0.484	0.585	0.680	0.318	0.375	0.519	0.617	0.710
	6	0.076	0.148	0.265	0.548	0.652	0.099	0.125	0.257	0.616	0.652
	7	0.169	0.378	0.524	0.402	0.386	0.221	0.420	0.504	0.383	0.403
	8	0.071	0.100	0.164	0.261	0.333	0.084	0.097	0.215	0.278	0.301
	9	0.456	0.595	0.688	0.801	0.937	0.522	0.614	0.648	0.804	0.838
	10	0.107	0.184	0.192	0.191	0.240	0.093	0.187	0.163	0.269	0.236
Internal factors	1	0.075	0.219	0.291	0.415	0.489	0.127	0.201	0.316	0.421	0.491
	2	0.321	0.564	0.619	0.723	0.836	0.255	0.546	0.680	0.726	0.909
	3	0.299	0.358	0.292	0.276	0.293	0.302	0.408	0.304	0.306	0.298
	4	0.154	0.301	0.225	0.399	0.426	0.259	0.300	0.236	0.451	0.467
	5	0.388	0.214	0.325	0.376	0.353	0.414	0.202	0.337	0.366	0.409
	6	0.321	0.439	0.451	0.490	0.765	0.326	0.389	0.458	0.506	0.746
	7	0.275	0.411	0.485	0.569	0.626	0.287	0.420	0.555	0.543	0.574

Table 8 Input Matrix $\mathbf{F}_2$ for PJSC «Lileia» for a weak degree of threat

		Lists of management decisions					
		1	*2*	*1*	*2*	*1*	*2*
	Weak degree of threat	0.092	0.085	0.096	0.13	0.146	0.147
Internal factors	1	0.137	0.239	0.172	0.173	0.123	0.200
	2	0.379	0.552	0.467	0.490	0.433	0.444
	3	0.165	0.205	0.223	0.067	0.055	0.075
	4	0.444	0.087	0.521	0.087	0.547	0.050
	5	0.638	0.080	0.589	0.125	0.641	0.043
	6	0.648	0.219	0.608	0.180	0.514	0.303
	7	0.336	0.430	0.280	0.491	0.351	0.382

Table 9 Matrix $\mathbf{F}_2$ for PJSC «Lileia» for a minor degree of threat

		Lists of management decisions					
		3	*4*	*3*	*4*	*3*	*4*
	Minor degree of threat	0.076	0.198	0.119	0.168	0.057	0.262
Internal factors	1	0.092	0.223	0.215	0.195	0.100	0.172
	2	0.424	0.452	0.456	0.378	0.466	0.485
	3	0.235	0.056	0.195	0.136	0.257	0.114
	4	0.375	0.359	0.452	0.409	0.447	0.342
	5	0.196	0.477	0.204	0.312	0.148	0.323
	6	0.123	0.286	0.296	0.301	0.183	0.360
	7	0.536	0.291	0.391	0.254	0.349	0.317

Table 10 Matrix $\mathbf{F}_2$ for PJSC «Lileia» at a moderate degree of threat

		Lists of management decisions								
		5	*6*	*7*	*5*	*6*	*7*	*5*	*6*	*7*
	Moderate degree of threat	0.453	0.548	0.458	0.478	0.463	0.335	0.46	0.445	0.389
Internal factors	1	0.078	0.086	0.423	0.105	0.058	0.291	0.056	0.067	0.255
	2	0.105	0.203	0.47	0.187	0.17	0.332	0.073	0.092	0.475
	3	0.113	0.583	0.116	0.203	0.555	0.046	0.259	0.542	0.115
	4	0.394	0.393	0.247	0.372	0.339	0.277	0.473	0.459	0.216
	5	0.528	0.28	0.707	0.62	0.375	0.688	0.604	0.327	0.689
	6	0.503	0.545	0.175	0.499	0.49	0.204	0.438	0.592	0.21
	7	0.248	0.294	0.101	0.277	0.325	0.118	0.279	0.282	0.097

Table 11 Matrix F_2 for PJSC «Lileia» for a strong degree of threat

		Lists of management decisions											
		8	***9***	***10***	***11***	***8***	***9***	***10***	***11***	***8***	***9***	***10***	***11***
	Strong degree of threat	0.806	0.419	0.131	0.080	0.694	0.368	0.137	0.097	0.810	0.387	0.108	0.094
Internal factors	1	0.664	0.104	0.11	0.174	0.749	0.077	0.169	0.169	0.722	0.140	0.089	0.245
	2	0.635	0.099	0.101	0.177	0.699	0.084	0.114	0.180	0.705	0.189	0.132	0.228
	3	0.101	0.215	0.713	0.168	0.062	0.176	0.868	0.294	0.078	0.094	0.823	0.169
	4	0.217	0.363	0.678	0.458	0.257	0.245	0.671	0.296	0.175	0.263	0.591	0.434
	5	0.319	0.163	0.759	0.078	0.220	0.227	0.809	0.046	0.211	0.269	0.616	0.067
	6	0.559	0.171	0.934	0.180	0.507	0.343	0.867	0.143	0.620	0.166	0.881	0.090
	7	0.106	0.336	0.293	0.451	0.101	0.306	0.355	0.426	0.157	0.252	0.401	0.337

Table 12 Matrix F_2 for PJSC «Lileia» for a critical level of threat

		Lists of management decisions																	
		12	***13***	***14***	***15***	***16***	***17***	***12***	***13***	***14***	***15***	***16***	***17***	***12***	***13***	***14***	***15***	***16***	***17***
Critical level of threat		0.027	0.330	0.488	0.766	0.824	0.994	0.150	0.285	0.509	0.672	0.900	0.992	0.097	0.311	0.543	0.685	0.851	0.923
Internal factors	1	0.127	0.225	0.353	0.460	0.180	0.274	0.113	0.186	0.286	0.366	0.178	0.318	0.183	0.274	0.385	0.447	0.228	0.273
	2	0.384	0.508	0.622	0.091	0.118	0.085	0.410	0.561	0.563	0.161	0.057	0.099	0.384	0.511	0.613	0.179	0.118	0.032
	3	0.36	0.467	0.311	0.668	0.130	0.129	0.398	0.398	0.341	0.680	0.085	0.174	0.309	0.447	0.331	0.718	0.105	0.313
	4	0.424	0.249	0.146	0.824	0.665	0.897	0.513	0.406	0.299	0.954	0.755	0.973	0.504	0.382	0.293	0.941	0.700	0.980
	5	0.240	0.23	0.294	0.354	0.636	0.881	0.120	0.192	0.365	0.383	0.676	0.934	0.168	0.176	0.375	0.417	0.778	0.838
	6	0.247	0.285	0.464	0.898	0.471	0.737	0.342	0.404	0.325	0.894	0.578	0.840	0.240	0.248	0.405	0.926	0.437	0.757
	7	0.446	0.334	0.458	0.246	0.88	0.939	0.335	0.357	0.463	0.235	0.969	0.890	0.221	0.370	0.361	0.394	0.935	0.861

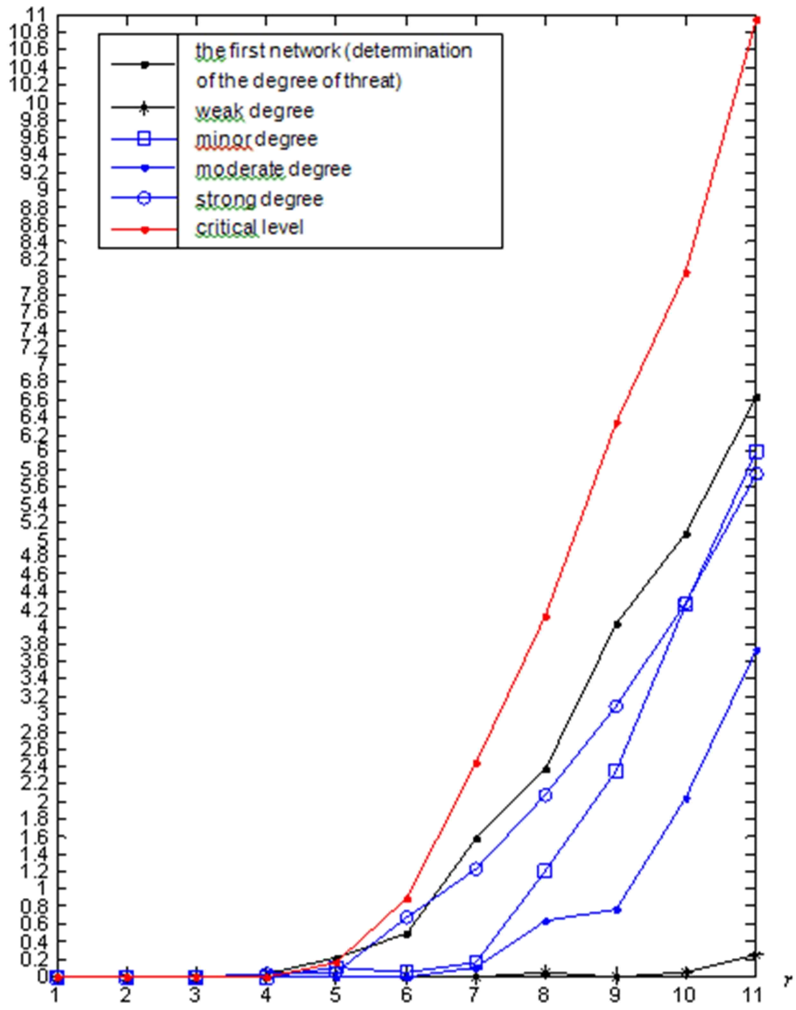


Figure 1 The performance of probabilistic neural networks in the form of the average percentage of erroneous answers for PJSC "Lileia"

After all the necessary data were collected, two probabilistic neural networks (8) and (17) were constructed. Their performance was studied according to the scheme:

$$\mathbf{F}_{\text{test}} = \overline{\mathbf{F}} + \zeta \cdot \left(\frac{r-1}{10} \right) \cdot \mathbf{\Theta} + \xi \cdot \left(\frac{r-1}{10} \right) \cdot \mathbf{\Theta}_1 \quad (r = \overline{1,11}) \quad (22)$$

where: $\bar{F}$ – averaged input matrix, Θ – matrix of randomly distributed values with zero mean, Θ_1 – matrix of randomly distributed values with zero mean, in which all columns are the same, ζ=0.15, ζ=0.075.

Next, the matrices (22) are fed to the input of the corresponding neural network in the manner of (10) and (19) and the statistics of responses are examined. In fact, expression (22) is a model of noise and discrepancies in expert judgments [37]. In this case, the performance of the neural network means the percentage of erroneous responses. Figure 1 shows all six dependences of this percentage (for all neural networks) on the level of noise and discrepancies $r = \overline{1,11}$.

Neural network diagnostics for agile control was performed as follows. As of April 3, 2020, the same 29 experts had evaluated the **V** and $\mathbf{V}_2$ vectors every Friday for two weeks.

Tables 13 and 14 show all such vector estimates that were applied to the input of neural networks (8) and (17), respectively.

Table 13 List of vectors V for PJSC «Lileia» and responses of the first neural network (8)

Date	Normal list	External factors (by numbers)										Internal factors (by numbers)							Network response (threat level)
		1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	
03.04	0.118	0.473	0.387	0.338	0.710	0.490	0.081	0.635	0.470	0.668	0.281	0.166	0.544	0.069	0.162	0.573	0.253	0.395	**3**
17.04	0.412	0.134	0.217	0.575	0.771	0.536	0.259	0.552	0.363	0.500	0.154	0.433	0.675	0.220	0.321	0.208	0.655	0.286	**3**
01.05	0.412	0.439	0.456	0.319	0.895	0.388	0.257	0.488	0.167	0.592	0.004	0.336	0.717	0.172	0.171	0.128	0.356	0.542	**3**
15.05	0.294	0.698	0.271	0.693	0.598	0.587	0.560	0.348	0.346	0.804	0.330	0.290	0.876	0.152	0.708	0.285	0.656	0.507	**4**
29.05	0.471	0.300	0.372	0.744	0.753	0.486	0.100	0.676	0.234	0.760	0.014	0.218	0.998	0.370	0.328	0.271	0.597	0.555	**3**
12.06	0.294	0.404	0.223	0.260	0.824	0.513	0.365	0.654	0.213	0.752	0.335	0.341	0.935	0.389	0.315	0.477	0.532	0.673	**3**
26.06	0.294	0.588	0.578	0.892	0.944	0.495	0.777	0.520	0.282	0.627	0.328	0.322	0.845	0.114	0.251	0.138	0.624	0.777	**4**
10.07	0.529	0.133	0.196	0.393	0.755	0.589	0.218	0.369	0.207	0.808	0.244	0.319	0.500	0.455	0.470	0.312	0.323	0.636	**3**
24.07	0.294	0.312	0.521	0.206	0.487	0.657	0.346	0.677	0.181	0.843	0.002	0.372	0.537	0.294	0.142	0.561	0.345	0.253	**3**
07.08	0.412	0.181	0.317	0.260	0.697	0.337	0.102	0.290	0.189	0.511	0.333	0.301	0.468	0.534	0.408	0.267	0.445	0.593	**2**
21.08	0.235	0.038	0.369	0.525	0.661	0.300	0.096	0.478	0.058	0.706	0.580	0.086	0.563	0.486	0.551	0.177	0.371	0.328	**2**
04.09	0.235	0.098	0.404	0.351	0.268	0.363	0.032	0.274	0.022	0.767	0.225	0.360	0.580	0.363	0.257	0.392	0.512	0.437	**2**
18.09	0.235	0.147	0.290	0.512	0.583	0.418	0.322	0.383	0.073	0.634	0.077	0.204	0.570	0.164	0.102	0.277	0.576	0.210	**2**
02.10	0.235	0.377	0.336	0.440	0.783	0.466	0.311	0.491	0.183	0.703	0.381	0.314	0.796	0.428	0.228	0.185	0.536	0.705	**3**
16.10	0.412	0.239	0.158	0.355	0.589	0.414	0.068	0.144	0.443	0.663	0.187	0.376	0.648	0.371	0.288	0.126	0.489	0.312	**3**
30.10	0.294	0.141	0.484	0.369	0.658	0.452	0.033	0.385	0.038	0.642	0.296	0.379	0.657	0.404	0.276	0.274	0.428	0.290	**2**
13.11	0.235	0.004	0.421	0.067	0.042	0.405	0.120	0.047	0.133	0.471	0.005	0.207	0.160	0.518	0.228	0.225	0.305	0.426	**1**
27.11	0.118	0.168	0.458	0.421	0.771	0.462	0.162	0.453	0.087	0.469	0.099	0.250	0.616	0.531	0.394	0.318	0.119	0.291	**2**
11.12	0.235	0.081	0.286	0.065	0.206	0.316	0.061	0.215	0.202	0.521	0.307	0.011	0.088	0.188	0.239	0.302	0.402	0.425	**1**
25.12	0.059	0.164	0.206	0.088	0.138	0.382	0.304	0.058	0.030	0.607	0.011	0.119	0.180	0.645	0.214	0.410	0.674	0.353	**1**

Table 14 List of vectors V2 for PJSC «Lileia» and responses of the original neural network (17)

Date	Normal degree of threat	Internal factors (by numbers)							The most relevant list of management decisions (see Table 2)
		1	2	3	4	5	6	7	
03.04	0.6	0.162	0.065	0.054	0.338	0.567	0.388	0.171	**7**
17.04	0.6	0.076	0.326	0.732	0.137	0.282	0.690	0.425	**7**
01.05	0.6	0.281	0.061	0.796	0.458	0.272	0.231	0.120	**5**
15.05	0.8	0.050	0.022	0.547	0.679	0.958	0.989	0.029	**8**
29.05	0.6	0.183	0.038	0.175	0.563	0.718	0.511	0.043	**5**
12.06	0.6	0.261	0.662	0.238	0.035	0.824	0.230	0.300	**5**
26.06	0.8	0.575	0.627	0.318	0.144	0.291	0.338	0.017	**9**
10.07	0.6	0.210	0.033	0.168	0.409	0.584	0.486	0.273	**5**
24.07	0.6	0.405	0.385	0.155	0.207	0.579	0.143	0.050	**7**
07.08	0.4	0.215	0.634	0.148	0.396	0.455	0.254	0.672	**4**
21.08	0.4	0.128	0.352	0.247	0.145	0.148	0.107	0.460	**4**
04.09	0.4	0.249	0.620	0.249	0.390	0.527	0.299	0.350	**4**
18.09	0.6	0.085	0.037	0.829	0.254	0.304	0.585	0.268	**4**
02.10	0.6	0.406	0.350	0.149	0.093	0.515	0.140	0.171	**7**
16.10	0.4	0.048	0.480	0.091	0.275	0.361	0.232	0.406	**5**
30.10	0.4	0.386	0.388	0.031	0.538	0.291	0.362	0.440	**4**
13.11	0.2	0.099	0.500	0.164	0.490	0.716	0.501	0.375	**2**
27.11	0.4	0.168	0.362	0.098	0.310	0.028	0.150	0.704	**4**
11.12	0.2	0.193	0.222	0.212	0.271	0.506	0.532	0.181	**1**
25.12	0.2	0.218	0.422	0.125	0.017	0.210	0.435	0.327	**2**

5 CONCLUSION

As we can see, thanks to the developed system of flexible management at PJSC «Lileia» (which has been implemented since the beginning of April 2020) it was possible to stabilize and eliminate threats to its economic security within four months. At the beginning of August 2020, the degree of threat was insignificant (see the darker colors of the more threatening situations in Tables 9 and 10), and this situation lasted until mid-September. At the same time, the most relevant list of management decisions in this period were actions aimed at partial reduction of working hours, partial (minimum) rebranding, as well as the introduction and further support of regular advertising on social networks and «promotion» of YouTube channels (see Table 2). Threats continued to rise due to deteriorating external factors (in particular, the economic crisis in Ukraine deepened), but in early November, PJSC «Lileia» management managed to stabilize the situation through flexible responses to threats. Finally, in order to maintain control over threats, PJSC «Lileia» management further supports the introduction of small incentives for employees, along with partial reductions in working hours (but not simultaneously!), advertising on social networks (including YouTube), minimal rebranding, and cooperation with loyal partner companies for additional marketing.

Of course, the development of management decisions at PJSC «Lileia» during the nine months of 2020 is quite difficult. However, this is a very large enterprise, so such diversification of management decisions is quite natural.

The proposals developed in the study on the use of the neural network allow enterprise management to respond quickly to current threats and risks. In this case, effective management decisions and the reaction of the management system are recorded by the network, which provides its gradual learning. This situation leads to the improvement of management system of enterprise in general and ensures its economic security in particular. In this context, there are prospects for further research, namely the issue of balanced development of management systems from the standpoint of safe operation in a changing competitive market. In addition, it is necessary to note the relevance and usefulness of the proposed approaches for light industry enterprises in general, since the industry specificity was taken into account when forming the initial conditions for the functioning of the developed neural network. This approach allows enterprise management to improve both internal system processes and provide an appropriate response to typical threats.

6 REFERENCES

1. Havlovska N., Rudnichenko Ye., Babiy I., Matiukh S., Liubokhynets L., Lopatovskyi V.: The strategy of choosing promising markets for the enterprise – subject of foreign economic activity on the basis of accessibility, safety and profitability criteria, Quality-Access to Success Journal 21(178), 2020, pp. 26-34
2. Havlovska N., Savina H., Davydova O., Savin S., Rudnichenko Y., Lisovskyi I.: Qualitative substantiation of strategic decisions in the field of cost management using the methods of economic mathematical modelling, TEM JOURNAL – Technology, Education, Management, Informatics 8(3), 2019, pp. 959-971
3. Illiashenko O., Rudnichenko Ye., Momot T., Havlovska N.: The enterprise economic security system: the state assessment using management functional types, International Journal for Quality Research 14(1), 2020, pp. 183-200, DOI: 10.24874/IJQR14.01-12
4. Liubokhynets L., Rudnichenko Ye., Dzhereliuk I., Illiashenko O., Kryvdyk V., Havlovska N.: Methodological foundations of flexible management and assessing the flexibility of an enterprise economic security system, International Journal of Scientific & Technology Research 9(3), 2020, pp. 14616-4621
5. Anderson D.J., Carmichael A.: Essential Kanban Condensed, 2016, https://www.thekanbanmaster.co.uk/wp-content/uploads/2016/09/Essential-Kanban-Condensed-v1.0.0.pdf
6. Ries E.: The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses, Crown Business, New York, NY, 2011, 336 p., ISBN: 978-0307887894
7. Rigby D.K., Sutherland J., Takeuchi H.: The Secret History of Agile Innovation, Harvard Business Review, 2016, https://www.bain.com/insights/the-secret-history-of-agile-innovation-hbr/
8. Salameh A., Bass J.M.: Spotify Tailoring for Promoting Effectiveness in Cross-Functional Autonomous Squads, In: Agile Processes in Software Engineering and Extreme Programming – Workshops, Hoda R. Ed), Springer International Publishing, 2019
9. Schwaber K., Sutherland J.: The Definitive Guide to Scrum: The Rules of the Game, 2017, https://www.scrumguides.org/docs/scrumguide/v2017/2017-Scrum-Guide-US.pdf
10. Takeuchi H., Nonaka I.: The New New Product Development Game, Harvard Business Review 64(1), 1986, pp. 137-146
11. Beck K., Andres C.: Extreme Programming Explained: Embrace Change, 2nd ed., Addison-Wesley, 2004, 224 p., ISBN: 978-0321278654, http://ptgmedia.pearsoncmg.com/images/9780321278654/samplepages/9780321278654.pdf
12. Johnson B., Woolfolk W.W., Miller R., Johnson C.: Flexible Software Design: Systems Development for Changing Requirements, Auerbach Publications, 2005, 464 p.

13. Havlovska N., Pokotylova V., Korpan O., Rudnichenko Ye., Sokyrnyk I.: Modeling of the process of functioning of the mechanism of economic security of foreign economic activity of enterprise taking into account weak signals and identification of risks and threats, International Journal of Scientific & Technology Research 8(12), 2019, pp. 2216-2522
14. Rudnichenko Ye., Dzhereliuk I., Mykhalchyshyna L., Savina S., Pokotylova V., Havlovska N.: Safe interaction management of state institutions and business entities based on the concepts of evolutionary economics: Modeling and scenario forecasting of processes, TEM JOURNAL – Technology, Education, Management, Informatics 9(1), 2020, pp. 233-241
15. Illiashenko O., Zhehus O., Matviychuk L., Lopatovskyi V., Rudnichenko Y., Havlovska N.: Improving accounting-analytical processes of personnel management in the context of relevant threats and risks for an enterprise economic security system, International Journal of Scientific & Technology Research 9(4), 2020, pp. 105-110
16. Kozachenko G.V., Pogorelov Yu.S., Bilousova A.Yu.: Development of threats to enterprise activity, In: Security of the XXI Century: National and Geopolitical Aspects: Collective monograph, Prague Czech Republic, 2019, pp. 134-140
17. Rudnichenko Ye., Korchevska L., Mykolaichuk V., Berezhniuk I., Havlovska N., Nagorichna O.: Customs qualitative impact on the system of enterprise economic security: Modeling and evaluating the results, TEM JOURNAL – Technology, Education, Management, Informatics 8(4), 2019, pp. 1176-1184
18. Vasyltsiv T., Lupak R., Osadchuk Yu.: Assessment of the level of penetration of import dependence in the context of the import substitution policy in Ukraine, Economic Annals-XXI, 167(9-10), 2017, pp. 13-17, https://doi.org/10.21003/ea.V167-03
19. Böhme R., Nowey T.: Economic Security Metrics. In: Eusgeld I., Freiling F.C., Reussner R. (Eds) Dependability Metrics, Lecture Notes in Computer Science 4909, 2008, pp. 176-187, Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-68947-8_15
20. Dynan K.E.: Changing Household Financial Opportunities and Economic Security, Journal of Economic Perspectives 23(4), 2009, pp. 49-68, DOI: 10.1257/jep.23.4.49
21. Korauš A., Dobrovič J., Polák J., Kelemen P.: Security position and detection of unusual business operations from science and research perspective, Entrepreneurship and Sustainability 6(3), 2019, pp. 1270-1279, DOI: 10.9770/jesi.2019.6.3(15)
22. Pierce T.H.: Artificial Intelligence Applications in Chemistry, ACS Symposium Series 306, Hohne B.A. (Ed), American Chemical Society, Washington, DC, 1986, 395 p., ISBN: 978-0841209664
23. Zupan J., Gasteiger J.: Neural networks: A new method for solving chemical problems or just a passing phase? Analytica Chimica Acta 248(1), 1991, pp. 1-30, https://doi.org/10.1016/S0003-2670(00)80865-X
24. Bounds D.G.: New optimization methods from physics and biology, Nature 329, 1987, pp. 215-219, https://doi.org/10.1038/329215a0
25. O'Farrell M., Lewis E., Flanagan C., Lyons W., Jackman N.: Comparison of k-NN and neural network methods in the classification of spectral data from an optical fibre-based sensor system used for quality control in the food industry, Sensors and Actuators B: Chemical 111-112, 2005, pp. 254-362, https://doi.org/10.1016/j.snb.2005.02.003
26. Dutta R., Morgan D., Baker N., Gardner J.W, Hines E.L.: Identification of Staphylococcus aurous infections in hospital environment: electronic nose based approach, Sensors and Actuators B: Chemical 109(2), 2005, pp. 355-362, https://doi.org/10.1016/j.snb.2005.01.013
27. Grover M., Singh B., Bakshi M., Singh S.: Quantitative structure-property relationships in pharmaceutical research – Part 1, Pharm Sci Technol Today 3(1), 2000, pp. 28-35, DOI: 10.1016/s1461-5347(99)00214-x
28. Foster J.G., Rzhetsky A., Evans J.A.: Tradition and innovation in scientists' research strategies, American Sociological Review 80(5), 2015, pp. 875-908, https://doi.org/10.1177/0003122415601618
29. Iacopini I., Milojevic S., Latora V.: Network dynamics of innovation processes, Physical Review Letters 120(4), 2018, https://doi.org/10.1103/PhysRevLett.120.048301
30. Abu-Mostafa Y.S.: Financial model calibration using consistency hints, IEEE Transactions on Neural Networks 12(4), 2001, pp. 791-808, DOI: 10.1109/72.935092
31. Ahn J.J., Kim D.H., Oh K.J., Kim T.Y.: Applying option Greeks to directional forecasting of implied volatility in the options market: an intelligent approach, Expert Systems with Applications 39(10), 2012, pp. 9315-9322, https://doi.org/10.1016/j.eswa.2012.02.070
32. Ahmed P., Swidler S.: Forecasting properties of neural network generated volatility estimates, In: Refenes AP.N., Burgess A.N., Moody J.E. (Eds), Decision Technologies for Computational Finance Advances in Computational Management Science 2, 1998, pp. 247-258, Springer, Boston, MA. https://doi.org/10.1007/978-1-4615-5625-1_19
33. Buehler H., Gonon L., Teichmann J., Wood B.: Deep hedging, Quantitative Finance 19(8), 2019, pp. 1271-1291, arXiv:1802.03042
34. Amilon H.: A neural network versus Black-Scholes: a comparison of pricing and hedging performances, Journal of Forecasting 22(4), 2003, pp. 317-335, https://doi.org/10.1002/for.867
35. Amornwattana S., Enke D., Dagli C.H.: A hybrid option pricing model using a neural network for estimating volatility, International Journal of General Systems 36(5), 2007, pp. 558-573, https://doi.org/10.1080/03081070701210303
36. Masters T.: Practical Neural Networks Recipes in C++, Academic Press, 1993
37. Haenni R., Romeijn J.-W., Wheeler G., Williamson J.: Probabilistic Logics and Probabilistic Networks, Springer Netherlands, 2011, 155 p., https://doi.org/10.1007/978-94-007-0008-6

THE ROLE OF ARTISANS IN THE BATIK DESIGNS DEVELOPMENT AS A TRADITIONAL TEXTILE IN INDONESIA

Desy Nurcahyanti[1], Mulyanto[2] and Agus Sachari[3]

[1]*Fine Arts Department, Faculty of Fine Arts and Design, Sebelas Maret University, Jl. Ir. Sutami 36A, Surakarta, 57126, INDONESIA*
[2]*Arts Education Department, Faculty of Teacher Training and Education, Sebelas Maret University, Jl. Ir. Sutami 36A, Surakarta, 57126, INDONESIA*
[3]*Product Design Department, Faculty of Arts and Design, Bandung Institute of Technology, Jl. Ganesha 10, Bandung, 40132, INDONESIA*
desynurcahyanti@staff.uns.ac.id; mulyanto@staff.uns.ac.id; aasachari@gmail.com

Abstract: *This study aims to examine the background and role of artisans in the development and visualization of batik designs. This background is related to batik design development's cause factors. The role that becomes a research question is the batik artisan involvement in Girilayu, Karanganyar Regency, Central Java, Indonesia. That involvement includes perceptions and participation in adding to the batik designs variety as traditional textiles; that attached to people's lives as a complement to traditional ceremonies and clothing needs. Data collection was carried out by literature review, interview, field observation and interactive methods analysis. The result shows that batik artisans' role motivation as an internal factor contributes to the Girilayu's batik designs development in Karanganyar. External factors that affect, among others, culture, the interaction between a community of crafters in the Girilayu region, beliefs, customs, geographical location, and natural conditions that directly affect the visualization of batik motifs. Design in that case acts as a mediator of the society's mindset and reality in producing product visualization. The role of batik artisans in design development is to produce contemporary motifs inspired by social trends and issues. Batik Girilayu's development designs are influenced by batik artisan ability to elaborate on experiences, insights, sensitivity, functional, contextual expertise and natural conditions that directly influence batik motifs visualization.*

Keywords*: artisans, batik, design development, roles, traditional textiles.*

1 INTRODUCTION

A traditional textile from Indonesia that has an exploratory appeal is batik. The development of batik designs is an interesting topic to research because there are assimilative and acculturative elements. Each batik area has its uniqueness and characteristics, both in decoration and in color. Design development equation lies in process and technique; while the differences are in the pattern, motif, color selection and function of the batik cloth. It adjusts the social life order and the natural environment. It is one indicator of the cultural dynamics of society. Some changes show creativity to adapt to society's condition. For example, Coastal Batik is influenced by social and environmental conditions [1]. Batik artisans in coastal area in which the inhabitants mostly earn from fisheries sector and live in fisheries environment (coastal area) tend to develop marine-themed motifs as well as bright color symmetrical patterns the character of the open society [2]. On the other hand, Inland Batik is influenced by the social and environmental conditions of the kingdom with a series of binding rules and norms. This directs the character of the Inland Batik motif to symmetrical pattern that reflects regularity, a motif with the theme of agrarian life or peasant society, and the choice of earth color that describes modesty [3]. The selection of earthy colors is in harmony with the social and cultural life of the Surakarta and Yogyakarta palaces which have a slow rhythm [4].

Batik from the island of Java is known to be smooth in the manufacturing process, has varied motifs and beautiful colors. Surakarta is one of the locations for the development of batik among batik centers in Central Java. The two palaces resulting from the division of territories stated in the Giyanti Agreement in 1755 and the Salatiga Agreement in 1757 are the Surakarta Palace and the Mangkunagaran Palace. The two places brought cultural influences, including the batik tradition in their respective territories, which is currently known as the Ex-Karesidenan Surakarta [5]. Mangkunagaran is a small kingdom at the level of a district full of regional autonomy to manage government, economy, politics and culture during rulers KGPAA Mangkunagara I to VII. The batik tradition spreads in Klaten (Bayat), Sukoharjo

(Bekonang), Sragen (Kliwonan), Wonogiri (Tirtomoyo) and Karanganyar (Girilayu). The batik designs that come from these four regions are considered contemporary. The resulting of contemporary batik design development is a composition of classic motifs from the palace and new creations of artisans [6]. An interesting area of batik is Girilayu which is located in Karanganyar Regency. Batik Girilayu originated from the batik activities of Astana Mangadeg's and Astana Girilayu's Keymaster. Astana Mangadeg and Astana Girilayu are namely the tombs of KGPAA Mangkunagara I – VIII, their relatives and also families, except for KGPAA Mangkunagara VI in Astana Utara, Nayu, Surakarta. Both of the tombs are located on the highest hill of Girilayu and surrounded by dense forest. KGPAA is stands for Kanjeng Gusti Pangeran Adipati Arya. The title is equivalent to the prince and has power under the king. Girilayu is currently in the administrative village form and became a part of the Karanganyar District nowadays.

The development of motif designs began in 1960 when the Girilayu people had a desire to produce and wear batik with local cultural characteristics. The motif designs developed are inspired by geographical, social, phenomena, trends and consumer tastes [7]. Examples of the development of contemporary batik motif designs are Manggis and Duren Matesih, which are stylized and adapted from the shapes of Mangosteen and Durian fruits which are the leading horticultural products from Matesih, especially Girilayu. Currently being developed are icons of excellent tourism potencies such as the Tri Dharma Monument and the Tri Dharma Gate located in the tomb complex of King Mangkunagaran I, namely KGPAA Mangkunagara I or Pangeran Samber Nyawa (Prince of the Soul Catcher) because he has ability and strategy to subdue his enemies [8]. The batik design icon of the potential for pilgrimage tourism is a source of inspiration based on consumer demand for batik souvenirs with Girilayu's motifs typically. Batik artisans in Girilayu have a perceptive and participatory role in the batik motif design development. Based on the latest data collected from the batik artisans association in Girilayu, namely the Giri Arum community in 2021, there are 12 groups in Girilayu namely Sido Mukti, Mekar Sari, Giri Wastrapura, Vocational, Kube Kirani, Kube Sekar, Truntum Kuncoro, Wahyu Asih, Mekar Jaya, Puta Kembar, Tresno Dharmo and Wahyu Sari. All those groups contribute to the batik design development in Girilayu with motif exploration, combination and innovation from design into the visualization process. Batik motif designs emerged and experienced development because of community ideas. Batik artisans act as executors of public perceptions.

The form of the artisans' role is to participate by visualizing ideas in the form of batik motif designs. Research, on the artisans' role in batik design development as traditional textiles, aims to complement the results of previous studies that missed the social and economic sphere in its discussion. Those are the main components that support culture sustainability and batik tradition as part of the life and livelihood of the Girilayu communities. The selection of Girilayu as the research location was based on the contradictory character of the region as a batik producing area with contemporary motif designs but was strongly influenced by the classical palace style of batik which tends to be full of rules. The results of previous studies have focused on aesthetic factors in the decorative motifs of batik and have not specifically discussed the artisan involvement in design development by involving aesthetic elements. The role of artisan as the first layer of motif design visualizers uses a consideration of complex factors.

2 METHOD

This qualitative research is based on the formulation to reveal problems contextually and to obtain a clear picture of the artisan perceptions and participation in the Batik Girilayu designs development. This qualitative research uses a single case study method to focuses on the target with one characteristic discussion. The intended targets are places and communities that have characteristics role and know the development of Batik Girilayu designs. The study was carried out by observation, literature exploration, and interviews in order to obtain complete data regarding the role of Batik Girilayu designs by the community. The single case study for this research was chosen because the research target in the form of a group of Batik Girilayu artisan has similarities in terms of character pattern and design motifs development. So, that one location was determined namely the batik artisan group or the community [9]. Girilayu was chosen as the research location with consideration of facts and strengthened by data as the largest batik center in Karanganyar, which is still running its business activities from the beginning of Batik Girilayu until now.

The research subjects are batik craftsman and the public who can provide explanations and understand about the Girilayu Batik design. The community includes community leaders, experts, consumers and academics. The concentration of interview data was obtained from resource persons of batik craftsman in Girilayu who have the main role to be fully involved in the batik process and participate in executing perceptions, ideas, materials, aesthetics and functions.

The interview data were completed from outside informants from academics and cultural arts experts. The research locations were spread across seven Batik Girilayu groups, namely the Sido Mukti (Ngadirejo), Wahyu Sari (Seberan), Truntum Kuncoro (Seberan), Tresno Dharma (Wetan Kali), Mekar Sari (Madang), Mekar Jaya (Plombokan), and Vocational (Wetan Kali). These locations act as a place to observe batik activities related to the design process of visualizing ideas and concepts in Batik Girilayu. In this case, artisan and designers have a reciprocal relationship that affects the Batik Girilayu development designs by criticizing each other and providing input to product visualizing. Artisans and designers complement shortcomings based on each other's perspectives and experiences. Artisans have perspective and experience in product visualization, so they know the suitable process and technique description. Meanwhile, the designer has an imaginative point of view and the final result. The data used for the analysis process comes from the motives of Batik Girilayu products that are related and represent problems surrounding the development of the design, in the form of recorded images or camera documentation. Selection of batik motifs based on recommendations from informants. The image is used as a result of data collection which is then analyzed to obtain conclusions about the aspects that surround it. Data processing uses interactive model analysis techniques, including data collection components, data presentation, drawing conclusions (verification) and reduction [10]. Data reduction was carried out from the time of data collection related to the Batik Girilayu design. At the time the data collection took place, data reduction was carried out by focusing on the background, identifying, and determining the formulation of the problem consisting of the background of the emergence, the role of the community and the socio-cultural linkages surrounding Batik Girilayu design development [11]. Husserl's phenomenological approach is used to find out in-depth the intent of the Girilayu Batik design development activity, especially from the social and economic side [12]. This is reinforced by Mohajan's statement in his writing on qualitative research methods that the phenomenological approach is an effective method to explore social behavior in organizational development. This research focuses on efforts to develop batik designs by artisan groups in Girilayu [13]. In this study, the data presented in the form of results consisted of descriptions and findings in the form of descriptions and processes of batik in Girilayu.

3 ANALYSIS

3.1 *Background for design development*

Batik Girilayu design development initially started with changes and updates in batik styles and motifs in 1980 by several batik artisan, after the construction of Astana Giribangun's tomb for the extended family of the 2nd President of Republic of Indonesia HM Soeharto and Mrs. Soeratinah (Mrs. Tien Soeharto). Craftsman made modifications by combining some characteristic features of the prohibition motifs according to the tastes and demands of the time, with priority for pilgrimage [14]. The work resulting from changes and renewal received appreciation and was accepted by the community [15]. Batik figures, entrepreneurs, enthusiasts, experts and artisans contribute to the development of batik designs. Girilayu batik after experiencing development becomes rich with character variations, due to the influence of Pekalongan, Laweyan (Saudagaran) and Madura [16]. Design development inspiration comes from everyday experiences, special events and the tastes of consumers (customers) who are mostly officials through repeated interactions with craftsmen [17]. An example of a batik motif with design development is Truntum Gurda which can be seen in Figure 1 and Truntum Sawunggaling hich can be seen in Figure 2.

Figure 1 The Truntum Gurda motif batik cloth, included in the category of developing classic motif designs by the Girilayu Batik craftsman, Mrs. Maryati, with natural dye of Soga tree wood with the Latin name Peltophorum Pterocarpum

Figure 2 Batik fabric with Truntum Sawunggaling motif by a Batik Girilayu craftsman, Mrs. Sri Wahyuni, included in the category of classic motif design development

Sawunggaling is a folk legend of the East Java region. The influence of East Java on the development of Batik Girilayu designs comes from the tastes of batik consumers from the Surabaya area. Sawunggaling for the Javanese is another representation of Garuda which means heroism [18]. The Truntum Gurda batik motif is a combination of classic Truntum batik motifs with Gurda ornaments. The classic Truntum motif consists of geometric ornaments as a result of the stylization of the stars scattered in the sky, which can be seen in Figure 3. Batik cloth with the Truntum motif is a garment used in the traditional life cycle of Javanese people in Indonesia, namely wedding ceremonies. The Truntum motif batik cloth is used by the parents of the bride and groom. This usage has a philosophical meaning as a prayer for the bride and groom to get along with the joys and sorrows in living a household life, from the origin of the word *tumaruntum* in Javanese to grow a sense of affection [19].

Figure 3 The classic Truntum Batik motif created by the second consort of Paku Buwono III, Kanjeng Ratu Beruk, inspired by the beauty of the stars in the night sky. The motive is an embodiment of the empress's love and longing for the king who is wandering

Figure 4 Gurda ornament inspired by the wing shape of the mythological bird character of the Javanese people, Garuda or Garudeya

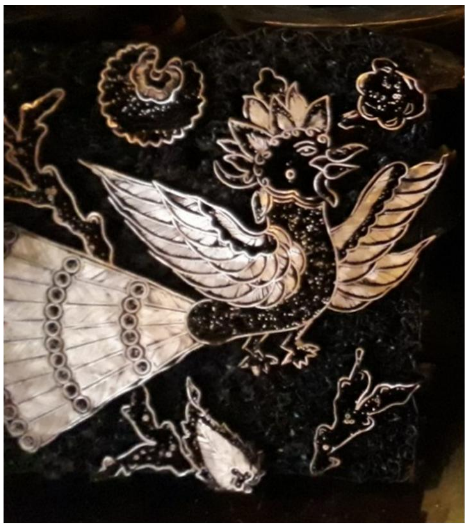


Figure 5 The Jatayu ornament on the copper batik canting cap inspired by the Jatayu bird character from the Ramayana story as a symbol of loyalty and knighthood

The Gurda ornament on the Truntum Gurda batik motif is a stylization of the mythological bird wing of the Javanese people, namely Garuda, which can be seen in Figure 4. The Garuda bird for the Javanese community is a symbol of strength. The mention of Garuda in several ancient manuscripts, namely Garudeya and Garudamukha, is a character from the Mahabharata story as the vehicle of Lord Vishnu and King Airlangga as the incarnation of Lord Vishnu. The Garuda symbol is also found on the reliefs of temples scattered in Central and East Java. Garuda is a decorative element and a metaphor for supreme power so that it is used as a symbol of the Republic of Indonesia namely Garuda Pancasila [20]. Kidal Temple, located in Kidal Village, Tumpang District, Malang Regency, is a building decorated with reliefs and a Garuda statue. Relief and the statue of Garuda in Kidal Temple according to the results of the analysis are the forms used to visualize the symbol of the Republic of Indonesia, based on the position of the beak and grip of the cloth that resembles a ribbon that says Bhinneka Tunggal Ika on the Garuda Pancasila [21]. The character of bird mythology in Javanese society besides Garuda is Jatayu, which is also often described as a batik motif. Jatayu in the Ramayana story is Garuda's nephew. He is a witness to the whereabouts of Sinta's location when Ravana kidnapped her. Jatayu in the Ramayana story is described as a character who sided with goodness [22]. The illustration of ornament with inspiration from Jatayu character can be seen in Figure 5.

Figure 6 The lush mountain nature at the foot of the Lawu Mountains supports the Girilayu people with their livelihoods as farmers. Vegetable and fruit products in Girilayu supply the food needs of the people of Karanganyar Regency and its surroundings

Figure 7 The view of the mustard garden that stretches out in Girilayu has inspired the development of batik motif designs

Themes or topics used as inspiration and ideas for the development of Batik Girilayu designs are phenomena of the community and the natural conditions of Girilayu in the form of hills, mountains, forests, agricultural land and plantations. Girilayu in Javanese comes from the word *giri* which means mountain and *layu* which means death or the end. Etymologically, it has a negative connotation with the mountain of death, because the village was chosen by the leader of Mangkunagaran Palace i.e. KGPAA Mangkunagara I as the final resting place for himself, his family and his descendants. However, the meaning of the name Girilayu is inversely proportional to its lush, green and beautiful natural situation. Illustrations of the natural and agricultural atmosphere in Girilayu can be seen in Figures 6 and 7. These thriving crops have inspired the development of Batik Girilayu designs including the Tepas Ros batik motif which comes from the Javanese word *tepas* which means hand fan and *ros* means rose flower, which can be seen in Figure 8. The Tepas Ros batik motif means that a person's good name depends on his actions, like someone who spreads coolness to other people who symbolized by a hand fan, then the goodness of the fragrant smells in various parts of the place symbolized by the rose flower representing beauty and fragrance. In ancient times, according to information from the people of Girilayu, roses were planted in the house yard, because they were used as flowers for grave pilgrimages and were sold to pilgrims. The new rule for grave pilgrims not to bring the sow flowers and dangerous thorns of the rose plant causes the plant to be cleaned from the yard [23].

Figure 8 The batik motif of Tepas Ros by Girilayu Batik craftsman, Mrs. Dwi Sunarti, which symbolizes a person's fragrant name will be obtained from good and beneficial actions

3.2 *The role of artisans in the development of Batik Girilayu designs as traditional textiles*

Girilayu Batik artisans play a role and influence the development of Batik Girilayu designs. This is evidenced by the emergence of new Batik Girilayu motifs by batik craftsman in Girilayu. The batik business in the area is located in one village area and is divided into 7 groups of craftsman, namely the Sido Mukti in Ngadirejo area, Wahyu Sari in Seberan area, Truntum Kuncoro in Seberan area, Tresna Dharma in Wetan Kali area, Mekar Sari in Madang area, Mekar Jaya in Plombokan area, the Vocational Group in Wetan Kali area belongs to the village government. The data is the result of information and instructions from the Girilayu Village Government, participation of local governments and government agencies through the CSR program in providing additional operational capital, training facilities, business support equipment and appropriate technology [24]. Bank Indonesia as the official bank of the Indonesian government is the agency that provides capital support and cooperation through programs on a national and international scale. The support of the Bank Indonesia program is in line with the activities of batik crafters in design development through collaboration between batik artisans and Indonesian fashion designers. Community and batik artisans are motivated to develop designs to show their identity and bring out the distinctive features of Batik Girilayu which have differences in terms of decorative details. These characteristics are a description of the geographical atmosphere, historical heritage and economic potential that exists in Girilayu. Batik is for Girilayu communities the foundation of life. The life that is meant by the Girilayu community is to live spiritually as a means of contemplation, become an education media form, and be economically able to improve welfare, even though it is not a primary object needed daily [25].

Figure 9 The new batik creations are the result of the development of designs by Batik Girilayu craftsman, Ms. Reni Supentangin, featuring butterfly motifs with soft color nuances, portraying a subtle and cheerful female character

4 DISCUSSION

The development work of the Girilayu Batik motif design is visualized in various forms of clothing designed by designers Tuty Adib and Djongko Raharjo. The works of the craftsman and the designs of designers Tuty Adib and Djongko Raharjo can be seen in Figures 9-11 [25]. The collaborative work was presented in an exhibition and fashion show entitled Pesona Batik Girilayu which took place on November 20, 2020 at Solia Zigna Hotel, Kampung Batik Laweyan, Surakarta. At the exhibition, batik products by batik craftsman from Girilayu were shown which were collaborated into fashion designs for women who wear hijab and a market for young women with an age range of 20-40 years. The event was also designed as a socialization for the public to be proud wearing clothes that made by Indonesian traditional fabric craftsman i.e. batik. Illustration of batik wearing as everyday clothes can be seen in Figures 12-14. Facilitation support from the government stimulates Batik Girilayu craftsmen to be more active and motivated to make new designs by adjusting market trends and demands [26].

Figure 10 The designer and owner of the BILQIS Muslimah Fashion House, Ibu Tuty Adib, along with the models wearing the collaborative designs of batik fabrics by Batik Girilayu craftsman, Ms. Reni Suprihatin

Figure 11 The famous Indonesian fashion designer from Solo (Surakarta), Mr. Djongko Raharjo, together with the models wearing his designs using batik cloth by Batik Girilayu craftsman Mrs. Yuliasih

Figure 12 The use of Batik Girilayu cloth for daily clothing for men consists of a headband, batik shirt and batik sarong

Figure 13 The use of Batik Girilayu cloth for daily clothing for women consists of batik kebaya and cloth with natural dyes from Secang wood extract

Figure 14 Fashionable batik clothing without cutting the fabric with a wrap and drapery system even though wearing classic motifs that are characteristic of Batik Girilayu

Basic knowledge of batik and carefulness in reading opportunities and trends are the capital for batik crafters to work. Indirectly, they have applied the aspects that must be considered in making textile designs, namely aesthetic functions, materials, fashion trends, consumer tastes and marketing. This can be an indicator of the efforts and activities of the Batik Girilayu artisans towards the goals and contributions of the development of batik designs as traditional textiles which are described in tabular form (can be seen in Table 1).

Table 1 is a summary of the roles and efforts of Batik Girilayu artisans who are supported by the community consisting of figures, government, consumers, and resellers, forming a support system and a special network in the development of Batik Girilayu designs. Braiding boils down to artisan as the main motor who carries out design development [27]. The role of a figure includes mentoring or as an advisory body. They consist of senior batik artisans belonging to the maestro category who are worthy of providing direction and insight into the traditions in the Girilayu region. The analysis description aspect explains that the function of aesthetics, materials, fashion trends, consumer tastes and marketing based on theories that emphasize internal and external aspects of the textile design development [28].

The traditional knowledge possessed by future generations comes from these maestro figures. An example of their role is to provide information about the name of motive, function, meaning and procedure for its use in every traditional celebration such as marriage, death and cleaning the village. The government's role, consumers and resellers are to encouraging the artisans to be able to fulfill orders according to the tastes or desires of the order. Batik Girilayu design is diverse as a positive impact on various consumer orders or desires.

Table 1 The role and efforts of Girilayu Batik craftsmen in the development of batik designs as traditional textiles

No.	Aspect reviewers	Changes in conditions and situations as a result of the development of batik designs by craftsmen	
		Before	After
1.	Function	As clothing	As clothing, complementary materials, complementary items for daily needs and souvenirs
2.	Aesthetics	Mangkunagaran Batik classic motifs and colors or Surakarta's style	Motifs and colors are a combination of Pesisiran Batik (Pekalongan) and East Java batik, especially Sidoarjo and Madura
3.	Material	2nd quality cotton fabric and natural dyes	1st quality cotton fabric, silk fabrics, pineapple fiber fabrics, banana fiber fabrics as well as a combination of natural and synthetic dyes
4.	Fashion trends	Classic batik patterns and motifs	Patterns and motifs conform to fashion trends directed by the Fashion Designers Association and suit consumer tastes
5.	Consumer tastes	For the upper middle class and the majority used by adults to old age	For the upper to lower class and can be used by ages ranging from children, adolescents, adults and the elderly
6.	Marketing	Officials, batik entrepreneurs, and individuals through direct sales (door to door)	Individuals, companies, designers, batik entrepreneurs, exclusive batik material textile shops, national and international scale exhibitions, imports to the Southeast Asian region, especially Malaysia, Brunei and Singapore as well as for the European region, especially the Netherlands and France, marketing through online shops (using social media and official web)

As the findings are role of the artisans is executor in an embodiment of design based on personal imagination as a result of accumulated experiences, insights, seeing the natural surroundings, phenomena in society and market trends. The efforts of the artisans to accommodate various inputs and wishes of various parties for visualizing batik motifs form their position as a key in the development of batik designs. Girilayu Batik designs are diverse as a positive impact on various consumer orders or desires. Government and designers are the support system that gets the benefits from batik design development. Their relationship is symbiotic [29]. The government gets benefits from the increase in the performance of gross domestic products due to increased sales and community activities, especially in Girilayu. The community and artisans also get benefit from legality and administrative support to strengthen branding as a regional superior product. Designers get material benefits for their design products produced by authentic local resources. This provides a significant advantage in reducing operating costs. Community and artisans also get the benefits of being able to learn to improve the quality performance of designer-class products that usually have high standards and details.

5 CONCLUSIONS

Social and cultural factors in the development of Batik Girilayu designs become the dominant influence on the visualization of new creative motifs. This can be seen through the various elements of ornamentation, decoration and design characters of the work of Batik Girilayu artisans. Girilayu batik artisans have a lineage of Mangkunagaran's Keymaster who have premium quality batik skills. Their ancestors previously carried out batik activities as a means of contemplation and fulfilled requests of court officials for traditional ceremonies and pilgrimages. This influenced the design lines developed by batik artisans in Girilayu.

Cultural conditions are related to the development of Batik Girilayu designs, reflected in the themes and topics that underlie ideas or inspire artisans. This was stated by the majority of speakers consisting of batik artisans in Girilayu. Trees, plants, mountains, hills, forests, nearby objects and daily activities are ideas that continue in the visualization of batik motif designs. Social interactions that are still maintained based on the values and norms of the community have become a phenomenon captured by artisans to become new design motives. The major influence associated with the development of Batik Girilayu designs is the culture of Mangkunagaran Palace. The journey of Batik Girilayu stems from the social and cultural scope of the palace to the scope of society where acculturation occurs which results in new cultural forms. Social and culture are intertwined in the Batik Girilayu culture which plays a role in the development bridged by the design of the batik motif. A series of ideas, experiences, needs, elements and aspects that exist in the behavior of the Girilayu people are directed by design in order to produce factual objects called Batik Girilayu.

ACKNOWLEDGMENT: The authors would like to express the gratitude to Universitas Sebelas Maret for fully supporting the research with the UNS 2020 PNBP Doctoral Dissertation Research funds and the Girilayu Batik artisans i.e. Mrs. Dwi Sunarti, Mrs. Maryati, Mrs. Yuliasih and Mrs. Reni Suprihatin, who have been cooperative to provide all information and documentation of the works for this article.

6 REFERENCES

1. Moussaïd M., Kämmer J.E., Analytis P.P., Neth H.: Social influence and the collective dynamics of opinion formation, PLOS ONE 8(11), 2013, e78433, https://doi.org/10.1371/journal.pone.0078433
2. Septiana U., Sunarya Y.Y., Haldani A.: Comparative studies between Bakaran's traditional batik patterns and Keraton Surakarta's batik patterns (Studi komparatif antara ragam hias batik tradisional Bakaran dengan ragam hias Batik Keraton Surakarta), ITB Journal of Visual Art and Design 5(1), 2013, pp. 20-34, http://dx.doi.org/10.5614%2Fitbj.vad.2013.5.1 (in Indonesian)
3. Stephenson N.: The past, present, and future of Javanese Batik: A bibliographic essay, Art Documentation: Journal of the Art Libraries Society of North America 12(3), 1993, pp. 107-113, https://www.jstor.org/stable/27948560
4. Kusumawati M.D., Hartowiyono E.R.: Philosophy, design batik Yogyakarta, and batik Surakarta made in Indonesia, International Journal of Latest Trends in Engineering and Technology 8(3), 2017, pp. 91-99, http://dx.doi.org/10.21172/1.83.012
5. Kurniadi E., Sarwono, Dartono F.A.: The Dynamics of Batik Art at Kampoeng Batik Laweyan of Surakarta, Proceeding of 2nd International Conference on Art, Language, and Culture, Graduate Program of Universitas Sebelas Maret, November 2017, Universitas Sebelas Maret, Indonesia, Nugraha D.A., Sulistyo E.T. (Eds.), pp. 451-458
6. Nurcahyanti D., Sachari A., Destiarmand A.H.: The role of Javanese local wisdom to traditional batik in Girilayu, Karanganyar, Indonesia (Peran kearifan lokal Masyarakat Jawa untuk melestarikan batik tradisi di Girilayu, Karanganyar, Indonesia), MUDRA Jurnal Seni Budaya 35(2), 2020, pp. 145-153, https://doi.org/10.31091/mudra.v35i2.816 (in Indonesian)
7. Mulyanto, Prameswari N.S., Afatara N., Hartono L.: Pattern design and motif placement of batik sanggit in short-sleeve shirt style, Vlakna a Textil (Fibres and Textiles) 26(2), 2019, pp. 37-42, http://vat.ft.tul.cz/2019/2/VaT_2019_2_7.pdf

8. Ricklefs, M.C.: The origin of prince Mangkunagara's I appelation as the catcher of souls, Journal of the Humanities and Social Sciences of the Southeast Asia and Oceania 171(4), 2015, pp. 543-548, https://doi.org/10.1163/22134379-17104003
9. Ebneyamini S., Moghadam M.R.S.: Toward developing a framework for conducting case study research, International Journal of Qualitative Methods 17(1), 2018, pp. 1-11, https://doi.org/10.1177/1609406918817954
10. Hussein A.: The use of triangulation in social science research: Can qualitative and quantitative methods be combined?, Journal of Comparative Social Work 4(1), 2009, pp. 1-12, https://doi.org/10.31265/jcsw.v4i1.48
11. Verdinelli S., Scagnoli N. I.: Data display in qualitative research, International Journal of Qualitative Methods 12(1), 2013, pp. 359-381, https://doi.org/10.1177%2F160940691301200117
12. Qutoshi S.R.: Phenomenology: A philosophy and methodology in social sciences and related subjects, Journal if Education and Educational Development 5(1), 2018, pp. 215-222, http://dx.doi.org/10.22555/joeed.v5i1.2154
13. Mohajan H.K.: Qualitative research methodology in social sciences and related subjects, Journal of Economic Development, Environment and People 7(1), 2018, pp. 23-48, https://doi.org/10.26458/jedep.v7i1.571
14. Syamwil R., Sugiarto E., Rohidi T.R., Nurrohmah S.: Weeds as a source of development idea on batik motive, Vlakna a Textil (Fibres and Textiles) 26(2), 2019, pp. 69-73, http://vat.ft.tul.cz/2019/2/VaT_2019_2_12.pdf
15. Wardoyo S.: Aesthetics study of Girilayu's batik motif in Karanganyar regency (Kajian estetika motif Batik Girilayu Kabupaten Karanganyar), CORAK Jurnal Seni Kriya 7(2), 2018, pp. 117-126, https://doi.org/10.24821/corak.v7i2 (in Indonesian)
16. Nurcahyanti D., Sachari A., Destiarmand A.H.: Regional potencies as a visual character in Girilayu's batik design (Potensi wilayah sebagai karakter visual dalam desain Batik Girilayu), Proceedings of Seminar Nasional: Seni, Teknologi, dan Masyarakat #4, Main Theatre Hall of Institut Seni Indonesia Surakarta, October 2019, ISI Surakarta Press, Indonesia, Guntur (Ed.), pp. 86-92 (in Indonesian)
17. Nurcahyanti D., Affanti T. B.: Contemporary batik design development based on regional potential and local wisdom (Pengembangan desain batik kontemporer berbasis potensi daerah dan kearifan lokal), Jurnal Sosioteknologi 17(3), 2018, pp. 391-402, http://dx.doi.org/10.5614%2Fsostek.itbj.2018.17.3 (in Indonesian)
18. Firmansyah A.Y.: Types and motifs in the folktales of Sawunggaling in Surabaya, NOBEL Journal of Literature and Language Teaching 8(1), 2017, pp.49-59, https://doi.org/10.15642/NOBEL.2017.8.1.49-59
19. Priyanto D., Wuryani, S.P.F.: Human fetal development and the ways of asthabrata as an idea in the creation of Sinjang Batik Tulis, Cultural Syndrome 1(2), 2020, pp. 96-106, https://doi.org/10.30998/cs.v1i2.231
20. Fibiona I.: Indonesiana cultural platform (Indonesiana Platform Kebudayaan), Available from https://kebudayaan.kemdikbud.go.id, Accessed: 2020-11-29 (in Indonesia)
21. Widianto E.: Terracotta (Terakota), Available from https://www.terakota.id, Accessed: 2020-11-29 (in Indonesian)
22. Sugara H.: Study of deconstruction characterization of Rahwana in Ramayana novel by Sunardi DM related to character education and cultural value, Journal Bahasa 1(2), 2019, pp. 71-85, https://doi.org/10.26499/bahasa.v1i2.12
23. Ismail E.H.: Republika (Republika), Available from https://republika.co.id, Accessed: 2020-11-29 (in Indonesia)
24. Tilt C.A.: Corporate social responsibility research: the importance context, International Journal of Corporate Social Responsibility 1(2), 2016, pp. 1-9, https://doi.org/10.1186/s40991-016-0003-7
25. Sachari A., Puspita A.A., Nurcahyanti D.: Girilayu Batik Motifs and their Forms of Symbolic Contemplation, Cultura International Journal of Philosophy of Culture and Axiology 17(2), 2020, pp. 207-216
26. Hwang J.Y.: How fashion designer think: The influence of cultural value in the creative design process, Journal of Fashion Technology and Textile Engineering 8(1), 2020, pp. 1-7, DOI: 10.37532/jfte.2020.8(1).185
27. Wever R., Vogtländer J.: Design for the Value of Sustainability. In: Handbook of Ethics, Values, and Technological Design, van den Hoven J., Vermaas P., van de Poel I. (Eds.) Springer, Dordrecht, 2014, pp. 1-31, https://doi.org/10.1007/978-94-007-6994-6_20-1
28. Valentine L., Ballie J., Bletcher J., Robertson S., Stevenson F.: Design thinking for textiles: let's make it meaningful, The Design Journal 20(1), 2017, pp. 964-976, https://doi.org/10.1080/14606925.2017.1353041
29. Temeltas H.: Collaboration and exchange between "craftsman" and "designer": symbiosis towards product innovation, The Design Journal 20(1), 2017, pp. S3713-S3723, https://doi.org/10.1080/14606925.2017.1352876

THE EFFECT OF ALTERNATIVE FILLERS BASED ON POLYPROPYLENE WASTE FROM FIBERS AND FOILS PRODUCTION ON PROPERTIES OF RUBBER COMPOUND

Mariana Pajtášová[1], Katarína Holcová[1,2], Darina Ondrušová[1], Róbert Janík[1], Petra Skalková[1], Silvia Ďurišová[1] and Andrej Dubec[1]

[1]*Department of Material Technologies and Environment, Faculty of Industrial Technologies in Púchov, Alexander Dubček University of Trenčín, I. Krasku 491/30, 020 01 Púchov, Slovak Republic*
[2]*Research Institute for Man-Made Fibres, JSC, Štúrova 2, 059 21 Svit, Slovak Republic*
[1]*mariana.pajtasova@tnuni.sk,* [2]*vuchv@vuchv.sk*

Abstract: *The submitted study represents the research of alternative fillers based on polypropylene (PP) waste from the production of PP fibres and PP foils and its application in the polymeric materials applied in rubber industry. Properties of alternative fillers based on PP fibers and PP powder were studied by spectral and thermal analysis. The study is aimed at the use of polypropylene fibres and polypropylene powder as fillers in rubber blend as a partial replacement of carbon black. The influence of amount and the type of used alternative filler in rubber blend was evaluated. Curing characteristics of prepared tread blends were studied. Physical-mechanical properties before and after accelerated thermal aging in air and dynamical mechanical properties of prepared vulcanizates were determined and studied. The evaluation of prepared tread blends respectively tread vulcanizates results the possibility of partial replacement of common used carbon black N339 by studied PP fibres and PP powder.*

Keywords: *polypropylene, alternative fillers, curing characteristics, physical-mechanical properties, dynamical and mechanical analysis.*

1 INTRODUCTION

Rubber blends consist of various additives whose representation can be up to 80% of the final blend. The development of industrial polymer production is progressing very fast and it is focused mainly to improve the properties of polymeric materials or the combination of different types of polymers. The combination of polymeric materials and addition of various ingredients into a rubber blend is very important to achieve specific performance [1-5].

Additives, mainly fillers significantly affect the physical and mechanical properties of the final product. Fillers are usually solid substances in form of a powder or short fibers. The improvement of the resulting vulcanizates properties is called stiffening [6-12].

Fillers are added to the rubber blend in order to adjust processing properties of the blend, to decrease elasticity, improve physical and mechanical properties, adhesion or aging resistance. On the other hand, fillers help to decrease the cost of the final product [6, 7, 13, 14]. Stiffening effect is formed due to the formation of the physical and chemical bonds between the filler and rubber, that is why the stiffening degree depends on a particle size, specific surface area or porosity and others [1, 4, 8, 15, 16].

For the development of automotive industry is also highly perspective the use of renewable sources of raw materials and the use of products such as starch, cellulose or lactic acid. The suitable renewable products are microbial polymeric materials e.g. polylactide fibers due to their biodegradation and other materials e.g. polypropylene powder respectively polypropylene fibers or alternative clay minerals and silica [13-18].

A polypropylene chain is formed by the carbon atoms, while every second atom is connected to the functional methyl group. According to the position of the functional methyl group is polypropylene PP divided into three types: isotactic, syndiotactic and atactic. Wide range of applications and unique polypropylene properties such as low density, high chemical resistance or resistance to heat or oil and high crystallinity makes PP suitable for application in rubber industry as the alternative filler [12-21].

This work is aimed at the evaluation of curing properties of prepared tread blends, physico-mechanical properties before and after acceleration thermal aginig and dynamic mechanical properties of vulcanizates with a certain content of alternative filler based on polypropylene waste from fibers and foils production, such as polypropylene powder and polypropylene fibers and its impact in automotive industry.

2 EXPERIMENTAL

2.1 Materials

Various types of fillers were examined, namely polypropylene waste from polypropylene fibers or foils production. Short polypropylene fibers (Figure 1) and polypropylene powder (Figure 2) were used instead of commonly used active filler – carbon black (N339) in rubber industry. Polypropylene fibers were used from isotactic polypropylene from the production of textile fibers. The length of the polypropylene fibers was from 0.1 - 100 mm. Polypropylene powder is a waste from the production of polypropylene foils that have been made from hardened polypropylene. The particle size of the polypropylene powder was from 20 to 200 µm.

Alternative fillers based on polypropylene fibers (abbreviated in this work as PV) or polypropylene powder (abbreviated in this work as PP), partially replaced the filler carbon black N339 (87 phr - *parts per hundreds of rubber*) in the amount of 1 phr (PP-1, PV-1), 5 phr (PP-5, PV-5) or 10 phr (PP-10) in the preparation of rubber compounds intended for treads.

2.2 Methods and preparation of rubber composites

Evaluation methods of thermal and spectral properties of alternative polypropylene fillers include differential scanning calorimetry (DSC) and infrared spectroscopy (FTIR).

DSC method was performed on a Perkin Elmer DIAMONT DSC instrument. Heating program was started at an initial temperature of 30°C and increased at a constant rate of 10°C/min to a final temperature of 200°C.

Crystalline content was calculated by formula (1), where *Kp* is crystalline content [%], ΔH^{+} is enthalpy of melting, ΔH (198.11 J/g) is enthalpy of melting of a completely crystalline polymer.

$$K_P = \frac{\Delta H^{+}}{\Delta H} *100 \qquad (1)$$

Infrared spectra of studied polypropylene fibers and powder were measured by spectrometer IFS8400S with Fourier transformation by a KBr tablet technique.

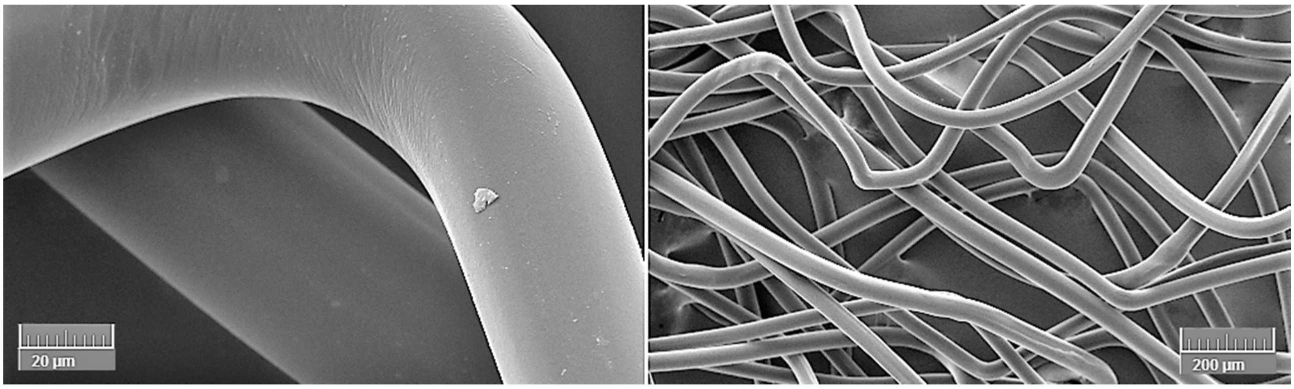


Figure 1 SEM images of short polypropylene fibers

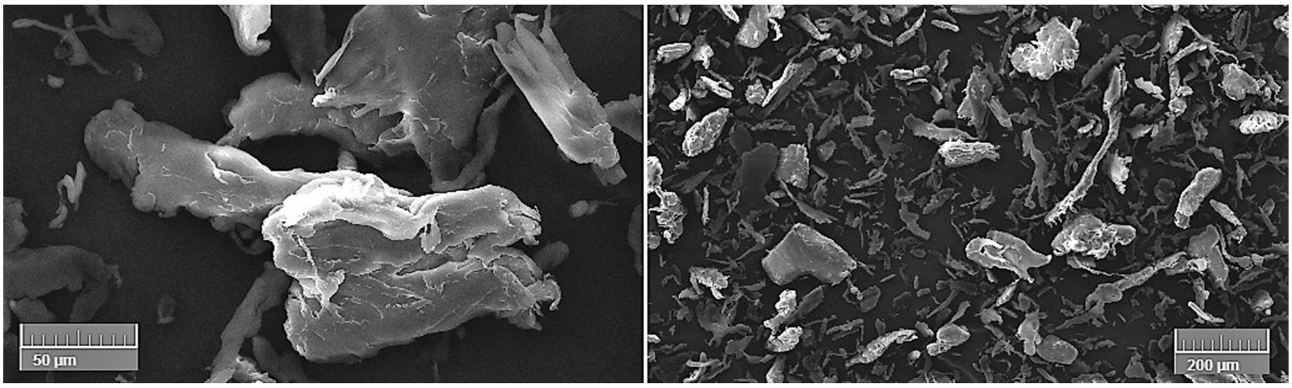


Figure 2 SEM images of polypropylene powder

The subjects PP fibers and PP powder were analyzed by a thermosemission scanning electron microscope in the secondary electron mode. Scanning electron microscopy (SEM) images of the PP fibers (Figure 1) and PP powder (Figure 2) were taken using the Vega 3 Tescan scanning electron microscope with EDX analyser x-act; Oxford Instruments. Image magnification was in the range of 100 to 1 000 x. HV (accelerating voltage): 0.20 - 30 kV, beam intensity level: 1 - 20, absorbed current: 1 pA - 35 nA. The fibers were ultrasonically cleaned, fixed on a conductive substrate and plated with Au-Pd alloy to achieve the optimal signal from the analyzed areas. This type of analysis allows the visualization of the micromorphology of the surface structures of the fibers for their evaluation. The fibers were observed in a macro view and also in a more detailed view of their surface micromorphology.

Synthetic rubber - SBR, activator of curing process - ZnO, stearic acid, accelerator of curing process based on N-cyclohexyl-2-benzothiazolesulfenamide, curing agent - sulfur, plasticizer - aromatic oils, relevant antioxidants and fillers (commercially used carbon black filler N339 and fillers based on polypropylene PP - as waste from the production of PP fibers and foils were used to prepare rubber compound.

The rubber compounds were prepared in kneading machine Plastrograf BRABENDER at a temperature of 120°C in stage I and at 100°C in stage II, at a speed of 50 rpm. After the first and second stage, the prepared rubber compounds were homogenized on laboratory twin-cylinder. 6 tread rubber compounds with different amount of filler were prepared. Curing characteristics of prepared rubber blends were measured on the instrument RHEOMETER 100 MONSANTO at the temperature of 150°C for 60 min. Basic parameters such as minimum and maximum torque, the onset of curing process t_s, optimal curing time $t_{c\ (90)}$ and optimal curing rate coefficient R_v (2) which characterizes the induction period length of the curing curve [min^{-1}] were measured by rheometer instrument.

$$R_V = \frac{100}{t_{c(90)} - t_s} \qquad (2)$$

Physical-mechanical properties of prepared vulcanizates were measured on the ZWICK blasting device at the laboratory temperature of 25°C.

Tensile strength was determined by formula (3) where F_m is max. recorded strength [N], W is width of the narrowed part of the cutting knife [mm] and t - thickness of working part [mm].

$$TS = \frac{F_m}{W.t} \qquad (3)$$

Elongation at break (E_b) was determined by formula (4), where L_b - length of the working part at break [mm], L_0 - initial length of the working part [mm].

$$E_b = \frac{100.(L_b - L_0)}{L_0} \qquad (4)$$

Hardness of resulting vulcanizates was determined by tester according to IRHD. Change of the physical-mechanical properties given by accelerated thermal aging in air can be determined by general formula (5), where A_0 is a physical property before accelerated thermal aging in air and A_1 is a physical property after accelerated thermal aging in air.

$$S = \frac{A_1 - A_0}{A_0} * 100 \qquad (5)$$

Dynamical-mechanical properties of selected vulcanizates were measured on DMA Q800, TA instruments device at temperature range from -70°C to 40°C, at frequency 1 Hz with a heating and cooling rate of 3°C/min^{-1}, an amplitude of 20 μm.

3 RESULTS AND DISCUSSION

3.1 Study of spectral and thermal properties of prepared alternative fillers

Infrared spectroscopy was used to study spectral properties of PP fibers and PP particles (powder form). Significant absorption peaks corresponding to the valence vibration of methyl group $–CH_3$ were observed in the area ~2960 - 2723 cm^{-1}. Characteristic absorption peaks of PP were observed at wavenumber ~1458 cm^{1}, corresponding to the asymmetric deformation vibration of $–CH_3$ group and peak at wavenumber ~1377 cm^{-1} which corresponds to deformation vibration of $–CH_2$ [22]. Absorption peaks at wavenumber ~997 - 974 cm^{-1} correspond to valence vibration of $–CH_3$ group.

Thermal properties are described in Table 1, where T_m is sample melting point, ΔH is enthalpy of sample melting point, K_p is crystalline content [%]. The results show that the melting temperatures T_m of the studied samples of materials are comparable. The highest values of the enthalpy of melting ΔH are shown by polypropylene fibers. Crystalline content K_p results of PV and PP powder are comparable.

Table 1 Thermal properties of polypropylene fibers and polypropylene powder

Sample	T_m [°C]	ΔH [J/g]	K_p [%]
Polypropylene fibers	169.7	71.22	35.95
Polypropylene powder	169.8	69.15	34.90

3.2 Study of vulcanization characteristics of tread blends

Table 2 shows the results of determination of curing characteristics of selected parameters (minimum M_L and maximum M_H torque, curing rate coefficient R_v, safety processing t_s and optimal $t_{c(90)}$ curing time) of tread blends, namely standard ST, blend samples containing 1 phr of PP powder as a filler (PP-1), samples PP-5 containing 5 phr of PP powder, blend samples PP-10 containing 10 phr of PP powder and samples of blends containing 1 phr of PP fibers (PV-1) and samples PV-5 containing 5 phr of PP fibers. Vulcanization characteristics results are shown in Figures 3-6.

The resulting values of minimal torque M_L (Figure 3) of analysed samples PV-1, PV-5 and PP-10 are comparable to minimal torque M_L of standard sample ST. Except for the sample PP-5 with PP powder, where value of minimal torque was lower than minimal torque M_L of standard sample.

In the case of the PP-1 sample containing 1 phr of filler, based on polypropylene powder, an increase in the minimum torque M_L is visible compared to the standard ST, which indicates a higher stiffness and viscosity of the sample with polypropylene powder. Maximum torque M_H of all tread blends is comparable to maximum torque M_H of standard sample ST. The highest maximum torque was obtained in the sample of blend PV-1, based on the PP fibres, compared to standard ST sample.

Almost all tread compounds obtained lower safety processing values t_s (Figure 4), compared to the standard´s safety processing value. The increase of t_s is visible at the sample PV-5, which positively affects processing and physical-mechanical properties of given vulcanizate.

Almost all tread blend samples obtained optimal curing time values $t_{c(90)}$ (Figure 5) smaller than standard ST sample. For the sample PV-5, a slight increase in $t_{c(90)}$ is observed over the standard ST.

The resulting values of curing rate coefficient *Rv* (Figure 6) are comparable for all tread compounds with the standard´s curing rate coefficient *Rv*, which indicates an efficient and intense mutual interactions of the used curing system components.

Table 2 Vulcanization characteristics of tread compounds ST, PP-1, PP-5, PP-10, PV-1 and PV-5

Samples	M_L [N.m]	M_H [N.m]	t_s [min]	$t_{c(90)}$ [min]	R_v [min^{-1}]
ST	6.9	29.8	7.60	16.80	10.87
(PP-1)	7.5	30.0	7.15	16.55	10.64
(PP-5)	6.4	29.2	7.31	16.54	10.83
(PP-10)	7.0	28.9	6.94	16.10	10.92
(PV-1)	7.1	30.7	6.53	15.90	10.67
(PV-5)	6.8	29.2	7.84	16.86	11.09

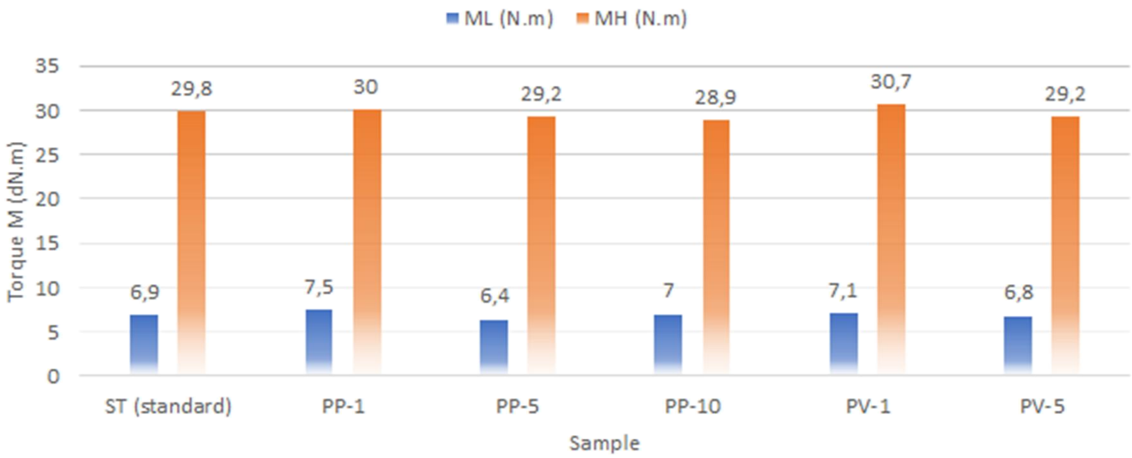


Figure 3 Minimum and maximum torque of tread blends ST, PP-1, PP-5, PP-10, PV-1 and PV-5

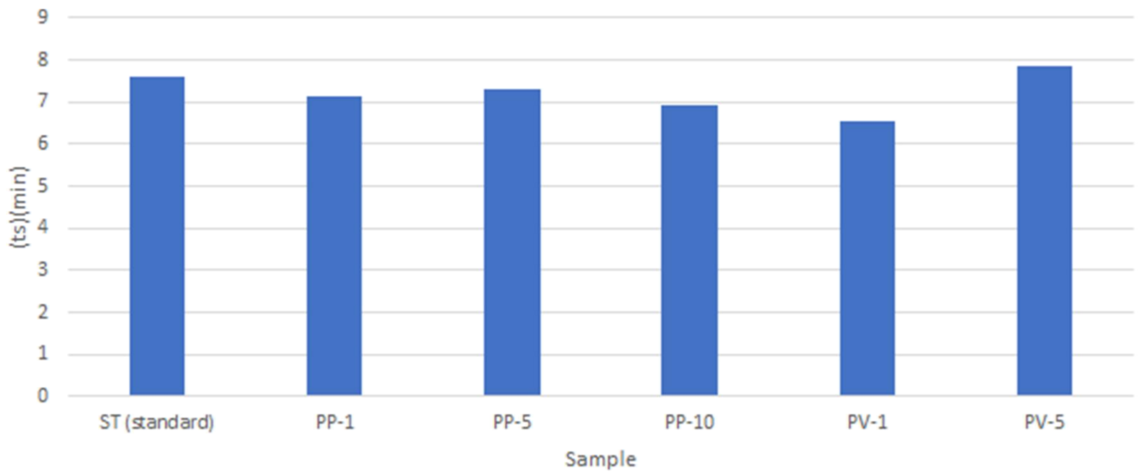


Figure 4 Safety processing of tread blends ST, PP-1, PP-5, PP-10, PV-1 and PV-5

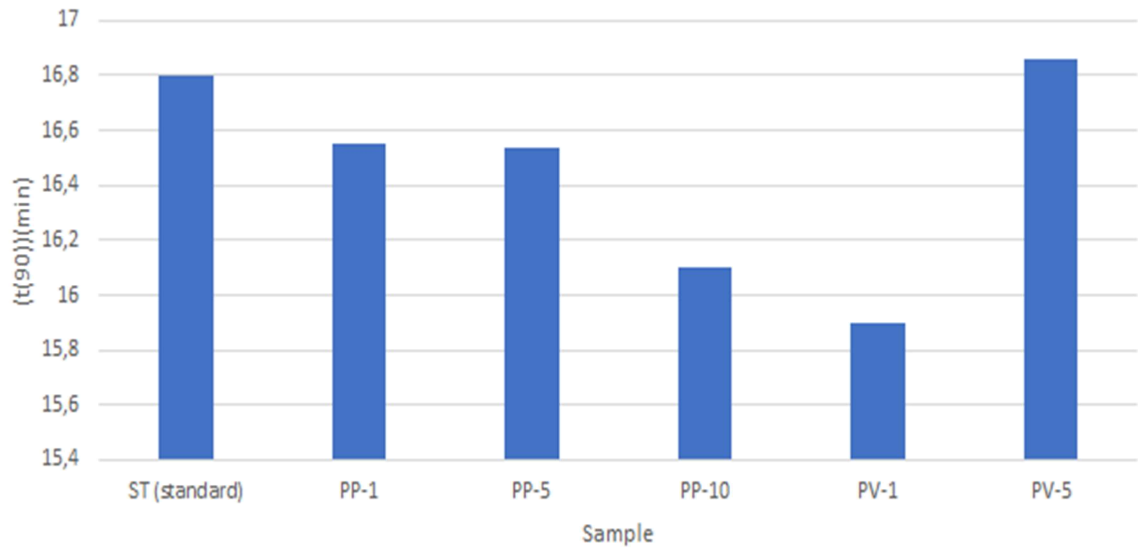


Figure 5 Optimal curing time of tread blends ST, PP-1, PP-5, PP-10, PV-1 and PV-5

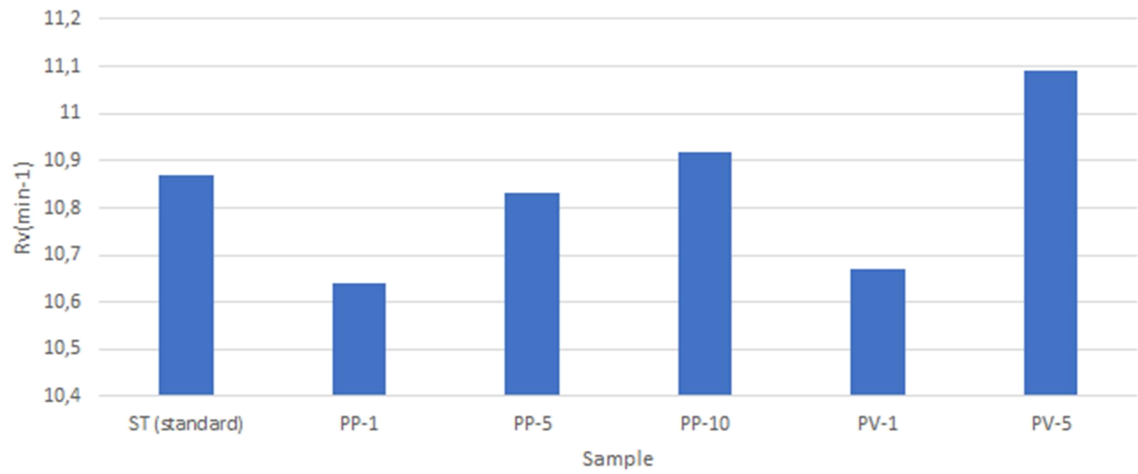


Figure 6 Curing rate coefficient of tread blends ST, PP-1, PP-5, PP-10, PV-1 and PV-5

3.3 *Study of the physical-mechanical properties before and after accelerated thermal aging*

Table 3 represents the results of the physical-mechanical properties (hardness, elongation at break and tensile strength) of studied vulcanizates (PP-1, PP-5, PP-10, PV-1 and PV-5) and standard ST before accelerated thermal aging. The results of physical-mechanical properties of studied vulcanizates and standard sample after accelerated thermal aging are given in Table 4. The results of selected physical-mechanical properties before and after accelerated thermal aging are visible in Figures 7-9.

Measured hardness values (Figure 7) were slightly higher for all tread vulcanizates before accelerated thermal aging compared to the hardness values of standard ST sample.

In case of the PV-5 sample with 5 phr PP fibres are hardness results the same before and after accelerated thermal aging.

Results from the elongation at break measurements of tread vulcanizates (Figure 8) show that the elongation at break of all studied samples is lower compared to the standard ST, which indicates a lower elasticity of prepared vulcanizates. The smallest elongation at break is achieved by the PP-10 sample with filler content 10 phr based on PP powder.

Table 3 Physical-mechanical properties of tread vulcanizates before accelerated thermal aging in air

Sample	Hardness [IRHD]	Elongation at break [%]	Tensile strength [MPa]
ST	66±1.09	321±6.88	17.71±0.70
PP-1	69±1.94	282±26.80	16.06±1.40
PP-5	71±1.09	295±4.81	15.84±0.14
PP-10	71±1.09	230±7.59	14.06±0.26
PV-1	72±1.64	272±3.91	16.87±0.57
PV-5	73±0.00	283±12.69	14.63±0.52

Table 4 Physical-mechanical properties of tread vulcanizates after accelerated thermal aging in air

Sample	Hardness [IRHD]	Elongation at break [%]	Tensile strength [MPa]
ST	73±1.41	258±5.83	17.03±0.70
PP-1	74±1.64	237±13.68	16.20±0.65
PP-5	74±0.44	232±7.22	14.47±0.66
PP-10	74±0.89	225±15.13	12.85±0.81
PV-1	75±0.83	221±5.26	15.68±0.71
PV-5	73±0.54	240±10.65	15.13±0.76

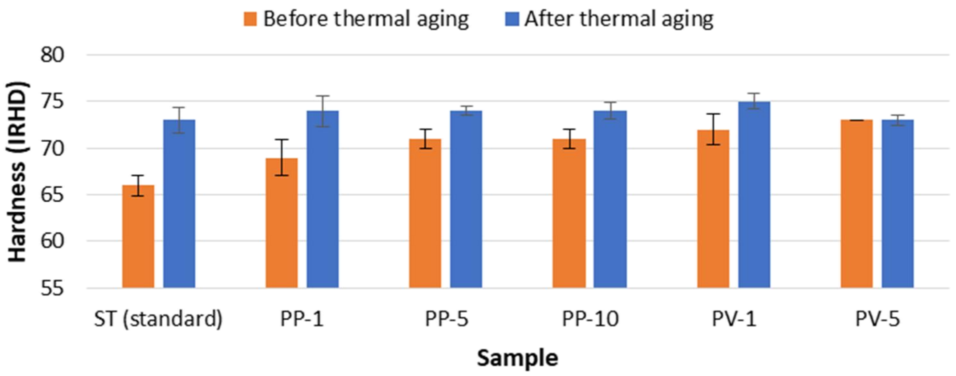


Figure 7 Hardness of tread vulcanizates before and after thermal aging

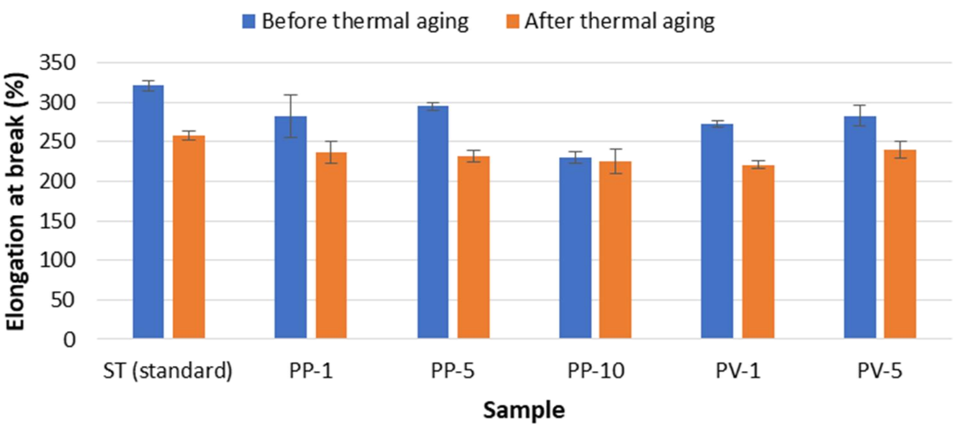


Figure 8 Elongation at break of tread vulcanizates before and after thermal aging

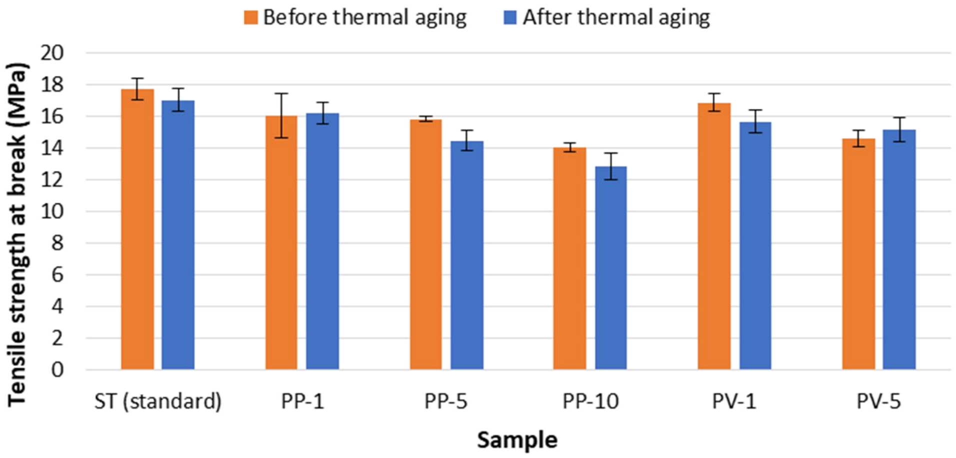


Figure 9 Tensile strength of tread vulcanizates before and after thermal aging

Comparing all results, it is clear that the elongation at break after accelerated thermal aging is lower than before running aging experiment.

Resulting values of tensile strength before accelerated thermal aging shows that all of the tread vulcanizates with PP obtains lower values than standard vulcanizate ST, except for the PV-1 sample which is comparable to standard. Lower tensile strength may relate to weaker interaction between filler particles and rubber matrix. Tensile strength decreases with increasing PP powder or fibres. The lowest tensile strength is achieved by the PP-10 vulcanizate with 10 phr PP filler.

Tensile strength changes results before and after accelerated thermal aging in air of tread vulcanizates (Figure 9) samples PV-1, PP-5 and PP-10 achieved larger tensile strength decrease than standard ST. Although the tensile strength values after aging of tread vulcanizates with alternative fillers are lower compared to the ST standard, they all meet the limit values set for treads.

The physico-mechanical properties of all vulcanizates before and after accelerated thermal aging were compared and the observed increase or decrease in the values of the studied parameters was expressed as a percentage (Table 5).

The obtained hardness results of tread vulcanizates with alternative PP fillers and the standard ST before and after accelerated thermal aging show that the all samples (PP-1, PP-5, PP-10, PV-1, PV-5) achieve a lower percentage increase in hardness, compared to the standard ST. It is a positive trend. Evaluation of the elongation at break results of the tread vulcanizates before and after accelerated thermal aging shows lower percentage changes in elongation at break compared to the ST standard, except for PP-5 vulcanizate. In the case of the PP-5 sample, the largest percentage change is visible compared to the standard ST. The PP-10 sample with 10 phr PP filler replacement achieved the smallest percentage change in elongation at break. An increase in tensile strength after thermal aging (expressed as a percentage) is observed for the PP-1 sample containing PP powder (1 phr) and the PV-5 sample with PP fibers (5 phr) compared to the ST standard, which is a positive finding.

Table 5 Changes in physical-mechanical properties of tread vulcanizates before and after accelerated thermal aging expressed in %

Sample	Hardness increment ↑ [%]	Elongation at break decline ↓ [%]	Tensile strength decline↓ /increment ↑ [%]
ST	↑ 10.6	↓19.62	↓ 3.83
PP-1	↑ 7.2	↓15.95	↑ 0.87
PP-5	↑ 4,2	↓21.35	↓ 8.64
PP-10	↑ 4.2	↓ 2.17	↓ 8.60
PV-1	↑ 4.2	↓18.75	↓ 7.05
PV-5	=	↓15.19	↑ 3.41

3.4 Study of selected properties of vulcanizates from DMA analysis

Viscoelastic behavior of prepared PV-1 vulcanizates containing filler based on PP fibers and vulcanizates PP-1, based on PP in powder form, was evaluated on the basis of obtained results by dynamic-mechanical analysis in the temperature range from -70°C to 40°C.

The studied values of T_g, *tg* δ_{max}, *tg* δ (at -25°C) and *tg* δ (at 0°C) for selected samples PP-1 and PV-1 compared to the standard ST are given in Table 6. Loss angles *tg* δ maximum peaks of study vulcanizates ST, PP-1 and PV-1 specify the glass transition temperatures. The values of the glass transition temperatures T_g are comparable for the vulcanizates PV-1 and PP-1 with alternative fillers with the standard vulcanizate ST. From the values of the maximum peaks *tg* δ (Table 6), it is possible to predict the stiffening effect of the chosen fillers based on PP powder or PP fibers in vulcanizates PP-1 and PV-1 in comparison with standard vulcanizate ST. The stiffening effect of the filler is related to the restriction of the mobility of the segments of the rubber molecules. The lower the value of *tg* δ_{max}, the higher the stiffening effect of the filler. In this case, the interaction of the filler with the rubber matrix increases [7, 23]. The peaks *tg* δ_{max} for vulcanizates samples PP-1 and PV-1 are lower compared to standard ST. The vulcanizate sample PV-1 with filler content based on PP fibers obtains lowest *tg* δ_{max} which indicates a better stiffening effect of resulting vulcanizates. The results show that the obtained *tg* values of the studied vulcanizates are influenced by the chemical composition and particle shape of the alternative filler.

Table 6 The values T_g, *tg* δ_{max}, *tg* δ (at -25°C) and *tg* δ (at 0°C) of selected samples of vulcanizates PP-1 and PV-1 compared to standart ST

Vulcanizates	T_g [°C]	*tg* δ_{max}	*tg* δ (at -25°C)	*tg* δ (at 0°C)
ST	-28.0	0.81	0.76	0.36
PP-1	-27.0	0.79	0.77	0.38
PV-1	-28.0	0.73	0.68	0.34

Properties such as traction of the tire tread on snow and ice (*tg* δ at -25°C) and wet traction (*tg* δ at 0°C) can be observed by the dependence of the loss angle on temperature for resulting vulcanizates.

Traction of the tire tread on snow and ice is characterized by *tg* δ at -25°C. The results of the measurements show that the sample of vulcanizate PP-1, has a slightly higher value of *tg* δ (at -25°C) compared to the ST standard, which is required for the evaluation of traction on snow and ice. The values of tg δ (-25°C) increase in order: v (PV-1) < v (ST) < v (PP-1). Wet traction of the tire tread is characterized by *tg* δ at 0°C. The results of the measurements show that the prepared sample of vulcanizate PP-1 in the amount of PP powder 1 phr, shows a higher value of *tg* δ (at 0°C) compared to the ST standard, which is positive in the evaluation of wet traction. The values of *tg* δ (0°C) increase in order: v (PV-1) < v (ST) < v (PP-1).

4 CONCLUSION

Five tread blends with certain amount of alternative fillers were prepared and study, namely three tread blends PP-1, PP-5, PP-10 with amount of 1 phr, 5 phr and 10 phr fillers based on polypropylene powder and 2 blends PV-1, PV-5 with amount of 1 phr and 5 phr of filler based on polypropylene fibers and one standard ST tread blends containing filler - carbon black (N339). Evaluation of optimal curing time results in the partial decrease of optimal curing time for PP-1 PP-5 PP-10 and PV-1 tread blends comparing with optimal curing time of standard ST. The vulcanization process was faster at described vulcanizates. Vulcanizates with a content of PP filler obtained lower values of tensile strength comparing to standard ST during the evaluation of vulcanizates physical mechanical properties before and after accelerated thermal aging in air at temperature of 100°C. Smaller values of tensile strength may be connected to a weaker interaction of filler particles with rubber matrix. Tensile strength values were decreasing gradually with an increasing content of alternative filler replacement. All of the prepared vulcanizates achieved the required values of tensile strength 12-18 MPa, determined for tread. Values of vulcanizates elongation at break with a content of alternative filler were lower comparing to standard ST before and after thermal aging. The trend for hardness values was opposite. Hardness values of vulcanizates with a content of PP fillers were higher before and after accelerated thermal aging in air comparing to standard.

The evaluation of the DMA analysis of the PP-1 and PV-1 tread vulcanizates showed that the glass transition temperature T_g of the PP-1 and PV-1 vulcanizates did not change significantly compared to the standard ST. Size values of max. peak *tg* δ_{max} were lower for vulcanizate samples comparing to the standard ST. The lowest values of *tg* δ_{max} were obtained from vulcanizate PV-1 with a content of 1 phr filler based on PP fibers, which indicates the best solidification of the resulting vulcanizates. Selected properties of tread vulcanizates, traction on snow and ice (-25°C) and wet traction (0°C) were evaluated by the dependence of the loss angle *tg* δ on the temperature. The results show that the prepared vulcanizate PP-1 had higher values of *tg* δ (-25°C) and *tg* δ (0°C) compared to the standard ST, which is a positive finding when evaluating traction on snow and ice and wet.

The evaluation results the possibility of the prepared tread blends to use selected studied materials in the function of fillers, as a partial replacement of standardly used fillers - carbon black N339. The results of the study provide new knowledge about the application of polypropylene waste from the production of PP fibers and PP foils in the function of fillers in rubber blends.

ACKNOWLEDGEMENT: *The authors would like to thank the Slovak Grant Agency for financial support (Grant KEGA 003TnUAD-4/2019). The work was supported by the project Advancement and support of R&D for centre of diagnostics and quality testing of materials in the domains of the RIS3 SK specialization, code NFP313011W442.*

5 REFERENCES

1. Ehrenstein G.W.: Polymer composite materials (Polymérní kompozitní materiály), Scientia, Praha, 2009, 352 p., ISBN: 978-80-86960-29-6 (in Czech)
2. Maláč J.: Rubber technology (Gumárenská technológie), Univerzita Tomáše Bati ve Zlíne, Zlín, 2005, 156 p., ISBN: 978-80-904949-0-9 (in Czech)
3. Dvořák Z.: Rubber processing processes for construction directions (*Zpracovatelské procesy gumárenské pro konstrukcní smery),* Univerzita Tomáše Bati ve Zlíne, Zlín, 2011, 182 p. (in Czech)
4. Ondrušová D., Pajtášová M.: Rubber components and their influence on rubber properties and environmental aspects of production, Spolok Slovákov v Poľsku, Krakow, 2011, 166 p., ISBN:80-8075-101-3
5. Holcová K., Pajtášová M., Špániková L., Palieskovà J., Jankurová Z., Janeková M.: Study of the properties for rubber compounds with fillers based on PLA and PP Fibers, Hutnické listy 3, 2014, pp. 106-109
6. Pajtášová M., Mičicová Z., Ondrušová D., Božeková S., Janík R., Pecušová B., Raník L.: Use of waste materials in rubber matrix, MATEC Web of Conferences 157, 2018, article no. 07009
7. Pajtášová M., Ondrušová D., Janík R., Mičicová Z., Pecušová B., Labaj I., Kohutiar M., Moricová K.: Using of alternative fillers based on the waste and its effect on the rubber properties, MATEC Web of Conferences 254, 2019, article no. 04010
8. Kücükrendeci I.: The investigation of suitable welding parameters in polypropylene sheets joined with friction stir welding, Bulletin of the Polish Academy of Sciences: Technical Sciences 67(1), 2019, pp. 133-140, DOI: 10.24425/bpas.2019.127342
9. Wang R., Li J., Zhang T., Czarnecki L.: Chemical interaction between polymer and cement in polymer-cement concrete, Bulletin of the Polish Academy of Sciences: Technical Sciences 64(4), 2016, pp. 785-792, DOI: 10.1515/bpasts-2016-0087
10. Cukrowicz S., Grabowska B., Kaczmarska K., Bobrowski A., Sitarz M., Tyliszczak B.: Structural studies (FTIR, XRD) od sodium carboxymethyl cellulose modified bentonite, Archives of Foundry Engineering 20(3), 2020, pp. 119-125, DOI: 10.24425/afe.2020.133340
11. Rogalski A., Chrzanowski K.: Infrared devices and techniques (revision), Metrology and Measurement System 21(4), 2014, pp. 565-618, DOI: 10.2478/mms-2014-0057
12. Kiran M.D., Govindaraju H.K.,Jayaraju T., Kumar N.: Review: Effect of fillers on mechanical properties of polymer matrix composites, Materials Today: Proceedings 5(10), 2018, pp. 22421-22424, https://doi.org/10.1016/j.matpr.2018.06.611
13. Kaczmarska K., Żymankowska-Kumon S., Grabowska B., Bobrowski A., Cukrowicz S.: Study of thermal degradation of starch-based binder by TG-DTG-DSC, Py-GC/MS and DRIFTS, Archives of Foundry Engineering 19(4), 2019, pp. 21-26, DOI: 10.24425/afe.2019.129624
14. Adegbola T.A, Olorundaisi E., Agboola O., Fayomi O.S.I.: Influence of fillers particles on material toughness properties during processing, Materials Today: Processing, 2020, article in press, https://doi.org/10.1016/j.matpr.2020.01.464
15. Rasana N., Malavika D., Aparna R., Deepak T., Haritha P.S., Jayaranayaran K.: Influence of multiphase fillers on mechanical transport and rheological properties of polypropylene, Materials Today: Proceedings 5(8), 2018, pp. 16478-16486, https://doi.org/10.1016/j.matpr.2018.05.151
16. Thakur V., Gohs U., Wagenknecht U., Heinrich G.: Electron-induced reactive processing of thermoplastic vulcanizate based on polypropylene and ethylene propylene diene terpolymer rubber, Polymer Journal 44, 2012, pp. 439-448, https://doi.org/10.1038/pj.2012.3
17. Thiele S., Bellgardt D., Holzleg M.: Polymer Functionalization: Novel Rubber for Tire Tread Application, KGK rubberpoint 61(5), 2008, pp. 244-245
18. Mohamad N., Zainol N.S., Rahim F.F., Maulod H.A.B., Rahim T.A., Shamsuri S.R., Azam M.A., Yaakub M.Y., Abdollah M.F.B., Manaf M.E.A.: Mechanical and morphological properties of polypropylene/epoxidized natural rubber blends at various mixing ratio, Procedia Engineering 68, 2013, pp. 439-445, https://doi.org/10.1016/j.proeng.2013.12.204
19. Zaeimoedin T.Z., Clarke J.: Improving the abrasion resistance of "green" tyre compounds, Proceedings of the 3rd World Congress on Mechanical, Chemical, and Material Engineering, Rome, Italy, June 8-10. 2017, DOI: 10.11159/iccpe17.121
20. Shubhra Q.T.H, Alam A.K.M.M, Quaiyyum M.A: Mechanical properties of polypropylene composites: A review, Journal of Thermoplastic Composite Materials 26(3), 2011, pp. 362-391, https://doi.org/10.1177/0892705711428659
21. Frida E.: The effect of size and crumb rubber composition as a filler with compatibilizer PP-g-MA in polypropylene blendsand SIR-20 compound on mechanical and thermal properties, Makara Journal of Technology 16(2), 2012, pp. 171-179, DOI: 10.7454/mst.v16i2.1517
22. Milata V., Segľa P.: Spectral methods in chemistry (Spektrálne metódy v chémii), Bratislava, STU 2002, p. 327. ISBN 80-227-2049-6 (in Slovak)
23. Das A., Jurk R., Stöckelhuber K.W., Heinrich G.: Effect of vulcanization ingredients on the intercalation-exfoliation process of layered silicate in an acrylonitrile butadiene rubber matrix, Macromolecular Materials and Engineering 293(6), 2008, pp. 479-490, https://doi.org/10.1002/mame.200700375

ANALYSIS OF METHODS OF PRINTING IMAGES ON TEXTILE MATERIALS AND EVALUATION OF THEIR QUALITY

Dmytro Prybeha[1], Julia Koshevko[1], Svitlana Smutko[1], Volodymyr Onofriichuk[1], Mykola Skyba[1], Oleg Synyuk[1], Svetlana Kuleshova[1], Svitlana Pidhaichuk[1] and Borys Zlotenko[2]

[1]*Khmelnitskyi National University, Institutska str. 11, Khmelnitskyi, Ukraine*
[2]*Kyiv National University of Technologies and Design, Nemyrovicha-Danchenka str. 2, Kyiv, Ukraine*
juliakoshevko@gmail.com; zlotenco@ukr.net

Abstract: *The peculiarities of the methods of printing images on textile materials are analyzed; the research of the criteria for choosing the method of printing is performed. The list of criteria is supplemented and presented in a form convenient for use in the analysis and selection of the method of printing images on textile materials in each case. The method of calculating the cost of a batch of products for each of the methods of printing the image is given. The results obtained, according to this method, make it possible to make an economic assessment of each of the printing methods and decide on the appropriateness of their use. In the course of experimental research the degrees of resistance of the images put by various methods of printing to friction and in the process of washing were established. The application of the results of this study will allow a qualitative and effective assessment of methods of printing images on textile materials depending on the production conditions for each type of product.*

Keywords: *images, textile materials, printing methods, screen printing, digital printing, sublimation printing, thermal transfer printing, printing cost, performance.*

1 INTRODUCTION

Art decoration of clothes, as an element of aesthetics of everyday life, is of great importance for many categories of the population in the modern world. Nowadays, there are many of ways to decorate clothes, which differ in the use of various technologies and materials. One of the ways to decorate light industry products is to print on textile materials.

Today, the print on clothes is popular both among people who want to stand out from the crowd, and among business owners who want to draw attention to their brand. Fabric printing first appeared in the 1950s in Florida, USA, thanks to Tropix Togs [1-2]. The method was used for inscriptions on T-shirts: mostly the names of popular resorts were printed. A little later, the organization received the right to apply images of Disney characters to clothing. After that, the method rapidly began to gain popularity among other companies; there were factories for printing on fabric, the largest of which was Sherry Manufacturing Company [3-4].

In 1959, a new stage in the history of printing on clothing began - durable inks were invented for printing on sweatshirts, T-shirts and other textiles, thanks to which it was possible to significantly diversify the possibilities of the method and significantly improve product quality. Only in the 80s of the twentieth century, the print on the fabric began to acquire a new meaning - it became a kind of way to tell the world about one`s views and hobbies [2].

In addition to clothing decoration, printing on textile materials is used to create souvenirs, and advertising on textiles has become the most popular area of business for printing. Stylish baseball cap or T-shirt with a logo can quickly increase the popularity of the brand, compared to expensive advertising on TV or radio. The main thing is to choose the right method of application and model of the product, which is suitable in accordance with this method of decoration. Types of printing on fabric allow you to get an inexpensive, but at the same time highly effective advertising tool that can be implemented on any textile: from caps and T-shirts to blankets, pillows and umbrellas. Creating a corporate style of the company, family look, promotional forms, interior design, all these areas require such a service as printing on textiles [5-10].

Despite the long history of the development of printing on fabric, there are still some problems that manufacturers face when organizing the application of high-quality images to textiles. Namely: there are no recommendations on the choice of the method of applying the image, the parameters of the selected technological process (temperature, time and pressure of processing), depending on the chemical composition of the material [2, 11-12].

2 DISCUSSION IDEAS

To date, there are several ways to print images on textiles used by modern manufacturers. The choice of imaging technology depends on several factors: the number of products; image areas; the number of image colors; raw material composition of the fabric; fabric color. Each method has its advantages and disadvantages that must be considered before applying the image. You need to understand that there is no better technology, because each type of product requires its own method. For printing on flat surfaces (flags, banner ads, scarves, tablecloths, etc.), one method can be used, and for products of complex shapes, such as baseball caps, other methods will be preferred. And not every one of them is suitable for certain types of textiles [11-17].

The available information on the criteria for selecting methods of printing images on textile materials is quite diverse, so it is necessary to systematize and present it in a form convenient for use in the analysis and selection of printing methods in each case.

The end user of the products with the applied image is interested in their operational characteristics. Therefore, for the manufacturer to increase the competitiveness of their products through the production of quality goods, it is important to have information about the stability during their operation of the images applied to textiles by different methods. A review of information sources did not reveal relevant information on this issue, so the authors of this study are tasked with investigating the preservation of the quality of images during their operation printed by different printing methods.

In addition, when choosing a method of printing images on textiles, manufacturers are interested in the financial aspect, so the task is to estimate the cost of applying the image per unit of product depending on the method of printing.

3 METHODS

To choose the method of printing on textile materials, it is necessary to take into account all the factors that will affect the quality and performance of the product. Consider in more detail each of the ways to apply the image on textiles. Including:

- screen printing, which is also called silk screen printing;
- direct printing on fabric by DTG (Direct to Garment) technology, which is also called digital;
- sublimation printing;
- thermal transfer printing or flex printing;
- thermal transfer made by screen printing.

Screen printing (silkscreen printing): The essence of this method of printing is to push by a special tool (squeegee) ink through the open holes of the flexible mesh stencil on the printing surface. Printing can be done on paper, tin, glass, fabric, polyethylene, plastic, leather and other sheet or roll materials and products from them.

The main differences between the process of screen printing on textiles, natural and artificial leather from printing on paper and other dense materials are the features of light industry materials, namely, their resistance to high temperatures, hygroscopicity, adhesive properties of paint and surface material, significant linear deformation, temperature shrinkage, operational features of clothing and footwear. For screen printing on textiles, artificial and natural leathers use inks that differ in their chemical composition, adhesive properties and temperature regimes. The most commonly used paints include plastisol, aqueous, solvent and etching ones [18-19].

This printing technique allows you to get any detailed image, but each color requires the manufacture of a separate stencil on the frame. Screen printing is advantageous to use in circulations of more than 100 copies. This method allows you to get a rich image with special effects through the use of metallized, reflective and fluorescent paints, foil and more.

Direct printing on fabric by DTG technology (digital): Digital printing is simple and one of the most competitive technologies. It is suitable for printing on both synthetic and cotton fabrics. The CMYK digital model is used for printing (the image is reproduced from an electronic file), thanks to which the photos are bright and saturated. The biggest problem with digital printing on fabrics is the reproduction of rich blue tones. They turn out either blue or dark purple, but not blue. The product after digital printing can withstand many washing cycles without losing brightness and the image is not erased from the surface of the material. This method of printing is quite expensive due to the peculiarities of the ink used, and therefore suitable only for small runs and branded products [3, 6].

Sublimation printing: This method allows you to transfer the image with a special paper on the fabric under the influence of high temperature, so it requires the use of equipment for heat treatment. It should be noted that this method of printing is suitable only for light fabrics with a high content of synthetic fibers. During printing, special inks are used, which under the action of high temperature turn into a gaseous state, fill the fibers of the fabric and are evenly distributed on the surface. The quality of images and colors in this type of printing is high.

The manufacturers declare that the main feature of the method is that the images are resistant to fading and are not destroyed during washing and operation. However, this information has not been confirmed by any experimental studies, or not covered in scientific journals. The method of sublimation printing is usually used to print small runs of T-shirts, caps and sportswear [6].

Thermal transfer printing (flex printing): This method is based on the transfer of the image from a special film to the fabric under the action of pressure and high temperature. The image is printed on a printer and cut out on a cutting plotter, excess film elements are removed, and then image is applied to the fabric and, by means of high temperature, transferred to it. The film consists of two layers: the first is a film that reacts to changes in temperature, and the second is a heat-resistant substrate that holds the film until it is transferred to the fabric. This method is considered to be one of the convenient options for applying images and has many advantages: applying both single and large batches of images; high resistance to washing, small amount time spent on preparation and application of the image. The main disadvantage is the inability to obtain small details of the image. In addition, this method of printing requires the use of additional equipment - a cutting plotter, which cuts only the heat-sensitive layer, and leaves the substrate uncut, which also requires additional removal of unnecessary elements of the print. If you use a printing plotter that runs on eco-solvent inks and has the function of a cutting plotter, you can get multi-color images. This method of application is often used for printing logos, quotes, souvenirs, gifts, etc. [4].

Thermal transfer made by screen printing: This method of applying images to textiles is similar to screen printing. The difference is that in direct screen printing the image is applied directly on the details of the cut or product, while in the transfer printing it is applied to the intermediate carrier - transfer. The image requires additional processing, namely mirror imaging. Accordingly, the printing plates for each color are prepared in a mirror image, and the application of colors is in reverse order. Similarly to direct screen printing, each color is dried, and after applying the last color, which acts as a base, special glue is applied. As a rule, the following glues are used: on a transparent plastisol base - for light types of fabrics; on a white plastisol base - for dark fabrics; or powder adhesives. Powder adhesives can be of different fractions: <70 μm, from 70 to 180 μm, from 180 to 300 μm and >300 μm. The desired fraction is obtained by grinding the granular material [19]. In terms of chemical composition, it can be polyurethane, co-polyester, etc. After applying the adhesive base it is dried in the temperature range from 105 to 120°C (depending on the manufacturer's recommendations). The transfer or intermediate carrier contains a special antistatic coating on the printing surface, which is used to eliminate the sticking of the powder in places where no image is provided, as well as a coating that allows you to easily remove the carrier after applying the image to the product without damaging the image. Transfer is carried out using a thermo-press or iron. Exposure time ranges from 10 to 20 seconds, and the temperature range from 145 to 170°C, depending on the type of carrier, type of paint and manufacturer's recommendations.

The first three methods are the application of paint (direct method, or sublimation), which penetrates directly between the weaves or into the fibers of the fabric. We refer them to the first conditional group. The second conditional group includes thermal transfer printing methods, the feature of which is that during heating the polymer adhesive or film melts and is fixed on the surface of the fabric under the action of pressure. Accordingly, these two conditional groups will have different adhesion between the fibers of the fabric and the image material.

Therefore, in our opinion, it is not correct to evaluate the above methods of printing images on textile materials by the same criteria. For these reasons, in this article the authors consider only the application of the image in the first three ways: direct digital printing, direct screen printing and sublimation.

Based on the information available in open sources and the empirical experience of the authors of the article, a systematization of the criteria for evaluating the methods of printing images on textiles is made [2-4, 11]. As a result of the analysis of information sources it is established that, first of all, the choice of the way of printing on textile materials depends on raw material structure and color of fabric.

For example, sublimation is possible only to light-colored synthetic fabrics, ideally white. While, direct printing on fabric by DTG technology is possible on both light and dark fabrics with a high content of natural fibers - cotton. Screen printing is possible on all types of fabric, regardless of chemical composition and color.

The solution of the problems of this research was performed on the example of applying to textile materials a drawing by the artist Patrice Murciano [7], which is executed in watercolor style. The dimensions of the image are 170x190 mm (Figure 1). In order to further divide it into colors and prepare individual printing plates for screen printing, the authors of the article translated the image into a color scheme CMYK.

Figure 1 shows markers for combining printing forms when applying an image to textiles by screen printing.

As a result of the analysis of the methods of printing images on textile materials, the criteria that are recommended to be used when choosing the method of printing in each case are highlighted.

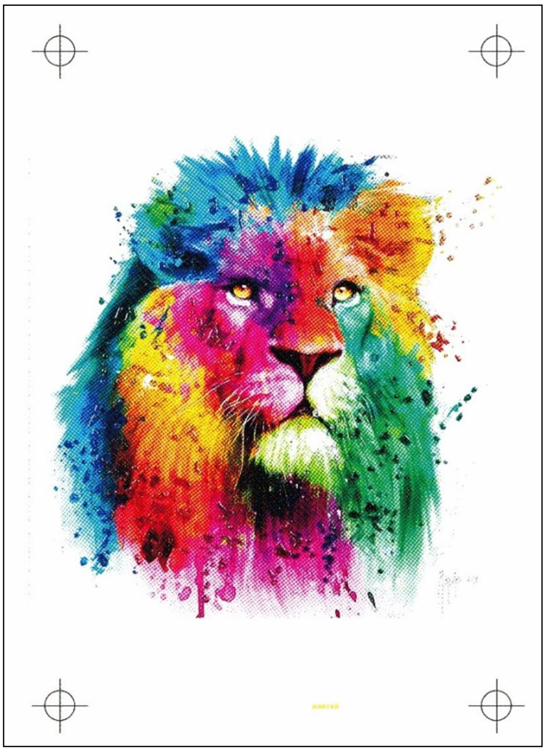


Figure 1 Pattern for application to textiles

Criteria for evaluating the methods of printing images on textiles are given in Table 1.

One of the factors influencing the choice of imaging technology is the color of the fabric. Applying images directly by direct digital printing on colored fabrics requires additional surface preparation. The print surface is first coated with a special base, called a primer, which acts as a barrier between the fabric and subsequent layers of ink. As a rule, the primer is fixed on a thermo-press. The barrier is applied to prevent the fabric dye from interacting with the white base of the print. After that, the image is applied to the surface, the first layer of which is a white base over the entire area of the print, and the next - a color image. Thus, a saturated image resistant to interaction with the fabric dye is obtained. Because for dark fabrics, the ink does not penetrate directly into the structure of the fibers and between them, the stability of the print depends on the adhesion between the primer and the fabric, as well as between the primer and the ink. Therefore, there is a need for additional research on the resistance to washing images applied to dark fabrics by direct digital printing.

Table 1 Types of printing on textile materials and their technological parameters

Evaluation criteria	**Printing method**		
	Direct printing on DTG technology (digital)	***Sublimation printing***	***Direct screen printing***
Fabric with a high content of synthetic fibers	-	+ (>70%) polyester	+
Fabric with a high content of cotton (> 60%)	+	-	+
Print on white fabric	+	+	+
Printing on colored fabrics with an additional substrate	+	-	+
Processing pressure [N/mm^2]	From 0.02 to 0.05	From 0.05 to 0.08	From 0.02 to 0.05
Processing temperature [°C]	170±5	195	From 40 to 180 depending on the type of paint
Print elasticity	+	+	+
Obtaining relief images or 3D prints	-	-	With the use of special additives
Ability to create additional effects (fluorescent, phosphor, reflector)	-	-	+
Basic equipment	Inkjet printer for printing on fabric	Inkjet printer, thermo-press	Workbench for screen printing
Additional equipment	The chamber for applying a primer, convection or tunnel dryer, thermo-press	-	Intermediate dryer, tunnel dryer, thermo-press
Additional tools	-	-	Printing forms, squeegee, cuvette
Materials used	Textile ink, primer	Sublimation paper - transfer, sublimation ink	Inks for screen printing, special additives for additional effects, means for the manufacture and preparation of printing plates
Loss of color on contact with the hotplate	+	-	-
Productivity at the printing on color / white fabrics, piece /hour	20/30	12	60/90 for manual printing device 360/500 for automated printing device

In direct screen printing, when applying the image to dark fabrics, a special barrier is also used as a base for the print, followed by the application of one or more layers of white ink. The base of the anti-migration primer - barrier and white paint, as a rule, has the same composition as the main paint, so it is not necessary to examine additional samples of images on dark fabrics for resistance to washing and abrasion.

One of the important factors influencing the choice of the method of applying the image to textile materials is the cost of making the print. To determine the total cost, it is necessary to take into account the cost of each stage of the technological sequence, as well as the cost of electricity and the cost of preparing the print. In order to determine the cost of one print (Figure 1) calculation was made for a batch of 100 units. Execution of a batch of 100 units made it possible to determine the cost of ink for different methods of printing. The above method of calculating the cost of a batch of products is simplified and corresponds to each of the methods of applying the image to textiles. However, each of the printing methods has its own technological operations that affect the final result of the cost calculation. The total cost of the batch of products:

$$C = C_D + C_E + C_p + C_I + C_W + C_{EI} \tag{1}$$

where: C_D - the cost of the designer`s work, [hryvnia (UAH)]; C_E - the cost of the manufacture of technological tools, UAH; C_p - the cost of paint [UAH]; C_I - the cost of the intermediate carrier [UAH]; C_W - the cost of the work of specialist in applying the image to the textile material [UAH]; C_{EI} - electricity cost [UAH].

Design preparation includes the cost of the designer's salary and takes into account the time spent on training and appropriate skills of the worker. The cost of electricity during the work of the designer is less than 1%, respectively, it can be neglected. Designer's work costs:

$$C_D = \frac{T_D \times N_D}{60} k_D, \tag{2}$$

where: T_D - designer's tariff rate [UAH/year]; N_D - rate of time for operation [min]; k_D - coefficient that takes into account additional costs and tax accruals on the salary.

For screen printing, the cost of technological tools per batch of 100 units (production of printing plates):

$$C_E = \frac{T_E \times N_E}{60} k_E + P_M + P_E, \tag{3}$$

where: T_E - the tariff rate of the worker for the manufacture of technological tools [UAH/hour]; N_E - time rate for the operation of manufacturing technological tools [min]; k_E - coefficient that takes into account additional costs and tax accruals on the salary; P_M - cost of materials [UAH]; P_E - the cost of energy consumption [UAH].

The cost of the work of specialist in applying the image to the textile material is:

$$C_W = C_1 + C_2 + C_3 = = \frac{T_1 \times N_1}{60} k_1 + \frac{T_2 \times N_2}{60} k_2 + \frac{T_3 \times N_3}{60} k_3, \tag{4}$$

where: C_1 - the cost of the specialist`s work to apply the image to the intermediate carrier [UAH]; $C_2$ - the cost of the specialist`s work to apply the image on the product/work-piece [UAH]; C_3 - the cost of the employee to fix the image [UAH]; T_1, T_2, T_3 - tariff rate of the specialist for applying the image on the intermediate carrier, product/work-piece and its fixing, respectively [UAH/hour]; N_1, N_2, N_3 - the rate of time for the operation of applying the image to the intermediate carrier, product/work-piece and its fixation, respectively; k_1, k_2, k_3 - coefficients that take into account additional costs and tax accruals on the salary for the operations of applying the image to the intermediate carrier, product / work-piece and its fixation, respectively.

Electricity costs are:

$$C_{EI} = P_1 + P_2 + P_3 \tag{5}$$

where: P_1 - the cost of electricity for transfer operations from the intermediate carrier to the product [UAH]; P_2 - electricity cost for intermediate drying operations [UAH]; P_3 - electricity cost for finishing drying operations [UAH].

Data for calculating the costs of manufacturing images on textile materials by different printing methods were obtained as a result of the practical activities of the authors of the article in terms of production in enterprises FOP Zozulyuk and Dprint Studio, Khmelnitsky, Ukraine. The results of calculations according to the above method are presented in Table 2. When an operation is absent in the technological sequence the sign «–» is put into Table 2. The calculation is given for the national currency of Ukraine, at the time of calculation the exchange rate of UAH to the EURO was 33:1 at the rate of the National Bank of Ukraine. The calculation for European countries will differ in the absolute value, but in relative terms, i.e. in percentage terms will be fair. This will give a general idea of the economic feasibility of using a particular method of printing images. Based on the results of the cost calculation summarized in Table 2, it is possible to draw conclusions about the economic feasibility of each of the methods under consideration. For a batch of 100 units, the cost of printing for all three methods differs for both light and dark fabrics. For example, for light fabrics, the difference between sublimation and screen printing is 60%, while for printing on dark fabrics, the difference between direct printing using DTG technology and screen printing is 300%.

If we consider the manufacture of a single sample, then in contrast to mass production, the cost of the product increases significantly. This is due to the fact that the cost of technological tools is fully transferred to the cost of the product. In this case, the cost of printing on light fabrics for the first two methods is almost equal, and for screen printing is 240% higher.

Table 2 The cost of applying the image to textile materials

№	Cost item	Printing method		
		Direct printing by DTG technology (digital)	**Sublimation printing**	**Direct screen printing**
1	Image design preparation [UAH]	80	80	80
2	The cost of technological tools for white / colored fabrics [UAH]	-	-	120/180
3	The cost of ink C_p for printing on white / colored fabrics [UAH]	112/1344	200	20/30
4	The cost of the intermediate carrier, C_1 [UAH]	-	250	-
5	Worker's labor costs [UAH:]			
	- applying the image to the intermediate medium;	800		200/300
	- drawing the image on a product or preparation;	-	200	-
	- fixing the image	200	-	200*
6	Electricity costs C_{El} for white / colored fabrics [UAH]:			
	- transfer from the intermediate carrier to the product;	-	10	-
	- intermediate drying operation;	-/10	-	23/35
	- finishing drying operation	10	-	17
∑	The cost of printing on white / colored fabrics [UAH:]			
	- batches of 100 units of products;	1202/2444	740	460/642
	- product units	12.02/24.44	7.4	4.6/6.42
	The cost of making a single sample on white / colored fabrics [UAH]	91.22/103.64	86.51	204.6/235.99

* only in case of additional processing on a thermopress

Therefore, in the case of single production, screen printing is considered inexpedient in terms of economic effect, however, for serial production it is the cheapest way to apply the image, and given the results in Table 1, it is the most productive and versatile in terms of raw material composition and fabric color.

4 EXPERIMENTAL

The next, no less important, step in choosing a printing method is to assess the performance of the applied image. The main performance characteristics that affect the quality of the applied images to the textile material are resistance to friction and washing.

The first stage of experimental research to assess the preservation of image quality on textile materials during friction was performed according to GOST 9733.27-83, DSTU ISO 105-X12: 2009. It is known that friction is a physical phenomenon that occurs during the contact interaction of two bodies. Friction can be external or internal. External friction occurs when the surfaces of two materials come into contact and move relative to each other. Internal friction occurs in the material between its structural elements, when exposed to the external environment (mechanical impact, electromagnetic field, etc.).

Devices for determining the abrasion resistance of textile materials must mimic the actual abrasion process during the operation of garments. The material can be worn on its plane surface, or on the folds - imitation of rubbing on the edges of the lapel and sleeves, the bend of the collar, the bottom of the pants and so on. To determine the resistance of textile materials to abrasion using one of the existing devices: DIT-M, TI-1M, IS-3M, ITIS, which simulate friction. As an abrasive material, in these devices, a gray overcoat woolen cloth is used. To stop the device at the moment of destruction of the sample, metal contact grids are placed between the membranes and the samples. The number of friction cycles is recorded by the counter. Samples with a diameter of 80 mm should be prepared for testing and fixed in the holder with the front side facing outwards. For each fabric sample, three tests are performed under the appropriate test conditions, and the arithmetic mean of the three tests is taken as the end result characterizing the abrasion resistance.

Tests of samples for friction resistance were performed on the device DIT-M (Figure 2), according to standardized methods [12]. During the image stability study, samples were scanned every 50 cycles and the image quality loss during operation was assessed. Abrasion was performed until complete destruction of the material.

Images of samples scanned at different stages of the study are shown in Table 3.

Sample 1: The image to the textile is applied by sublimation. Knitted fabric is used with fibrous polyester composition of the studied sample.

After 50 cycles there are no peels, no color loss.

After 100 cycles: small peels are visible to the naked eye, no discoloration is observed, no mechanical damage to the fabric.

At 150 cycles, the number of peels increases; barely noticeable loss of color along the abrasion trajectory, due to the growth of peels and optical perception.

200 cycles: the number of peels increases; there is a barely noticeable loss of color along the abrasion trajectory; the structure of the fabric is broken. The study of this sample is stopped.

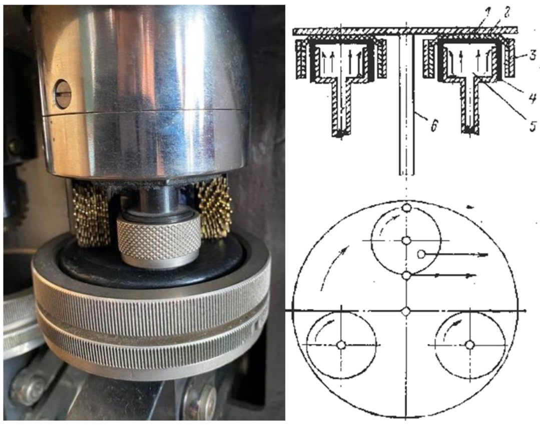


Figure 2 Photograph and diagram of the working bodies of the device for the external friction measurement: 1 - friction disk; 2 - sample material; 3 - clip; 4 - rubber membrane; 5 - working heads; 6 - axis

Sample 2: The image on the textile is printed by screen printing. Knitted fabric is used with fibrous composition of the studied sample includes: cotton, nitron.
After 50 cycles: no saws, no color loss.
After 100 cycles: no peels; no discoloration; no mechanical damage to the fabric.
At 150 cycles: no peels; barely noticeable loss of color along the abrasion trajectory, due to abrasion of paint particles.
After 200 cycles: no peels; color loss along the abrasion trajectory becomes more noticeable; the fabric structure is broken. The study of this sample is stopped.

Sample 3: The image to the textile is applied by direct printing using DTG technology. Digital printing is made on a white base. The fibrous composition of the studied sample of knitted fabric includes: polyester, cotton, elastane.
After 50 cycles of friction, there is a slight loss of color; but the structure of the fabric is destroyed. The study of this sample is stopped.

Sample 4: The image to the textile is applied by direct printing using DTG technology. Digital printing of primer and white ink, as the fabric is white. Fibrous composition of the knitted fabric for studied sample consists of cotton.
After 50 cycles there are no peels; no other changes in image characteristics.
As a result of performance of 100 cycles: there are no peels; insignificant change of color is observed; the structure of fabric is broken. The study of this sample is stopped.

The next step in the study of the performance characteristics of images on textiles was to determine the stability of the image during washing. According to the results of research, based on organoleptic evaluation, it is possible to draw conclusions about the gradual loss of color of each sample. The most resistant to washing were samples with sublimation and screen printing, but Digital printing is less stable.

Table 3 The results of the study of image stability during friction

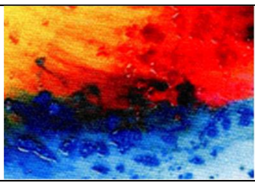
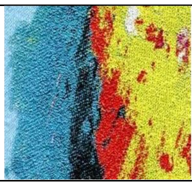
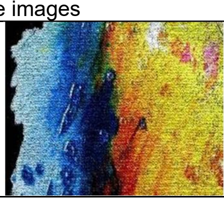
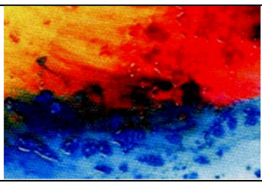
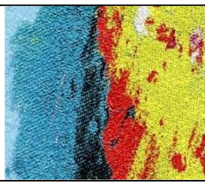
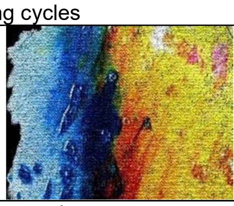
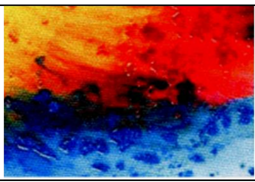
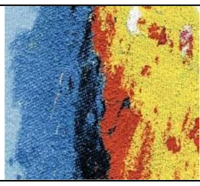
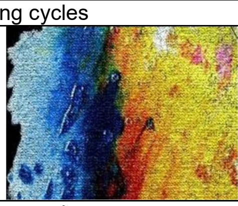
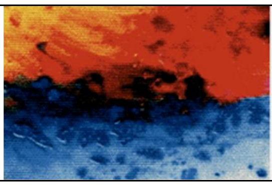
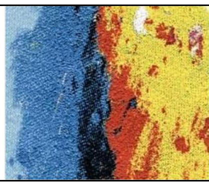
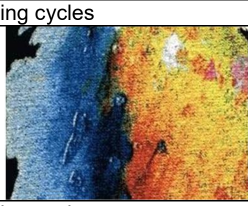
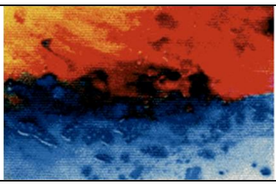
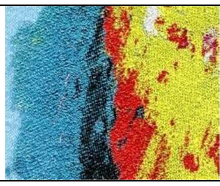
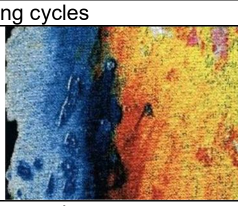
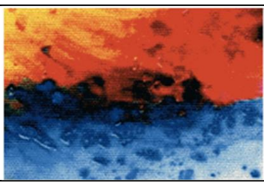
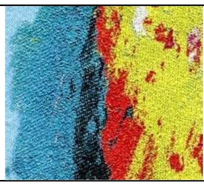
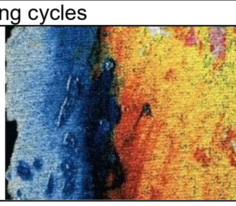
Sample №	Raw material composition and printing method	Photographs of the sample after friction				
		Reference images	50 cycles	100 cycles	150 cycles	200 cycles
1	Polyester Sublimation					
2	Cotton, nitron Screen printing					
3	Polyester, cotton, elastane Digital printing on a white base					
4	Cotton Digital printing without a base					

Washing is considered as a method of cleaning textiles, which consists in the hydro-mechanical treatment of things using soap or detergent. As a result of such cleaning, the aqueous detergent solution is able to separate the contaminants from the surface of the textile during hydro-mechanical treatment, transfer them to the solution, and keep it there. Laundry can be washed manually, using household washing machines, using ultrasound.

Washing was performed according to DSTU ISO 105-C06:2009 on a household washing machine using detergents, in accordance with the composition of the textile. The temperature mode is 40°C; washing time 30 minutes; spin 800 min^{-1}. Drying took place in a vertical position until completely dry, after which the ironing of the sample was performed at a temperature of 100-110°C. For each sample, 25 washing cycles were performed, which corresponds to the maximum period of operation of textile products [9]. Sample scans were performed every five wash cycles.

The results of studies of the loss of image quality on textiles during washing are presented in Table 4. Samples for washing and abrasion tests were cut from one print, but in different places; so the Figures in Table 4 show a different fragment of the image, not the same as in Table 4.

Table 4 The results of research on the loss of image quality on textiles during washing

Printing method			
Sublimation	***Screen printing***	***Digital printing on a white base***	***Digital printing without a base***
Reference images			
			
5 washing cycles			
			
10 washing cycles			
			
15 washing cycles			
			
20 washing cycles			
			
25 washing cycles			
			

As a result of organoleptic evaluation of images on textiles applied by different printing methods, a gradual loss of color of each sample was established. The most resistant to washing were the samples of images applied by sublimation and screen printing on a white base. The image obtained by digital printing turned out to be less stable. Analyzing the image of digital printing on black fabric (Table 4), it seems that the image after washing becomes more saturated and bright. This is an optical illusion caused by the removal of the primer and the white base of the print, as a result of which the fabric itself is visible and the overall picture becomes darker.

5 RESULTS

In addition to organoleptic evaluation of the degree of wear of the print as a result of testing on the abrasion machine, repeated washing and ironing, which is a subjective method of evaluation and based solely on human experience and visual perception, there is a need to develop an objective method of assessing wear. To this end, a PC program has been developed that compares the reference image (immediately after application) with the image that has been tested for abrasion and washing.

In order to verify the reliability of the software, a comparison of the two figures is made. The first figure with a resolution of 7x9 pixels contains 28 black pixels, and the second figure with a similar resolution contains 14 black pixels, i.e. 50% less than the first (Figure 3).

The comparison algorithm is as follows:

1. Translation of reference and worn images in grayscale
2. Conversion of images in bit format with the same parameters.
3. Uploading images to the comparison program.
4. Pixel-by-pixel comparison on the abscissa axis of the selected image fragment corresponding to the first pixel of the ordinate axis.
5. Going to the second pixel on the ordinate axis.
6. Pixel-by-pixel comparison on the abscissa axis of the selected image fragment corresponding to the second pixel of the ordinate axis.
7. Going to the n-pixel on the ordinate axis.
8. Pixel-by-pixel comparison along the abscissa axis of the selected image fragment corresponding to the n-pixel along the ordinate axis.
9. Carrying out calculations.
10. Derivation of the comparison result.

According to the results of the comparison of the two figures, the wear is 50%, which corresponds to the specified parameters and confirms the reliability of the software.

The software was also tested to determine the level of wear in the selected fragment for further comparison of the samples tested for abrasion resistance. For this purpose, the initial computer simulation of the process of image wear at 50% of the initial level of only the image fragment was performed.

The image in the CMYK color scheme with the subsequent conversion to a bit format is selected as the reference. According to the results of computer comparison of the reference and software "worn" image, the wear is 50% in the area of artificial wear, which corresponds to the specified parameters. The results of computer image modeling and artificial wear are shown in Table 5.

This software was then used to compare scanned reference images and images that were subject to wear and repeated washing.

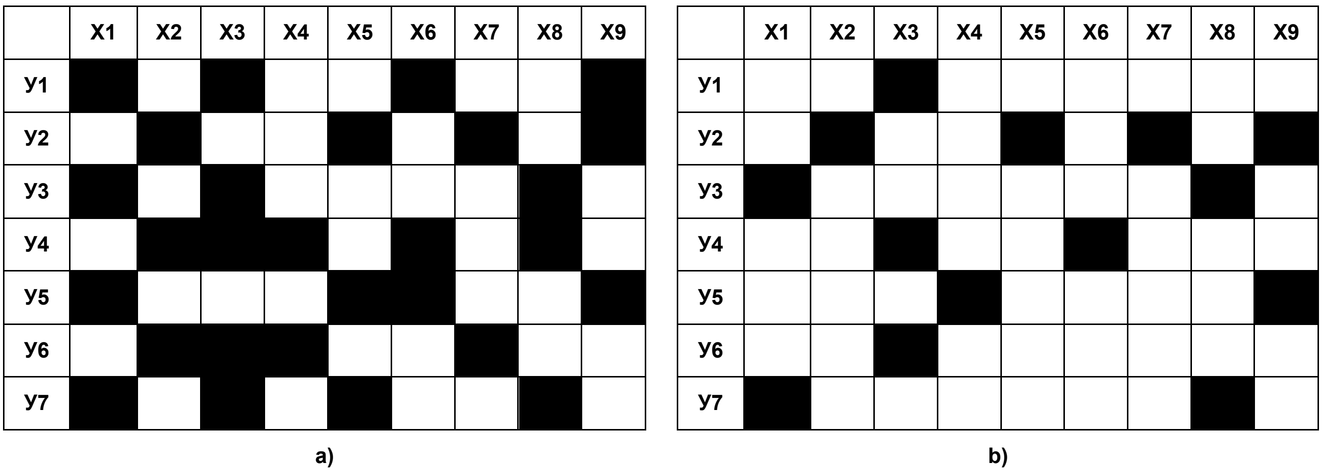
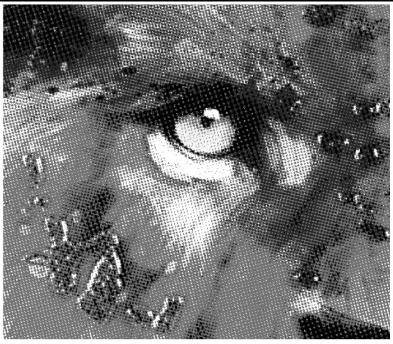
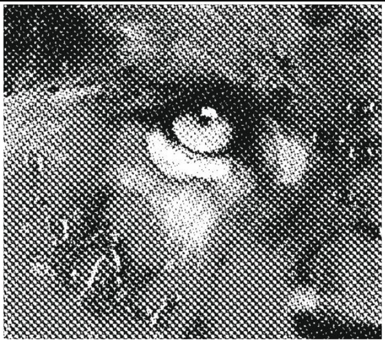
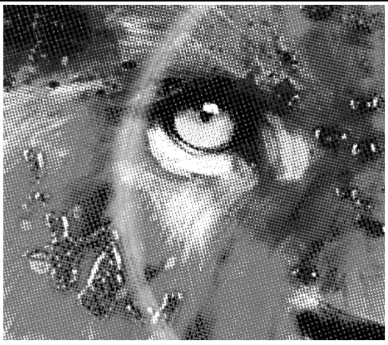
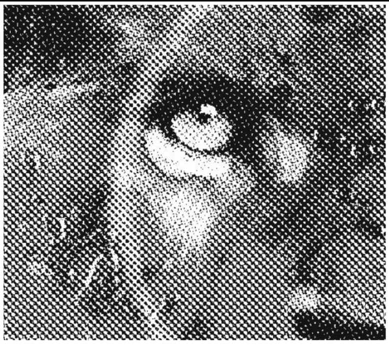


Figure 3 Pixel layout in the test image of the software: a) the total number of pixels - 63, the number of dark pixels - 28; b) the total number of pixels - 63, the number of dark pixels - 14

Table 5 Computer simulation of image wear

Images in CMYK color scheme	Grayscale image	Images in bit format
Reference images		
		
Artificially worn images		
		

For samples tested for abrasion, the program compares the intensity or degree of wear only by the friction trajectory. For samples tested for repeated washing, the comparison took place over the entire area of the test sample. The results of software evaluation of image quality for resistance to washing and abrasion are presented in Table 6.

As a result of using the proposed computer method for assessing image quality, it was found that the image quality during friction in sublimation printing samples is lost by 1.5% compared to the reference; screen printing loses 10% quality compared to the reference with the same number of cycles.

Table 6 The results of software evaluation of image quality for resistance to washing and abrasion

Research method	Loss of quality of the sample relative to the reference image [%]			
	Sublimation	***Screen printing***	***Digital printing on a white base***	***Digital printing without a base***
Study of image stability during friction	50 cycles			
	-	3.0	25.0	10.0
	100 cycles			
	1.5	10.0	-	17.0
	150 cycles			
	2.7	-	-	-
	200 cycles			
	5.0	-	-	-
Investigation of image quality loss during washing	5 cycles			
	-	-	1.1	0.8
	10 cycles			
	1.3	1.5	2.5	2.0
	15 cycles			
	4.0	4.0	8.5	6.5
	20 cycles			
	8.0	10.0	12.3	10.0
	25 cycles			
	10.0	14.0	18.0	15.0

Digital printing as a result of research is less stable than the previous two. The investigated samples of digital printing on a white basis lose 25% of image quality from the reference after 50 cycles. Baseless digital printing loses 17% after 100 cycles.

Studies of image quality dependence on wash cycles quantity have shown the following result. The most stable were samples made by screen and sublimation printing; less stable were samples made by digital printing on a white base and without a base.

6 CONCLUSIONS

In the process of analyzing the information available in open sources, it was found that the choice of technology for applying images to textile materials depends on the following factors: the number of products in the batch; image area; the number of image colors; raw material composition of the fabric; fabric color.

As a result of this study, the list of criteria is supplemented and presented in a form convenient for use in the analysis and selection of the method of printing images on textile materials in each case (Table 1).

One of the important factors influencing the choice of the method of applying the image to textile materials - the cost of making the print - was considered separately.

According to the simplified method of calculation, the cost of a 100 unit batch of products is determined for each of the image printing methods. The influence of the features of individual technological operations of each printing method on the final result of the calculation is taken into account.

The obtained results (Table 2) make it possible to perform an economic assessment of each of the methods and decide on the appropriateness of their use in each case.

The next result of this study is the evaluation of the performance of the image on textile materials, applied by different printing methods. In the course of experimental researches the degree of resistance of the images made by various ways of the printing to friction and in the course of washing was established.

The conclusions obtained as a result of organoleptic assessment of image quality loss in the process of testing on the abrasion machine (Table 3), repeated washing and ironing (Table 4) are confirmed by the results obtained using a specially developed computer method for image quality assessment (Table 6). It was found that the most resistant to abrasion and washing were samples of images applied by screen printing and sublimation.

Therefore, we can conclude that the application of the results of this study will allow a qualitative and effective assessment of methods of printing images on textile materials, depending on the manufacturing conditions for each type of product.

7 REFFERENCES

1. History of printing on fabric, URL: https://singleprint.com.ua/blog/istoriya-pechati-na-tkani/, (date of application: 10.02.2021), (in Ukrainian)
2. Kuleshova S.G.: Color in the art of designing clothes: study guide, Khmelnytskyi: KhNU, 2016, 395 p. (in Ukrainian)
3. Pressroll printing house: types of printing on fabric URL: https://pressroll.ru/blog/vidy-pechati-na-tkani/, (date of application: 10.02.2021), (in Ukrainian)
4. ORIGINAL printing studio: ways to print an image on fabric URL: https://original-shop.by/sposoby-pechati-izobrazheniya-na-tkani/, (date of application: 15.02.2021), (in Ukrainian)
5. 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 textil (Fibres and Textiles) 27(4), 2020, pp. 106-117
6. Koshevko J., Kushevskiy N.: Design of energy-saving technology of shaping and fixing the shape of headdresses parts, Eastern-European Journal of Enterprise Technologies 3/6(81), 2016, pp. 16-26, DOI: 10.15587/1729-4061.2016.71242
7. Zakharkevich O., Zhylenko T., Koshevko Y., Kuleshova S., Ditkovska O., Shvets G.: Expert system to select the fabrics for transformable garments, Vlakna a textil (Fibres and Textiles) 25(2), 2018, pp. 105-112
8. Norman D.A.: Emotional design: Why we Love (or Hate) Everyday Things, New York: Basic Books, 2005, 268 p., ISBN: 978-0465051366
9. Schutte S.: Engineering Emotional Values in Product Design, Kansei Engineering in Development, Linkoping University, Department of Mechanical Engineering, Disertation 951, 2005, 106 p., ISBN 91-85299-46-4
10. Nagamachi M.: Kansei/Affective Engineering, Taylor & Francis Group, 2010, 334 p., https://doi.org/10.1201/EBK1439821336
11. Prybeha D., Smutko S., Mitsa V., Khrushch A.: Research of the technological process of screen printing on textile and knitting materials, In: Proceeding of the International Conference on Technics, Technologies and Education ICTTE 2019, 16-18. 10. 2019, Yambol, pp. 344-351
12. Zhylenko T., Zakharkevich O., Koshevko J., Kuleshova S.: Parametrization of the hierarchical structure of the tree of pills emergence during pilling formation on textile materials, Vlakna a textil (Fibres and Textiles) 27(4), 2020, pp. 150-156
13. Chouprina N.V.: Characteristics of «fast fashion» concept in fashion industry, Vlákna a textil (Fibres and Textiles) 21(1), 2014, pp. 31-36

14. Nada Y.A., Meshref H.: Analysis, design, and implementation of intelligent expert system for clothes style selection, International Journal of Computer Applications 105(4), 2014, pp. 15-20, DOI: 10.5120/18364-9508
15. Slavinskaya A., Dombrovska O., Mytsa V., Dombrovskyi A., Ivanishena T.: Method of control of the compatibility of the children's clothing design using coefficients of dimentional features gradation, Vlakna a textil (Fibres and Textiles) 27(1), 2020, pp. 76-86
16. Nagamachi M.: Perspectives and the new trend of Kansei/affective engineering, The TQM Journal 20(4), 2008, pp. 290-298, https://doi.org/10.1108/17542730810881285
17. Rajasekera J., Karunasena H.: Apparel design optimization for global market: Kansei engineering preference model, International Journal of Affective Engineering 14(2), 2015, pp. 119-126, https://doi.org/10.5057/ijae.14.119
18. Qiao X., Wang P., Li Y., Hu Z.: Study on a correlation model between the Kansei image and the texture harmony, International Journal of Signal Processing, Image Processing and Pattern Recognition 7(4), 2014, pp. 73-84, http://dx.doi.org/10.14257/ijsip.2014.7.4.07
19. Synyuk O., Musiał J., Zlotenko B., Kulik, T.: Development of equipment for injection molding of polymer products filled with recycled polymer waste, Polymers 12(11), 2725; 2020, pp. 1-20, doi:10.3390/polym12112725

STRETCHABLE DENIM PROPERTIES DEPENDENCY ON INDUSTRIAL WASHING TECHNIQUES

Md. Reazuddin Repon[1, 2, 3*], Tarikul Islam[4], Halima Tus Sadia[4], Md. Rezaul Karim[5], Muhammad Usman Munir[3] and Mohammad Abdul Jalil[6]

[1]ZR Research Institute for Advanced Materials, Sherpur-2100, Bangladesh
[2]Department of Textile Engineering, Khwaja Yunus Ali University, Sirajgang-6751, Bangladesh
[3]Department of Production Engineering, Faculty of Mechanical Engineering and Design, Kaunas University of Technology, Studentu 56, LT-51424, Kaunas, Lithuania
[4]Department of Textile Engineering, Jashore University of Science and Technology, Jashore-7408, Bangladesh
[5]Department of Textile Engineering, Port City International University, Chittagong-4202, Bangladesh
[6]Department of Textile Engineering, Khulna University of Engineering and Technology, Khulna -9203, Bangladesh
**reazmbstu.te@gmail.com; md.repon@ktu.edu*

***Abstract:** Day by day washing process of denim is turning into the art of new fashion trends as it can create various sorts of style and effect in the denim garment. On account of washing, the properties of denim are additionally built up that expands consumer esteem. The target of the present research work is to disclose the modification of the characteristics of the spandex containing denim fabrics after applying different industrial washing techniques. To perform this work, 3/1 twill weave denim fabric composed of 98% cotton along with 2% spandex has been taken and subjected to different industrial washing techniques viz. bleach, acid, potassium permanganate, enzyme and stone enzyme washing. The surface density of the fabric, weight loss, shrinkage, colour fastness to wash, rubbing, phenolic yellowing, tearing strength and tensile strength have been determined to assess the impact of washing techniques on spandex containing denim fabric. The tested results claim that significant changes have occurred in the denim properties by introducing different washing techniques.*

***Keywords:** Denim washing, phenolic yellowing, spandex, tearing strength, tensile strength.*

1 INTRODUCTION

The fashions of today are incomplete without denim. Denim comes in a variety of styles, looks and washes to complement every outfit. Denim is now notably using apparel globally for its consolation and durability. It is leading to the people of every age as it's the symbol of youth, fashion, and attitude and has social and cultural influence. It is an incredibly sturdy, rigid and hard-wearing woven fabric. Denim is generally composed of cotton and twill weave structured cloth used for jeans, work and informal wear, made with coloured warp and white weft yarn [1-4]. Twill fabrics are used to make durable fibrous products that are used in harsh environments. The high longevity of twill fabric is due to the twill structure's few interlacing per inch, which allows for higher fabric counts or more yarn packing. Now-a-days, several developments and innovations are done to customize the denim fabrics employing various kinds of fibres, yarns and finishing treatments. A new trend is introduced to the customer by manufacturing stretch denim fabrics. This breakthrough was made possible by the use of synthetic elastane fibres like Lycra, which can extend up to six times their original length and return to its original state several times. The lack of recovery and sagginess in older jeans after a few wears prompted this concept. Stretch yarn can be unidirectional or bidirectional in both weft and warp [4-7].

Washing is an important finishing process for amendment and introducing new fashion. The denim washing procedure is provided with a rewarding and glassy outlook with the aid of using chemical and mechanical washing processes those consumers so desire. Raw denim fabric is not suitable for clothing because of its weave structure and dyeing effects. So, in order to ensure comfort, the finishing treatments should be carried out. For this, a finishing treatment is basically required to make it softer, more flexible, smooth and comfortable to wear [7-12]. After applying different finishing treatments to the denim fabrics, it offers different shades and interferes with various properties of colour that makes denim attractive as well as influences the clients to purchase them. All applied finishing treatments make some changes of physical, mechanical and colour properties to increase the wear comfort with durability and aesthetical view [13-22].

Over the past few years, several investigators have studied the washing effects of denim garments applying different techniques [11-22]. But, a few works on the washing effects of spandex containing denim garments have been done to establish novel design and high performance fashion [3, 4]. However, there is still a lack of information in the writing on findings of denim products with incorporated spandex, as well as changes in properties during wear.

Therefore, this article aims to determine the impacts of different industrial washing techniques on the properties of stretchable denim fabrics. The surface density of the fabric, weight loss percentage, shrinkage percentage, colour fastness to washing, rubbing, and phenolic yellowing, tearing strength and tensile strength have been observed conducive to detect the impact of washing techniques on stretchable denim properties.

2 EXPERIMENTAL

2.1 Materials

3/1 twill structure denim fabrics composed of 98% cotton and 2% spandex were used for the experiment. The main characteristics of the spandex containing denim fabric are shown in Table 1. The chemicals used for washing were procured from Redox Chemicals Ltd, Sri Lanka. All chemicals were industrial grade and used without any rectification.

2.2 Methods

<u>Sampling design</u>

Five different washing processes have been used in this current work. The descriptions of denim industrial washing techniques are identified in Table 2.

<u>Test analysis</u>

In accordance with ASTM D 3776, the fabric surface density (GSM) was determined [23] and weight loss percentage was calculated from the difference of weight (GSM) before and after the treatment of fabric. As stated in AATCC test method 96, the shrinkage percentage was determined from the difference in fabric length before and after treatment [24]. The colour fastness to washing, rubbing and phenolic yellowing were measured followed by ISO 105-C06:2010 [25], ISO 105-X12:2016 [26] and ISO 105-X18:2007 [27], respectively. Tearing strength and tensile strength of the samples were evaluated according to ASTM D1424:09 [28] and ASTM D5034 [29] correspondingly. Before testing, treated fabrics were conditioned in 65% RH at 20°C temperature for 24 hrs as maintained by ASTM D1776 [30].

Table 1 Characteristics of the unwashed sample

Fabric code	Weave	Composition	Warp and weft density [cm^{-1}]		Surface density W [g/m^2]	Linear density [tex]	
			warp	weft		warp	weft
F0	Twill 3/1	98% cotton 2% spandex	180	102	370	83	74

Table 2 Sample identification and descriptions of denim industrial washing techniques

Fabric code	Washing techniques	Description		
		Main process	Softening	Hydro-extracting and drying
F1	Bleach washing	A standard recipe of bleaching powder (10 g/L), soda ash (5 g/L), sequestering agent (2 ml/L) at pH 10, and 1:5 material-liquor ratio was applied for bleach wash and this process was carried out for 20 min at temperature of 40°C. After washing, the cold wash was carried out for 5 min.	GN Soft 150 softener was used for softening keeping the concentration of 1 g/L at liquor ratio of 1:4 for 5 min.	The processed stretchable denim fabric was squeezed in a hydro-extractor at 200 rpm for 4 min and then dried in a tumble drier for 30 min.
F2	Acid washing	Acid wash was done by acetic acid with potassium permanganate (1 g/L) and 1:5 materials to liquor ratio at room temperature for 20 min. The thermocol balls are placed in the washing machine and the solvent is diffused through the machine. Washing was accomplished at temperature of 40°C for 20 min. The cold wash was executed for 5 min after washing.		
F3	PP washing	A standard recipe of potassium permanganate (5 g/L), sodium metabisulfite (1.5 g/L), sequestering agent (2 ml/L) at 1:5 material-liquor ratio was applied for potassium permanganate washing. Washing was carried out at 40°C for 20 min. After PP wash, the cold wash was follow-out for 5 min and lastly invalidated in sodium metabisulfite solution for 20 min.		
F4	Enzyme washing	The enzyme wash was done with acetic acid (1 ml/L), anti-back staining agent (0.5 g/L), wetting agent (1 g/L), sequestering agent (2 ml /L) at pH 5.5 and material to liquor ratio of 1:4 with Cellulase enzyme (1.5 g/L) for 40 min at 50°C. And then, the cold wash was carried out.		
F5	Stone-enzyme washing	Same as Enzyme washing but only 10 kg of pumice stone was employed in the bath during enzyme wash.		

3 RESULTS AND DISCUSSION

The certain physical, mechanical and colour properties were determined to judge the impact of different industrial washing on spandex containing denim fabrics qualities. Here, the numbers of specimens are six and the result of changes in surface density, weight loss percentage, shrinkage percentage, colour fastness to washing, rubbing and phenolic yellowing, tensile strength and tearing strength are discussed.

3.1 Washing effect on surface density

The surface density was measured for all samples to analyse the impact of washing. The results are presented in Figure 1.

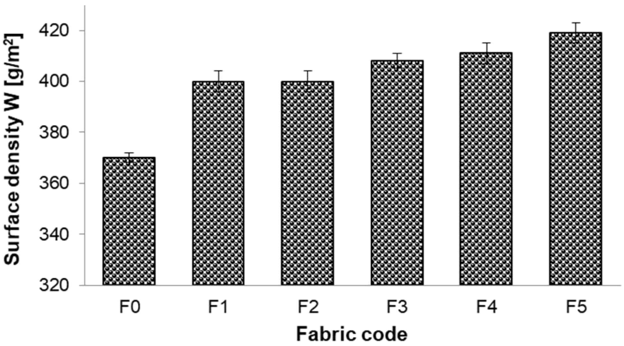


Figure 1 Surface density changes of stretchable denim fabrics at different washing techniques

As a consequence of the washing process, all the washed denim fabrics show an increase in surface density (weight per square meter). The increment of fabric weight shows the following order: F5>F4>F3>F2=F1>F0. The reason behind the increasing weight of fabrics can be explained by the changes in fabric structural parameters, like increasing the density of the yarn because of fabric shrinkage. From Figure 1, the higher increase of fabric GSM has been observed for the fabrics F5 and it is 13.24% higher than F0. Correspondingly, it was found that the surface density was shown by 8.11%, 8.11%, 10.27%, and 11.08% higher for F1, F2, F3 and F4 respectively compared to the sample F0.

3.2 Weight loss percentage

A main aspect of washing is the weight loss percentage of the denim washed specimens, as it is linked to cost benefit, excellence of washed fabrics, durability, comfort capacity and other features. The weight loss percentage of the stretchable denim fabrics has been evaluated and the results of the weight loss percentage are reported in Figure 2. The weight loss percentage of dyed denim fabric was observed not too significant. This is because of the structure of the fabric and there is less potential to allow the agencies to destroy fibres. However, the weight loss percentage of bleach wash, acid wash and PP washed samples showed moderately high among all types of washing techniques, since oxidative treatment caused some damage to cellulose. In comparison, the cellulase enzyme hydrolyses the cotton during enzyme wash which is very prominent in knit fabrics due to this floppy structure. Whatever, firstly cellulose enzyme impairs projecting fibres on the surface, then attacks on the yarn portion; here the hydrolyse action is very slow due to the compact structure of denim. That is why in case of enzyme and enzyme-stone washing, cellulose degradation or weight loss percentage is insignificant for denim wash. However, the highest weight loss was observed for bleach washed sample and lowest for enzyme washed sample. The sample order was found as F1>F3>F2>F5>F4.

The weight loss was observed 177.8%, 144.4%, 155.6% and 44.4% higher for bleach, acid, PP and stone-enzyme washed specimen compared to enzyme washed specimen.

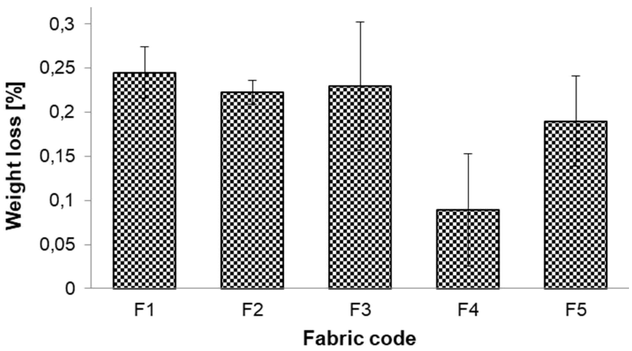


Figure 2 Weight loss percentage of stretchable denim fabrics at different washing techniques

3.3 Shrinkage percentage

It is important to measure fabric shrinkage in the phase of clothing design; otherwise, measurements of a readymade article would mismatch the planned ones. Results of the denim shrinking capacity after industrial washing are presented in Figure 3.

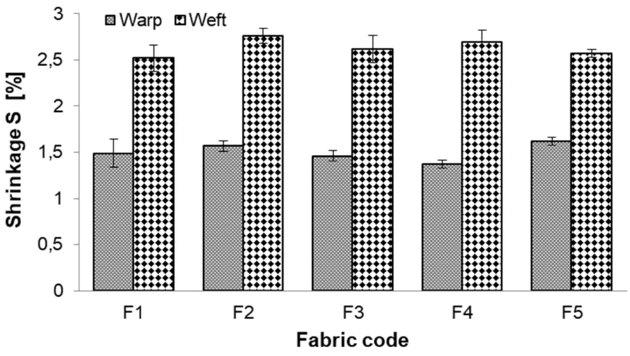


Figure 3 Shrinkage behaviour of denim of stretchable denim fabrics at different washing techniques

Table 3 Colour fastness to wash

Fabric code	Colour change	Staining					
		Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
F0	4	4/5	4	5	4/5	4	4/5
F1	4	4/5	4	5	4/5	4	3/4
F2	3/4	4	3/4	4	4/5	3/4	4
F3	4	4	3/4	4	4/5	4	4
F4	4	4/5	4/5	4/5	4/5	4/5	3/4
F5	4	4	3/4	4/5	5	4/5	4

Analysis of the findings reveals that different shrinkage value has found against various washing techniques. The shrinkage of stretchable denim is intimately linked to the alternation in its structural features after washing. Shrinkage in the weft showed higher than that of warp direction. In the case of warp direction shrinkage, the sample order was found as F5>F2>F1>F3>F4. Regarding weft direction shrinkage, the sample order was found as F4>F2>F3>F5>F1.

The stone-enzyme washed sample shrank the most in the warp direction, while the enzyme washed sample shrank the least. As compared to enzyme washed specimens, shrinkages were 8.76%, 14.59%, 6.57%, and 19.71% higher for bleach, acid, PP and stone-enzyme washed specimens in the warp direction.

In the weft direction, the highest shrinkage was observed for the acid washed samples and the lowest for bleach washed samples. The shrinkages were observed 9.52%, 3.97%, 7.14% and 1.98% higher for acid, PP, enzyme and stone-enzyme washed specimen compared to bleach washed specimen in the weft direction.

3.4 Colour fastness to wash

Table 3 presented the colour fastness to wash. The overall results of colour fastness to washing of samples were very good to excellent.

F1, F3, F4 and F5 samples were shown very good and F2 showed good to very good results in colour change. From the Table 3 it is depicted that only washing does not affect the colour fastness property of denim fabric too much. Before washing, colour change grading was 4. Slightly colour staining has occurred on cotton and wool for all samples.

3.5 Colour fastness to rubbing

Observing the changes in colour properties of the denim after rubbing is an important factor. The rubbing fastness of the washed denim specimens is presented in Table 4.

From the Table 4, it is observed that better results showed for dry rubbing than wet rubbing in all cases. The very good to excellent fastness properties have been found for the denim fabrics F1 and F2. Very good fastness result has been shown by the sample F3 and moderate results showed for F4 and F5 in dry conditions. A very poor result has been found for the fabric F4 caused by enzyme washing in wet conditions. So, it is cleared that bleach and acid washed specimens showed very good to excellent rubbing fastness in dry conditions. Conversely, bleach, acid and PP washed samples showed comparatively good rubbing results in wet conditions.

Table 4 Colour fastness to rubbing for dry and wet

Fabric code	Rubbing	
	Dry	Wet
F0	4	2
F1	4/5	3
F2	4/5	2/3
F3	4	2/3
F4	3	1
F5	3	1/2

3.6 Colour fastness to phenolic yellowing

Table 5 indicates the effect of washing on colour fastness to phenolic yellowing of denim fabric.

Table 5 Colour fastness to phenolic yellowing

Fabric code	Change in colour
F0	4/5
F1	4/5
F2	4/5
F3	4/5
F4	4
F5	4

According to the Table 5, it is depicted that colour fastness properties to phenolic yellowing were shown grading of 4-5 for the fabric sample of F0, F1, F2 and F3. That means, the specimens of before wash and after bleach, acid and PP wash were shown very good to excellent colour fastness to phenolic yellowing. For the fabrics of F4 and F5, the fastness to phenolic yellowing grading decreases and it is 4. It means, by doing enzyme and stone enzyme wash, it shows a very good washing effect to the denim fabrics.

3.7 Washing effects on tearing strength

The data of differently washed denim fabric is shown in Figure 4 describes tearing strength changes of the fabric both in warp and weft direction.

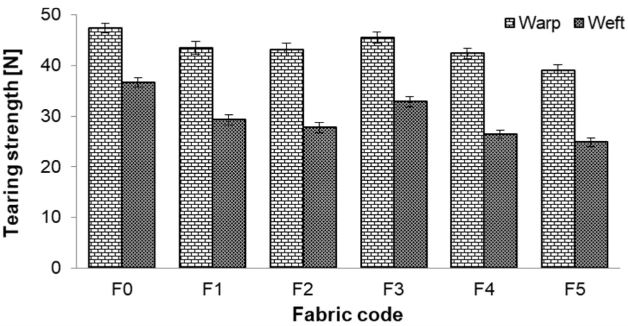


Figure 4 Changes in tearing strength of stretchable denim fabrics at different washing techniques

From the Figure 4, it was found that tearing strength alters due to washing and it decreases. Enzyme washed sample was excessively affected in both its warp and weft direction because the enzyme hydrolysed the cotton. In the case of tearing strength in the warp direction, it was observed that the change was not very prominent. The higher tearing strength was detected in warp direction caused by PP wash and less by stone enzyme wash compared in all washing processes (Figure 4). It was observed that the tearing strength in warp direction was 8.32%, 8.98%, 3.93%, 10.52%, and 17.80% lower for F1, F2, F3, F4, and F5 respectively compared to the sample F0.

Accordingly, in the warp direction tearing strength, it was observed that the change was noticeable in the weft direction. The higher tearing strength was detected in the weft direction caused by PP wash and less by stone enzyme wash also compared in all washing processes (Figure 4). It was observed that the tearing strength was 20.24%, 24.20%, 10.43%, 27.94%, and 32.34% lower for F1, F2, F3, F4, and F5 respectively compared to the sample F0 in the weft direction. So, it is found that the best washing effect on tearing strength was gained by PP wash. On the contrary, stone enzyme wash shows less tearing strength both for warp and weft direction.

3.8 Washing effects on tensile strength

The tensile strength of denim is a dominant variable and basically, testing is carried out onto warp and weft direction separately. Here, Figure 5 presents the results of the effects of washing on tensile strength in the direction of warp and weft for the denim fabric.

For tensile strength in the warp direction, it was observed from Figure 5 that the sample F3 showed the highest strength, and F4 showed the lowest strength. It was found that the tensile strength was 9.80%, 8.26%, 6.24%, 14.90%, and 11.76% lower for F1, F2, F3, F4, and F5 respectively compared to the sample F0.

For weft direction, the same scenario was observed for tensile strength. The specimen of F3 showed the highest tensile strength and F2 and F4 showed the lowest tensile strength (Figure 5). It was observed that the tensile strength was 16.96%, 22.32%, 11.61, 22.32% and 16.96% lower for F1, F2, F3, F4, and F5 respectively compared to the sample F0. So, it is depicted that enzymes give the higher washing effect of tensile strength in both warp, and weft direction and less effect were obtained for PP wash.

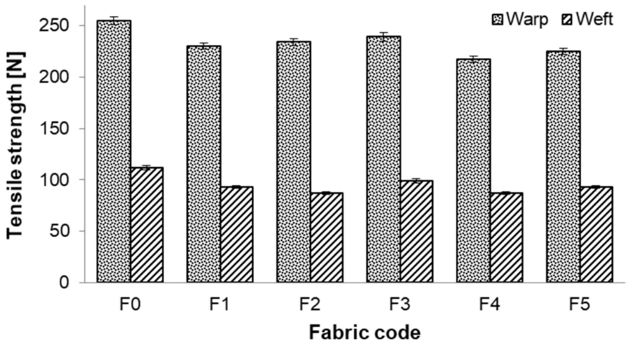


Figure 5 Changes in tensile strength of stretchable denim fabrics at different washing techniques

4 CONCLUSIONS

Denim washing is the core of the denim finishing and final process of denim production. After washing it becomes preferable to wear. This experiment deals with the changes of different properties of denim fabric after implementing different industrial wash. In this study, different characterizations such as surface density changes, shrinkage and weight loss percentage, colour fastness to wash, rubbing and phenolic yellowing, tearing strength and tensile strength were evaluated. Based on the related test outcomes it was obtained that the surface density of the fabrics increases especially stone enzyme washed specimen shows higher value. The colour fastness of the denim fabrics due to washing is very good to excellent for all washes. Excellent colour fastness is gained to phenolic yellowing for bleach, PP and acid washes and good colour fastness is found for enzyme and stone enzyme wash. For dry conditions, bleach and acid wash show excellent rubbing fastness than PP, enzyme and stone enzyme wash. For wet conditions, bleach wash shows good rubbing fastness. Tearing strength in the warp direction of PP wash is higher and less for stone enzyme wash while in the weft direction enzyme wash shows higher tearing strength and stone enzyme wash shows less. Determining tensile strength in the warp direction, the highest value is found for stone enzyme wash, while acid and enzyme wash shows less tensile strength. All these test results will help to make sure of new possibilities for further changes in denim production to grab consumer attraction.

Acknowledgments: *Technical support from "ZR Research Institute for Advanced Materials", Sherpur-2100, Bangladesh is gratefully acknowledged.*

5 REFERENCES

1. Razzaque M.A.: Garment & Textile Merchandising, 1st ed., Popular Publications, Dhaka, 2004, 226 p., ISBN: 984-32-1728-1
2. Kashem M.A.: Garments Merchandising, 1st ed., Granthanir Prokashoni, Dhaka, 2015, 308 p., ISBN: 9789849111252
3. Eryuruk S.H.: The effects of elastane and finishing processes on the performance properties of denim fabrics, International Journal of Clothing Science and Technology 31(2), 2019, pp. 243-258, https://doi.org/10.1108/IJCST-01-2018-0009
4. Ertaş O.G., Zervent Ünal B., Çelik N.: Analyzing the effect of the elastane-containing dual-core weft yarn density on the denim fabric performance properties, The Journal of the Textile Institute 107(1), 2016, pp.116-126, https://doi.org/10.1080/00405000.2015.1016319
5. Elmogahzy Y.: Engineering Textiles: Integrating the Design and Manufacture of Textile Products, 2nd ed., Woodhead Publishing, London, 2019, 462 p., ISBN: 9780081024881
6. Akter N., Repon M.R., Rashid M.A., Shiddique M.N.A.: Performance analysis of spandex incorporated single jersey fabrics for sportswear, Indian Journal of Science and Technology 13(20), 2020, pp. 1998-2009, https://doi.org/10.17485/IJST/v13i20.316
7. Paul R. (Ed.): Denim: Manufacture, Finishing and Applications, Woodhead Publishing, UK, 2015,612 p., https://doi.org/10.1016/C2013-0-16377-5
8. Khan M.M., Mondal M.I.: Physico-mechanical properties of finished denim garment by stone-bleach treatment, Journal of Chemical Engineering 28(1), 2013, pp. 36-40, https://www.banglajol.info/index.php/JCE/article/view/18109
9. Hossain M., Rony M.S., Hasan K.F., Hossain M.K., Hossain M.A., Zhou Y.: Effective mechanical and chemical washing process in garment industries, American Journal of Applied Physics 2(1), 2017, pp. 1-25, https://core.ac.uk/download/pdf/286338405.pdf
10. Akçagün E., Dal V., Atmaca M., Ceviz N., Yıldız Z., Yılmaz A., Kurtuluş A.B.: The Effects of Various Denim Washing Formulas on Clothing Comfort, In: 14th AUTEX World Textile Conference, Turkey, 2014, pp. 1-3
11. Khedher F., Dhouib S., Msahli S., Saklı F.: The influence of industrial finishing treatments and their succession on the mechanical properties of denim garment, AUTEX Research Journal 9(3), 2009, pp. 93-100, http://www.autexrj.com/cms/zalaczone_pliki/7_0311.pdf
12. Mir S., Hossain M., Biswas P., Hossain A., Idris M.A.: Evaluation of mechanical properties of denim garments after enzymatic bio-washing, World Applied Sciences Journal 31(9), 2014, pp. 1661-1665, https://www.idosi.org/wasj/wasj31(9)14/19.pdf
13. Hoque M., Hossain M.J., Imtiaz M.A., Das S., Rashid M.A.: Scope of dry wood & wood composite alternate to stone in case of acid wash on denim fabric, International Journal of Current Engineering and Technology 8(2), 2018, pp. 382-388, https://doi.org/10.14741/ijcet/v.8.2.32
14. Değırmencı Z.: Study on the loss of strength of denim-like knitted fabrics after different washing treatments, Fibres & Textiles in Eastern Europe 25(3), 2017, pp. 98-105, DOI: 10.5604/01.3001.0010.1697
15. Khalil E., Rahman A., Solaiman M.: Investigation of the influence of potassium permanganate on denim jeans processing during acid wash, AASCIT Communication 2(6), 2015, pp. 271-275, http://doi.org/10.5281/zenodo.31939
16. Jucienė M., Dobilaitė V., Kazlauskaitė G.: Influence of industrial washing on denim properties, Materials Science (MEDŽIAGOTYRA) 12(4), 2006, pp. 355-359, https://www.matsc.ktu.lt/index.php/MatSc/article/view/26475
17. El-Dessouki H.A.: Effect of different washing methods on mechanical properties of Egyptian denim fabrics, International Design Journal 5(3), 2015, pp. 1099-1107, https://dx.doi.org/10.21608/idj.2015.101517
18. Sarkar J., Khalil E.: Effect of industrial bleach wash and softening on the physical, mechanical and color properties of denim garments, IOSR Journal of Polymer and Textile Engineering 1(3), 2014, pp. 46-49, http://www.iosrjournals.org/iosr-jpte/papers/Vol1-issue3/G0134649.pdf
19. Heikinheimo L., Buchert J., Miettinen-Oinonen A., Suominen P.: Treating denim fabrics with Trichoderma reesei cellulases, Textile Research Journal 70(11), 2000, pp. 969-973, https://doi.org/10.1177%2F004051750007001106
20. Mezarciöz S., Toksöz M.: Investigation of effect of special washing processes on denim fabrics properties, Tekstil ve Konfeksiyon 24(1), 2014, pp. 86-95, https://dergipark.org.tr/en/download/article-file/218375
21. Khan M.M., Mondal M.I., Uddin M.Z.: Effect of bleach wash on the physical and mechanical properties of denim Garments, In International Conference on Mechanical Engineering, Dhaka, Bangladesh, ICME11 -FL-022, 2011, p.1-6, https://me.buet.ac.bd/icme/icme2011/Proceedings/PDF/ICME%2011-FL-022.pdf
22. Abdelfattah Halleb N., Sahnoun M., Cheikhrouhou M.: The effect of washing treatments on the sensory properties of denim fabric, Textile Research Journal 85(2), 2015, pp. 150-159, https://doi.org/10.1177%2F0040517514542971
23. ASTM D3776 / D3776M-20. Standard Test Methods for Mass Per Unit Area (Weight) of Fabric
24. AATCC 96. Test Method for Dimensional Changes in Commercial Laundering of Woven and Knitted Fabrics Except Wool

25. ISO 105-C06:2010. Textiles – Tests for colour fastness – Part C06: Colour fastness to domestic and commercial laundering
26. ISO 105-X12:2016. Textiles – Tests for colour fastness – Part X12: Colour fastness to rubbing
27. ISO 105-X18:2007. Textiles – Tests for colour fastness – Part X18: Assessment of the potential to phenolic yellowing of materials
28. ASTM D1424 – 09. Standard Test Method for Tearing Strength of Fabrics by Falling – Pendulum (Elmendorf – Type) Apparatus
29. ASTM D5034 – 09. Standard Test Method for Breaking Strength and Elongation of Textile Fabrics (Grab Test)
30. ASTM D1776 / D1776M-20. Standard Practice for Conditioning and Testing Textiles

A NEW MODERN THEORETICAL VIEW OF THE STRUCTURAL MODEL OF THE STRUCTURE OF NATURAL LEATHER

Mykola Skyba[1], Oleg Synyuk[1], Borys Zlotenko[2], Tetiana Kulik[2] and Svitlana Natroshvili[2]

[1]*Khmelnytskyi National University, Instytuts'ka str. 11, Khmelnytskyi 29016, Ukraine*
[2]*Kyiv National University of Technologies and Design, Nemyrovycha-Danchenka Street 2, Kyiv 01011, Ukraine*
rector@khnu.km.ua; synoleg@ukr.net; zlotenco@ukr.net; t-81@ukr.net; friit@knutd.edu.ua

Abstract: *The article presents approaches to the processing of waste from natural leather to artificial leather while preserving the beneficial properties of natural leather. It is proposed not to grind, but to defiber leather waste, i.e. before the destruction of the material you need to weaken its structure so that the fibers are easily separated at loads less than the breaking point of a single fiber. As a result of the analysis it is established that the structure and properties of leather materials form the basis of the processes of their defibering. A structural model of the structure of natural leather has been developed, which makes it possible to determine the change in the properties of leather fibers under the action of loads in the process of defibering natural leather waste and to establish a relationship with the properties of artificial leather obtained from recycled natural leather. It is established that the fibers, joining in bundles that look like strands or ribbons, and intertwining in all directions form a structural element of the natural leather. Elastic fibers, when combined with tannins and glycoproteins, which are unbound between the structural elements of the natural leather, form a macroscopic element of the natural leather.*

Keywords: *waste, leather, fibrils, collagen, fibers, material, properties.*

1 INTRODUCTION

Over the last century, humanity has made such progress in its own development that it has not been able to achieve during the previous two thousand years. Great scientific discoveries, the invention of new technologies and substances have increased many times the human need for raw materials, energy and water resources. Of course, no production is waste-free. All of Europe and America have long spoken of the great damage done to the environment by urban landfills, polluting not only the air but also the soil and groundwater that humans eventually consume. This is the law of the great terrestrial water cycle. It should also be noted that the areas where landfills are located, even after their elimination will be unsuitable for any use for many decades.

Waste incineration is also not an option. Toxic gases come to us again in the form of rain. And what is to say about large industrial enterprises, because they are the biggest polluters. It is their work that has given rise to such a term as "global environmental problems".

Most developed countries are already quite successful in combating these problems, using the latest processing technologies, repeated cycles of raw materials. Of course, the efficient and rational use of technological waste and secondary material resources received from enterprises and the population affects the intensity of economic development and, most importantly, requires a new approach to saving production and raw materials. However, this does not completely solve this problem, which is faced by many manufacturers. Today, special attention is paid to solving this problem. Many companies have long included in their production programs specialized machines for processing secondary material resources and various technological wastes. These machines are characterized by a high degree of automation, automatic control systems and versatility of design. Automated lines for the processing of secondary material resources and waste include various technological processes (for example, the production of shoe cardboard, nonwovens, yarn and fibers for various purposes). Nowadays, such machines are produced that can process technological waste from mixtures of different materials into high-quality products with high waste content or from pure secondary raw materials.

Waste of footwear and leather goods production is about 25-40% of all raw materials for leather and fur. Of course, workers in these industries can help reduce production costs by maximizing the use of leather, as well as employing its proper processing using advanced production methods. As a result, the production and processing of natural leather will expand, although the amount of waste will also increase. On the other hand, the growing tendency to chemicalize leather and footwear production will reduce the use of natural leather.

Waste generated in the process of preparation and processing of leather raw materials can be divided into sold, which can be used for the manufacture of various products and semi-finished products, and those that are taken to landfill. The fully used wastes include wool as well as core, scrap and chips of leather obtained by the chrome tanning method [1, 2].

Waste subjected to dechromization can be used not only for the manufacture of core glue, household soap and feed protein additives, but also for the production of synthetic rubbers, fiberboards, foaming agents.

When processing leather waste, more attention should be paid to preserving the valuable properties characteristics of natural raw materials. Therefore, when defibering waste, it is necessary to preserve the structure of fiber bundles, as well as their original length. The presence of short fibers in the future in the production of artificial leather such as cardboard requires the use of binders for their bonding, in some cases in an amount of more than 100% by weight of the fiber [3, 4]. At the same time, the hygienic properties of cardboard type artificial leather significantly deteriorate [5].

The use of existing technologies and equipment for defibering leads to the destruction of the material due to excessive crushing of fiber bundles. This is due to the strong fibrous-mesh structure of natural leather. As a result of the mutual pressure, twisting and looping of the fibers, they are clamped in volume, just as individual strands are clamped in a complex rope, and therefore the strength of the weave is greater than the natural strength of the fiber bundles. The works [6-8] are devoted to the study of physical and mechanical properties of leather and the nature of connections between fibers, where it is confirmed that when fibrous materials such as leather, felt, cardboard and artificial leather are tested for rupture, the tensile strength decreases with decreasing stripe width; a decrease in the tensile strength is observed when the stripe size is less than 5 mm.

To preserve in the artificial material made of recycled leather waste, the useful properties characteristics of natural leather, this waste must not be ground, but defibered. To do this, you need to find a way to weaken the structure of the leather before defibering so that the fibers can be easily separated without grinding.

2 DISCUSSION AND ANALYSIS

Before proceeding to the development of technologies for the defibering of leather waste, let's focus on general issues of its structure and microstructure in order to establish how the properties of leather fibers change under the influence of individual production processes, and how they affect the properties of the finished products. As noted in studies [5, 8, 9], the produced leather retains the natural fibrous structure inherent in animal skin.

2.1 General ideas about the structure of leather

In the animal skin there are three layers (Figure 1) [5, 8]: 1) a relatively thin upper cell layer - the epidermis;
2) the thickest dense fibrous layer - the dermis;
3) porous-fibrous layer that connects the skin with the body of the animal that is called subcutaneous tissue.

In the process of leather production, the epidermis, hair, sebaceous and sweat glands, as well as subcutaneous tissue are completely removed. The finished leather is only the middle layer of the skin - the dermis, treated accordingly.

The main histological elements of the dermis are fibrils, which are the thinnest threads up to 0.5 µm in diameter. Fibrils form fibers. The fiber can contain up to 10,000 fibrils. The fibers, in turn, are connected in bundles that have the form of strands or ribbons that intertwine in all directions and form a tissue.

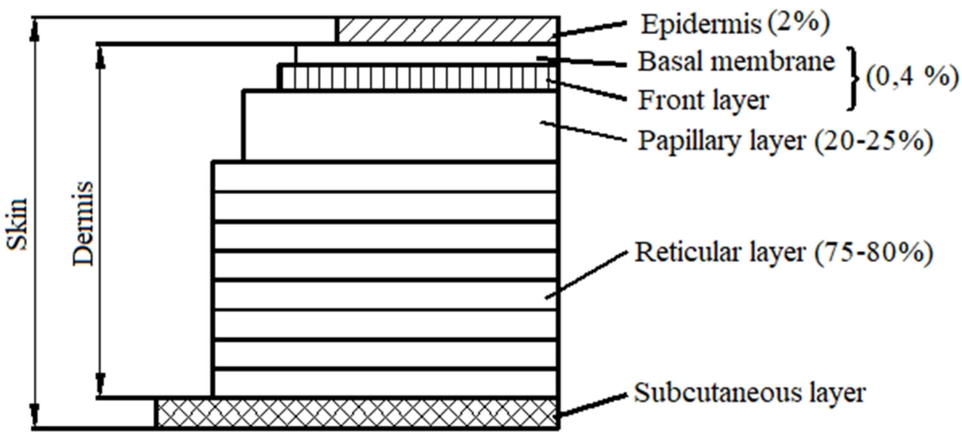


Figure 1 Scheme of layers in the dermis of cattle [5]

It is possible to compare the sizes of structural elements of a derma tissue on their transverse sizes [8]: a bunch 50-100 µm; fiber 20-40 µm; fiber 2 µm; fibril 0.5 µm.

The main component of the dermis fibers is a protein - collagen. Along with collagen fibers, the dermis also contains elastin and reticulum fibers. Elastin fibers are positioned in different directions and create a grid that serves as a framework for different structural elements. Reticulum fibers in the upper part of the dermis also form a dense network. Intertwined, the bundles of collagen fibers form a tissue in which the network of the bundles of collagen fibers changes depending on the species of animal, and in animals of the same species - depending on the topographic area of the skin.

At transition from intermediate levels of formation of skin collagen to the final one – the dermis – the principle of parallelism of structural elements (polypeptides, molecules, subfibrils, microfibrils, fibrils, primary and secondary fibers) packing is lost. Within the dermis, the fibers intertwine in different directions, forming a network. The size of the gaps between the collagen fibers of the dermis was determined by the parametric method [5, 6]. Thus, it was found that the average pore diameter in the dermis of cattle is 5 µm, i.e. almost 10 times smaller than the diameter of the secondary fibers.

To characterize the interfiber spaces of the dermis, as well as the products of its processing in leather production, in addition to porosity, the values are used: the volume of the dermis, which contains 100 g of collagen [9, 10]. Table 1 shows the ratio of these indicators of the dermis.

Table 1 Porosity, bulk density and bulk yield of air-dry dermis (humidity 15%, density excluding pore volume, 1.35 g/cm^3) [8]

Porosity [%]	Bulk density [g/sm^3]	Bulk yield [sm^3/100 g]
20	1.08	88.90
40	0.81	123.45
60	0.54	176.00
80	0.27	370.35

Using an optical microscope on the incisions of the dermis, you can see the secondary fibers located in the plane of intersection at different angles to the surface of the dermis. Schematically, this is shown in Figure 2 [5].

By measuring the angle of inclination of a large number of secondary fibers, you can calculate its average value, which depends on the topographic area of the skin.

The largest average angle of inclination of the fibers has the dermis in the back (about 50°), the smallest - in the abdomen (about 17°). Between themselves, the secondary collagen fibers of the dermis in the plane of its incision form rhombic shapes [8]. It seems that the fibers inside the dermis form a network of spirals, diamonds like threads in artificial nonwovens [5, 8, 11]. The sides of the rhombuses found in the incisions of the dermis are projections of the turns of the spirals, part of which are these fibers.

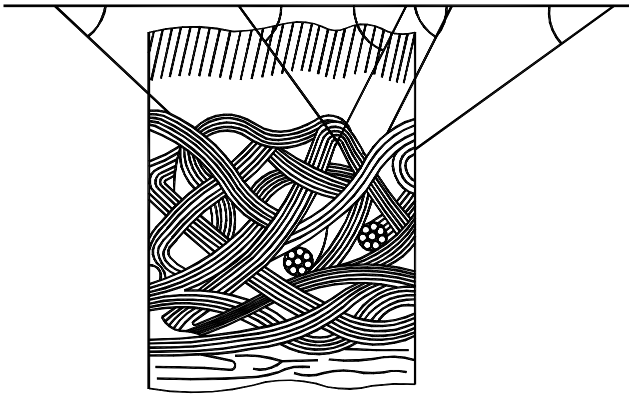


Figure 2 Layout of secondary fibers in the dermis [5]

It is always necessary to take into account the possibility of fluctuations in the indicators values of the cattle skin dermis structure. In particular, its density in different layers of the skin and in different topographic areas is not the same (Figure 3).

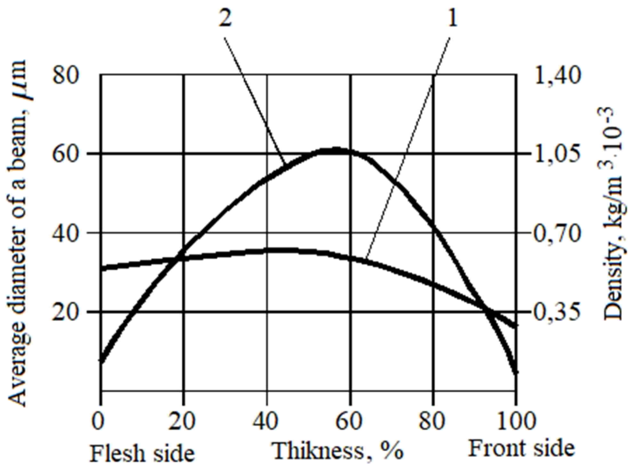


Figure 3 Density (1) and cross section of fibers (2) in the layers of the dermis of cattle

In the papillary layer of the cattle dermis the secondary fibers are twice as thin as in the reticular one, and are very close to each other. Even thinner elements of the structure are located in layers in contact with the epidermis, in which the fibrils are not combined into fibers. In the skin of sheep skin, the papillary layer accounts for up to 66% of its thickness, and in the skin of goats, this share is 33-50%. In the skin of pig skins it is impossible to distinguish papillary and reticular layers. Another feature of the dermis of pig skins is the strong branching of secondary fibers. The thickness of the epidermis of the skin of pigs reaches 5%, while in cattle, sheep, goats and horses it does not exceed 2%.

2.2 Structural levels of the fibrous structure of collagen

Skin collagen can be considered as a complex composite of fibrous structure at all levels of its structure. Consideration of the levels of collagen structure of the skin should start with the molecular level and go to larger structures [8]. Collagen is a fibrous protein that contains glycine, proline and oxyproline as the main components, and other amino acids in different proportions. The chains have a uniform length - 290 nm. Three such chains form a triple helical element called tropocollagen (Figure 4a). As noted in recent studies [5, 8, 9], five such tropocollagen elements form a microfibril (Figure 4b). These elements are located on the ledges along the longitudinal axis of the microfibrils in a section of fixed length (about 1/4 of the length of the molecule).

It is assumed that such a ledge together with the distance between the ends of the following tropocollagen is responsible for the characteristic period of the structure with a step of 65 nm, visible both in the electron microscope and at low-angle diffraction. It is also assumed that the five tropocollagens are intertwined in an elongated triple helix.

Microfibrils are enclosed in tetragonal or hexagonal lattices, which have a period of 3.8 nm (Figure 4d). They form a known fibrous element of collagen - collagen fibril (Figure 4d), which has a structure period of 65 nm and visible in an electron microscope. The diameter of these fibrils varies between 100-500 nm in mature animals.

There are a number of indications that fibrils may not be homogeneous throughout their cross section. Proof of this is the nature of the color of the interfibrillar carbohydrate matrix [5, 12], visible under an electron microscope. References to the subfibrillar region have appeared in other works [8]. When considering micrographs of strongly deformed fibers, the splitting of fibrils into separate subfibrils - fibrous elements with a diameter of 15 nm is visible (Figure 4d).

Collagen fibrils are surrounded by an interfibrillary matrix, which consists mainly of mucopolysaccharides and to a lesser extent of structural glycoproteins, and it has been found that this structure spreads in width, forming collagen elements with a diameter of several hundred μm.

These elements, connecting with elastic fibers and fibroblasts, form a macroscopic element of the skin. The element of collagen with a smooth outer surface is presented in Figure 5a.

The cross section of such collagen is not round – the ratio of its main diameters is in the range of 0.5-1.0. This shape is closer to the shape of a flattened cylinder than to what could be called a stripe. The diameter varies from 100 to 500 μm. With the appropriate orientation, the element considered in polarized light shows periodically fading bands with a period of about 100 μm along the fibers. This stripe character is due to the periodicity of the change in the orientation of the element of birefringence (Figure 5a). In separation experiments, it was found that these optical effects are characteristic of the structure of small beams of fibrils. When considering sections of collagen in polarized light, it is seen that all the stripes are corrugated in phase, and the planes of the stripes are parallel throughout the thickness of the skin (Figure 5b).

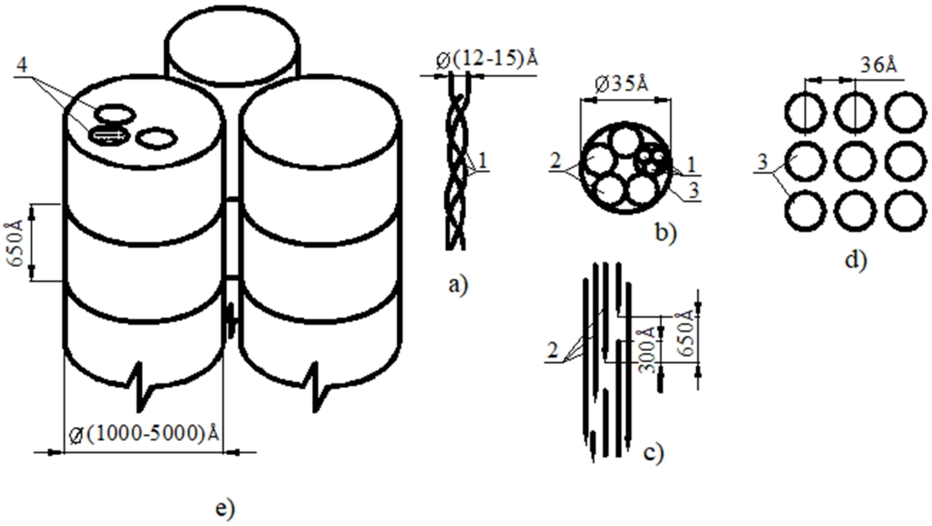


Figure 4 Scheme of structural levels of collagen, starting from the molecular level: a) triple helix of tropocollagen; b) cross section of microfibrils; c) longitudinal section of microfibrils; d) tetragonal packaging of microfibrils; e) collagen fibrils. 1 - peptide chains; 2 - tropocollagen; 3 - microfibrils; 4 - a separate subfibril formed by a lattice of microfibrils

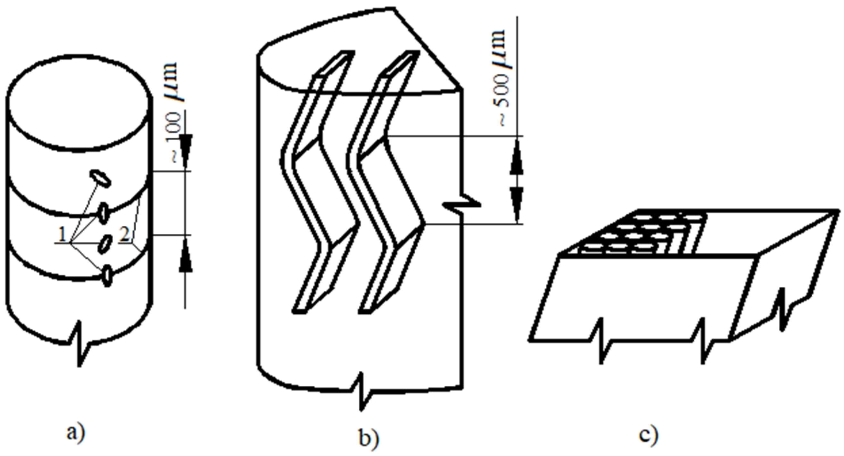


Figure 5 Scheme of the structure of collagen fiber at the macroscopic level: a) element of collagen fiber; b) the location of flat corrugated stripes in the fiber element; c) axonometric view of the cross section of the stripe, consisting of collagen fibrils. 1 - optical indicators, 2 - attenuation bands

To date, the dimensions of the cross section of these stripes are not precisely defined. It is believed that they vary from 2-3 to several tens of μm. Large elements are split into smaller ones until the smallest element with a noticeable stripe structure remains (Figure 5c). This condition corresponds to the structure of collagen fibrils shown in Figure 4d.

The nature of the relationship of structural levels depends on the mechanical behavior of the entire system. Larger elements of the structure have the properties of the tissue as a whole. Stretching in the area of small deformations leads to the reversible removal of the periodicity and the corresponding straightening of the folds. The mechanical model allows analyzing structures of smaller sizes. As mentioned earlier, the diameter of the load-bearing element cannot be measured on a macroscopic sample. To comply with experimental data, it is required that it be within the size of collagen fibrils (Figure 4d).

Mechanical behavior, obviously, reflects the relationship between different elements. When determining the structural level of the connecting elements, it should be borne in mind that there may be further splitting of the elements into smaller ones - depending on whether the collagen of the skin is in a state of growth (before obtaining leather) or in aging (after obtaining leather). After reaching the maturity of collagen, the modulus of its elements does not change; the increase in strength can be attributed to the possible connections between the fibrils: since large deformations cause flow and fracture, including sliding of adjacent elements, the bonds that connect the sliding elements will create the necessary reinforcement. In young skin, the fibrils in the matrix do not touch each other, in mature - begin to touch, and then, perhaps, they are fused [8]. In the latter case, the effective diameter of the fibrils is increased, and a direct chemical bond may occur between the fibrils. Despite the fact that the fibrils are separated by an interfibrillar matrix, there may be a direct mechanical connection between them (Figure 4d). In the electron microscope, the consistency of the internal structure of the fibrils is noticeable [4], which allows us to make assumptions about the similar nature of the striation. Thread-like structures that branch and connect groups of fibrils over long distances are described in [5].

Non-collagen components should also be considered in the block diagram. It has been established that mucopolysaccharides and, to a lesser extent, glycoproteins are associated with fibrils [3, 9]. They form a matrix surrounding the fibrils. However, mucopolysaccharides and glycoproteins may be at other structural levels. Thus, in [3] it was noted that saccharides are located between microfibrils, forming an interfibrillar space.

3 RESULTS AND DISCUSSION

The use of polarization optics has shown that periodically fading bands in the collagen structure are due to the presence of corrugated elements [4]. When collagen fibers are stretched, this "stripe character" gradually disappears. Analysis of the deformable properties of collagen showed that the load is mainly carried by a fiber whose diameter is several orders of magnitude smaller than that of the fiber visible in an optical microscope ($d \geq 2$ μm). The best model describing straightening of folds is based on the idea of stretching folds with rigid hinges. This model assumes the existence of the main load-bearing element, the diameter of which increases with age from 100 to 500 nm. The behavior of the material at high deformation rates indicates that the load-bearing fibrils themselves are fibrous composites and break down into smaller elements during fracture.

Consider the relationship between different structural levels of collagen fibers, in particular, the interaction of individual components of collagen fibers. For satisfactory modeling of the stress-strain behavior of collagen, it is necessary to determine the role of fibrils with a diameter smaller than visible in an optical microscope (*d* > 2 μm). The existence of such fibers is confirmed by electronic micrographs of individual parts [8]. One part of the samples was examined before loading, and the other - after cyclic deformation or failure.

In the cross section of undeformed collagen fibrils, stained areas of 3.0-3.5 nm in size are visible, which are identified as individual microfibrils [5, 8]. In animals of any age, except newborns, fibrils in the thickness of the skin are located regularly. In this distribution, the smaller fibrils fill the cavities between the larger ones, creating an interfibrillar matrix with a high volume content of fibrils. The close proximity of fibrils obviously leads to their fusion or germination into each other.

When the structure of the skin is subjected to mechanical impact, the formation of cavities and subsequent splitting of the fibrils of the interfibrillar space, it seems to us, are the main and general mechanism of deformation. The splitting of fibrils increases with increasing mechanical impact. Initially, in some fibrils there are random cavities; with a further increase in the mechanical impact the cavities spread throughout the fibril. By the time of destruction, the fibril completely decomposes into subfibrils with a diameter of about 15 nm, each of which contains several sections of 3.5 nm. A longitudinal section of a split fibril shows that subfibrils with a diameter of 15 nm are individual longitudinal elements with an unstable length. The characteristic periodicity (65 nm) visible in undeformed collagen fibrils is absent in subfibrils, which indicates the deformation that occurs in these elements.

The main age effect is a change in the number of splits that occur before destruction. It is highest at a young age of collagen (1.5 months), and decreases with age. Since fibril cleavage is the main mechanism of destruction at any age, the observed change in the number of cleavages may be the result of increased adhesion between subfibrils and microfibrils. This is consistent with the aging hypothesis based on the fact of increasing the density of cross-links at such structural levels, where these links can effectively reduce the possibility of slipping between subfibrils and microfibrils.

As noted, the crystalline interferences on the collagen radiograph revealed that the proportion of crystalline zones depends on the content of amino acid residues (proline and oxyproline) in the collagen polypeptides. The degree of crystallinity of the structure can be judged by determining the intensity of interference on radiographs and the half-width of reflexes [5, 8]. The results of these experiments are shown in Table 2.

In the initial stages of the study of supramolecular aggregates, the object of study was only one level of ultrastructure - fibrillar. Thinner filaments formed by the cleavage of fibrils by enzymes and certain chemical compounds were considered as random packets of molecules of different diameters. As a result of further experiments, the existence of structural additional protofibrillar levels was established.

Table 2 Crystallinity of tropocollagen with different content of amino acid residues [5]

Tropocollagen	The content of amino acid residues in the polypeptide	The proportion of the crystalline phase [%]
Mammal dermis	214	35
Pike dermis	189	30
Cod dermis	155	26

The analysis of spatial structures based on the principle of shear led to the finding of another additional level of collagen ultrastructure - microfibrillar. In the cross section of the fibrils there are five collagen molecules, which, depending on the humidity, form a hollow cylinder with a diameter of 3-5 nm. The scheme of such cylindrical collagen microfibrils is shown in Figure 6.

Another, related, scheme of microfibrils with four collagen molecules in cross section has been proposed in [5]. Experimental confirmation of the fact that collagen fibrils are aggregates of microfibrils of the same diameter is electronic microphotographs of negatively contrasted samples, on which it is clearly visible at high magnification.

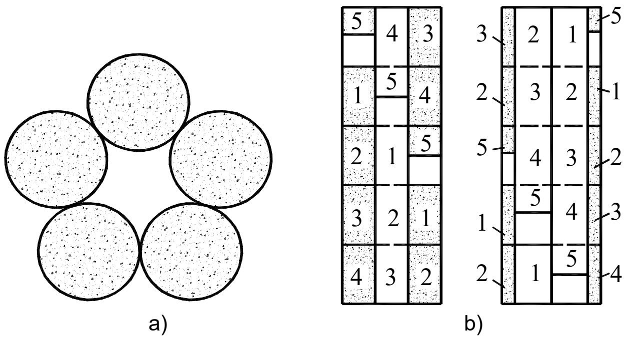


Figure 6 Scheme of collagen microfibrils: a) cross section; b) longitudinal section [5]

Data on the density of fibrous collagen, as well as gelatin of collagen-like conformation, can be a strong proof of the tubular nature of microfibrils (Figure 6b). Examination of air-dry collagen and gelatin preparations or after drying without special precautions reveals that their density usually does not exceed 1.4 g/sm^3, which corresponds to a specific volume of 0.71 sm^3/g. This value is much higher than the atomic volume of the same proteins, which does not exceed 0.5 sm^3/g. This indicates that in collagen the principle of dense packing of atoms in the crystal structure is not maintained. Thoroughly dehydrated collagen preparations, as well as collagen-like gelatin, have a density of about 2.0 /sm^3.

The above experimental data and considerations can be used to substantiate the scheme of self-assembly of microfibrils, which is subject to different laws than the ordered aggregation of protofibrils. The mechanism of fibrillation proposed in [9] can be considered the most substantiated. A very significant addition to the views expressed by these authors is the inclusion in the scheme of fibril formation of collagen molecules of two structural intermediate levels - protofibrillar and microfibrillar. Measurements of electron microscopic images of the filaments in the thickness of negatively stained fibrils indicate that they have a diameter of 3-4 nm, which corresponds to the diameter of the microfibrils. In this regard, there is every reason to use the idea of combining microfibrils into fibrils to consider the process. According to this scheme, in the collagen microfibrils, which are mistakenly identified with protein molecules, the areas of autogenesis of adjacent elements of structures and intermediate areas alternate. This alternation of areas of autogenesis and intermediate areas is fully consistent with the scheme of microfibrils, in which each period D contains areas of fusion. In their cross section there are five protofibrils, thickened with a layer of glycosaminoglycans (GAG), and intermediate sections consisting of only four molecular strands, on the surface of which there are fewer carbohydrates.

Possible types of interaction between microfibrils, leading to aggregates of the following supramolecular, i.e. fibrillar level, are: a) oriented, multilayer adsorption at the phase boundary; b) self-assembly in the interstructural fluid, i.e. in the absence of contact with the pre-formed phase boundary; c) fibril formation in jells.

Elements of the superfibrillary structure of the dermis of various mammals, as well as collagen fibers, of which it is mainly composed, have many features. In addition to the type of organism, the properties of the fibers and the dermis are influenced by the topographic features of the sampling site, as well as other factors (age of the mammal, sex, layer of the dermis, conditions of development of the organism, etc.). The anatomy and histology of the skin are mainly descriptive [8]. Some histological parameters of the dermis of a number of mammals are given in Table. 3.

Secondary fibers, or collagen bundles, are bundles of primary fibers (Table 4). The most common objects of study are secondary fibers that are plucked from the skin. The easiest way to achieve adefibering of the scalp of cattle. The thickest and longest bundles are located in this area.

Contacts between the fibers, which complicate the defibering of the dermis, occur as a result of pre-dehydration of the skin by air drying. In this case, between the elements of the structure of the fibers, as well as between the fibers in the dermis, there is an additional interaction that remains after dehydration.

Table 3 Basic structural parameters of the mammalian dermis [8]

Animal	Dermal thickness [µm]	Reticular layer thickness [% of dermis thickness]	Diameter of secondary fibers [µm]
Cattle	4000-6600	60-80	20-100
Pig	2500-5000	100	5-10
Sheep	2800	42	11.5
Goat	400-600	10-35	3.0-6.6
Squirrel	860	60-65	–
Hare	270	47	–
Mole	270-630	35-50	3.6-5.3
Fox	460	55	6.0

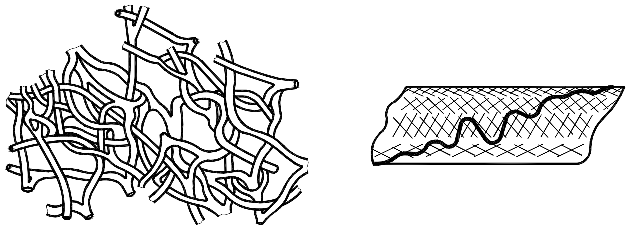
Table 4 The tortuosity and length of secondary fibers in different areas of the cattle skin dermis [5, 8]

№	Indicators	The area of the dermis	
		back	*head*
1	Dermis thickness [mm]	4.75	6.60
2	The average length of the secondary fiber [mm]	24.50	110.60
3	Fiber tortuosity:total (2:1)	5.20	16.80
4	The tortuosity of the fiber:per 1 mm of its length (2:3)	4.70	6.60

In the formation of primary and secondary collagen fibers of the dermis, the effect of mutual orientation and interaction of fibrils with a diameter of hundreds of nanometers is manifested. Therefore, it is worth noting the comparison of some elementary processes of obtaining artificial fibers by the spin method and the method of aggregation of collagen fibrils in the dermis of mammals. The deformations that the fibrils accumulate can be compared with those to which the spinning solutions of polymers are subjected as a result of forced syneresis during the formation of fibers by the spin method.

In the dermis, the parallel orientation of collagen particles is completed at the level of the secondary fibers that have the greatest length and diameter in the neck. The skin in this area of the dermis has greater mobility than in the back, abdomen and other areas. By cutting pieces of dermis of cow skin into horizontal layers, it was possible to determine the length of secondary collagen fibers in different topographic areas of the skin [5, 8]. The average lengths of secondary fibers in dense areas of the dermis reach 24.8 mm and in loose areas 109.7 mm. The number of branched fibers is 4- 9% of their total number. The length of the tortuous fibers significantly exceeds the thickness of the dermis (Table 4).

Most of the secondary fibers of the cattle dermis (70-80%) do not branch at all. Others have one branch. The difference between the tortuosity divided by the thickness of the dermis and tortuosity per 1 mm of fiber length is partly due to its unequal average slope relative to the surface. An important feature of the secondary fibers of the cattle dermis is that their ends, which have a diameter of 5-10 µm, are usually located in the surface layers of the dermis. In its middle layer, they thicken to up 20 µm [5]. Each of them combines 20-1000 primary fibers with a diameter of about 5 µm, in the cross section of which are 200-800 fibrils. The scheme of fibers branching in a derma and an arrangement of secondary fibers is given in Figure 7.

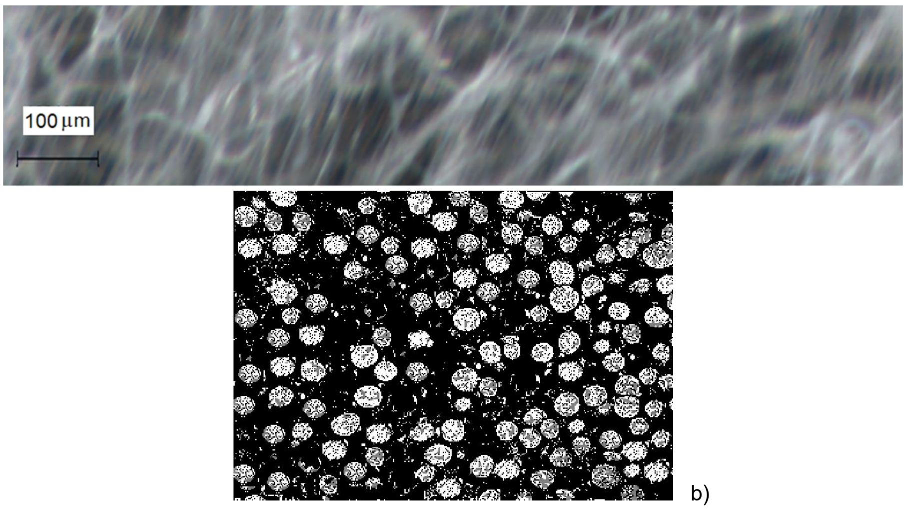


a) b)

Figure 7 Scheme of branching fibers in the dermis of pigs (a) and the location of secondary fibers (b)

The source of fiber formation can be considered the primary fiber that occurs in the layer of the dermis close to the epidermis. It is a rod to which the primary fibers formed in the middle layer of the dermis join without merging. Differences in the change in the diameter of the primary fibers along their length, in contrast to the secondary, are not observed. In the primary fibers, along with the equally directed stacking of adjacent fibrils, there is also a multidirectional stacking, which can be seen by analyzing the cross-sectional pattern [3]. Collagen fibers, compared to other fibrous materials, in the air-dry state contain more interstructural gaps. This confirms the electron microscopic image of their cross section (Figure 8).

The consequence of the "porosity" of the structure is the difference between the true and imaginary density of the fiber. It was found that the density of the protein substance of collagen, which was not subjected to complete dehydration, is equal to 1.4 [5]. The apparent density of protein fibers is 1.096 kg/m^3 [8]. Thus, the interfibrillary troughs occupy approximately 22% of their volume. As a result of intensive compression, the diameter of the fibers decreases by 20-40%.



a)

b)

Figure 8 Photomicrographs of leather sections parallel (a) and perpendicular (b) to the fibers

4 CONCLUSION

Today, equipment for processing natural leather waste into various products is widely produced. But when using existing technologies and equipment, leather waste is ground, i.e. the destruction of the material is carried out through excessive crushing of fiber bundles. The production of artificial leather from small fibers requires the use of binders to bind them, sometimes in the amount of 100% by weight of the fiber. At the same time hygienic properties of artificial leather considerably worsen.

The grinding of the fibers is due to the fibrous-mesh structure of natural leather. As a result of the looping of the fibers, they are twisted into a certain volume, and the strength of the intertwined bundle of fibers is much greater than the strength of a single fiber.

The article presents approaches to the processing of waste from natural leather to artificial leather while preserving the beneficial properties of natural leather. It is proposed not to grind, but to defiber leather waste, i.e. before the destruction of the material you need to weaken its structure so that the fibers are easily separated at loads less than the breaking point of a single fiber.

As a result of the analysis it is established that the structure and properties of leather materials form the basis of the processes of their defibering.

The main histological element of the dermis is fibrils, which form fibers. The main component of the fibers of the dermis is a protein - collagen. Skin collagen can be considered as a complex composite of fibrous structure at all levels. Along with collagen fibers, the dermis also contains elastin and reticulum fibers. Elastin and reticulum fibers are positioned in different directions and create a grid that serves as a framework for different structural elements.

Fibrils enclosed in a hexagonal or tetragonal lattice form the main fibrous element of skin collagen. Collagen fibrils are surrounded by an interfibrillary matrix, which consists more of tannins and to a lesser extent of structural glycoproteins, which are also unbound between the structural elements of the skin. These elements of structural levels, connecting with elastic fibers, form a macroscopic element of the skin.

5 REFERENCES

1. Laing R.M.: Natural fibres in next-to-skin textiles: current perspectives on human body odour, SN Appl. Sci. 1, 2019, pp. 1329, https://doi.org/10.1007/s42452-019-1388-1
2. Danylkovych A., Bilinskiy S., Potakh Yu.: Plasticification of leather semifinished chrome tanning using biocatalitic modifier, EUREKA: Physics and Engineering No. 1, 2018, pp. 12-18, http://dx.doi.org/10.21303/2461-4262.2018.00527
3. Maruhlenko M.O., Palamar V.A., Mokrousova O.R.: Stabilizing derma collagen structure with modified dispersions of montmorillonite, IOP Conf. Ser.: Mater. Sci. Eng., Baltic Polymer Symposium, Sigulda, Latvia, 16-18 September 2015, IOP Publishing, Vol. 111, 2016, 012023, http://dx.doi.org/10.1088/1757-899X/111/1/012023
4. Bhushan B., Chen S., Ge Sh.: Friction and durability of virgin and damaged skin with and without skin cream treatment using atomic force microscopy, Beilstein J. Nanotechnol No. 3., 2012, pp. 731-746, https://doi.org/10.3762/bjnano.3.83
5. Skyba M.E.: Technological processes and equipment for defibering leather and fibrous materials, Monograph, Khmelnytsky: PP Kovalsky V.V., 2003, 135 p. (in Ukrainian)
6. Pahlawan I.F., Griyanitasari G.: Physico-mechanical properties of cattle hide leather for working gloves with flame retardant addition, Livest. Anim. Res. 18(2), 2020, pp. 151-159, https://doi.org/10.20961/lar.v18i2.42937
7. Sudha T.B., Thanikaivelan P., Aaron K.P., Krishnaraj, K., Chandrasekaran B.: Comfort, Chemical, Mechanical, and Structural Properties of Natural and Synthetic Leathers Used for Apparel, J. of Applied Polymer Sci. 114(3), 2009, pp. 1761-1767, https://doi.org/10.1002/app.30589
8. Montelli S., Corain L., Cozzi B., Peruffo A.: Histological analysis of the skin dermal components in bovine hides stored under different conditions, J. of the American Leather Chemists Association 110(2), 2015, pp. 54-61, https://journals.uc.edu/index.php/JALCA/article/view/3594
9. He L., Lan W., Zhao Yu., Chen Sh., Liu Sh., Cen L., Cao Sh., Dong L., Jin R., Liu Ya.: Characterization of biocompatible pig skin collagen and application of collagen-based films for enzyme immobilization, RSC Advances No. 10, 2020, pp. 7170-7180, https://doi.org/10.1039/C9RA10794K
10. Meyer M.: Processing of collagen based biomaterials and the resulting materials properties, Biomedical engineering online 18(24), 2019, pp.1-74, https://doi.org/10.1186/s12938-019-0647-0
11. Bereznenko S., Bereznenko N., Skyba M., Yakymchuk D., Artemenko T., Prybeha D., Synyuk O., Kalinsky E.: Novel equipment for making nanocomposites for investigating the antimicrobial properties of nanotextiles, International Journal of Clothing Science and Technology 33(1), 2020, pp. 25-34, https://doi.org/10.1108/IJCST-07-2019-0107
12. Skyba M.Ye., Synyuk O.M., Zlotenko B.M.: Model of changing the stressed-deformed state of a polymer sheet during stretching, Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu No 1, 2019, pp. 83-89, https://doi.org/10.29202/nvngu/2019-1/4

APPLICATION OF ARDUINO-LIKE SYSTEMS FOR DETERMINATION OF PHYSICAL AND MECHANICAL INDICATORS OF FLAX FIBER

Volodymyr Tolmachov[1] and Andriy Ryabko[2]

[1]Department of Professional Education and Computer Technologies of the Olexander Dovzhenko Hlukhiv National Pedagogical University, Kyievo-Moskovska str. 24, Hlukhiv, Ukraine
[2]Department of Physics and Mathematics Education and Informatics of the Olexander Dovzhenko Hlukhiv National Pedagogical University, Kyievo-Moskovska str. 24, Hlukhiv, Ukraine
tvs-@ukr.net, ryabko@meta.ua

Abstract: *Ways of application of Arduino-like systems in devices for measurement of physical and mechanical indices of quality of long flax fiber that will allow to improve process of measurement and to reduce time for its carrying out are described. Different approaches to determining of the average length of flax fiber are analysed. The developed method for determining the average length of flax fiber using Arduino systems is considered.*

Keywords: *flax fiber, quality indices, average length, rating number, algorithm, microcontroller, measurement methods, Arduino.*

1 INTRODUCTION

Product quality is determined by the properties of raw materials, proper technological process, product structure and its properties. But no less important are the validity of the requirements for the level of quality indices, as well as the correctness and reliability of the evaluation results, which depend on the accepted methods of quality assessment. Therefore, when assessing or determining the quality of products it is necessary to determine and justify the following:

- a sufficiently reliable method of assessing the compliance of material properties with regulatory requirements, taking into account errors in determining these properties;
- the choice of quality indices that fully characterize the suitability of the material for its intended use;
- rational level of regulatory requirements taking into account the capabilities of the supplier.

There are various methods for determining the quality of materials, which include the following: measuring (experimental or instrumental), registration, calculation, organoleptic, sociological and expert. The most common method is a measurement method based on the measurement and analysis of indices using instruments and expressed in quantitative terms. Measurement methods are sometimes divided into: physical, chemical, physicochemical, microscopic, biological, physiological and technological and others.

The purpose of the article is: a) to develop an automated method for measuring and calculating the average length of flax fiber, which consists in passing a handful of fibers through a pair of cylindrical rollers and determining the height of the longitudinal section in various regions along the length of the bundle; b) to develop an automated method for determining the colour of flax fiber, which consists in the analysis of light reflected from the test sample.

In recent years, there has been a steady trend towards the use of natural fibers for the manufacture of high quality light industry products, with special attention paid to hemp and flax fibers. The practice of the primary processing of bast raw materials shows that the quality of the obtained fiber depends on the objective determination of the characteristics of the raw material that comes for processing.

The need for a comprehensive assessment of the quality of bast materials in modern conditions is of particular interest. This is due to the fact that flax fiber has a wide range of applications: in the manufacture of textiles and building materials, in mechanical engineering, medicine and many other industries.

However, the analysis of scientific and technical literature and production experience showed that new technologies for processing or modification of fibers are more often developed, and methods for assessing their geometric, physical-mechanical and other quality indexes remain unchanged or borrowed from regulatory and technical documentation for other similar materials. In general, the methods of analysis used today to determine the quality of bast raw materials and products do not take into account the latest changes in processing technologies. Therefore, now in the textile industry it is necessary to introduce additional qualimetric instrumental and sensory methods for assessing the quality of fibrous materials.

Based on the above, the development of methods for assessing the quality of bast fibers is an urgent problem, the solution of which will contribute to obtaining high-quality raw materials that can be used to produce competitive products that meet high consumer requirements. Also, it should be noted that these methods are used to determine indicators for fiber flax (*Linum usitatissimum L.*).

2 DISCUSSION OF IDEAS

To determine the number of scutched flax (*Linum usitatissimum*, long flax), it is necessary to calculate the sum of points that correspond to the arithmetic mean values of length, breaking load, flexibility of the fiber and its number by colour group. The next step is to determine the number of scutched flax by the sum of the scores of the four indicators. Sometimes a combined quality assessment is used, when a comprehensive quality index does not fully characterize all the features of the product.

The fiber number shows what number of skeins of singing yarn can be trimmed from one fiber weight. The basis for a good quality assessment of the fiber is its spinning quality, so that the quality of the fiber is reworked in the yarn of the given production and with the singular characteristics, as it is possible to change it on the main, additional and attendant. Up to the main properties, which directly influence on the quality of the yarn, are carried out the breaking load, flexibility and linear density. Additional properties are injected into the intensity and nature of the production process. These properties include content of scutch, bumping and underprocessing. The attendant properties do not influence on yarn quality but convey its main properties. Attendant properties are the colour, the weight, the oiliness and brightness. The unevenness of the fiber in any property significantly reduces its value as a spun material.

The main features of high quality fiber include sufficient length, high strength, elasticity, weight, ribbon, thinness and evenness. The longer the elementary fiber, the narrower the cavity will be, the more it is multifaceted in cross section, the more fibers in the bundle, the higher the quality of the fiber.

Waterbury and Drzal [1] developed a method for determining the strength of a fiber at short calibration lengths by monitoring the process of fiber fracture during a single fiber fragmentation test. A computerized model of the weakest fiber was used to analyse the data. Data on the strength of the fiber at short calibration lengths can be obtained directly using this method without the need for extrapolation from longer samples.

Charlet et al. [2], in the process of studying the properties of natural flax fiber inserted that the beginning of the stress-strain curve of flax fiber during stretching is markedly nonlinear, which the authors explain by the progressive alignment of cellulose microfibrils with the axis of stretching. Two methods of fiber size measurement are compared to test their effect on the scatter of properties and reduction of mechanical properties of fiber as a function of fiber diameter.

Baley [3] notes that flax fibers which come from renewable resources are an interesting alternative to mineral fibers. Their low cost, together with their low density, high specific weight, rigidity and recyclability are the main incentives for their use in composite materials. A common feature of natural fibers is their heterogeneous geometric characteristics, so in the process of determining of the strength it is important to take into account the change in geometric dimensions, i.e. the transverse and longitudinal dimensions of the fibers.

Methods for determining the properties of composite materials based on flax fiber are being actively studied. Flax fiber composites with thermoset and thermoplastic polymer matrices have been manufactured and tested for stiffness and strength under uniaxial tension. Andersons and Joffe [4] found that the unidirectional orientation of natural fibers in the polymer composite provides the highest reinforcement efficiency. To estimate the upper tensile strength of a composite of natural flax fiber, a statistical model of the strength of solid composites reinforced with UD fiber is used.

In order to explore the long-term reliability of flax fiber reinforced composites under fluctuating loads through high cycle fatigue strength (HCFS), fatigue tests were conducted on unidirectional flax fiber reinforced thermoset composites at different percentages load of ultimate tensile strength (UTS) with a loading frequency of 5 Hz [5].

Romhany e al. [6] demonstrated that the strength of flax corresponds to the two-parameter Weibull model. The mode and sequence of failures were studied in situ (i.e. during loading) using SEM and acoustic radiation (AE). The failure sequence (axial splitting of the technical fiber along its elementary constituents, radial cracking of the elementary fibers, multiple fracture of the elementary fibers) concluded reflected the hierarchical build-up of the flax bast fibers.

Barton et al. [7] measured the fiber content of flax stems by near-infrared spectroscopy (NIRS) using whole pieces of stem in a large cell, in reflectance mode. Compared to the conventional method, the standard error of performance of the NIRS method was between 0.96 and 1.45% (dry matter basis), depending on the model and data processing used.

Tebmann et al. [8] presented a new, automatic and non-destructive approach for the determination of fiber length distribution in fiber reinforced polymers. For this purpose, high-resolution computed tomography is used as imaging method together with subsequent image analysis for evaluation. The image analysis consists of an iterative process where single fibers are detected automatically in each iteration step after having applied image enhancement algorithms.

Depuydt et al. [9] have developed a new type of fiber-reinforced fibrous materials for fused deposition modeling applications. Polylactic acid (PLA), compounded with two types of plasticizer, is reinforced with bamboo and flax fibers. The fiber fractions are characterized by measuring their length (*l*) over diameter (*d*) before and after compounding so that the effect of the *l/d* on the final filament properties can be systematically studied.

Bourmaud et al. [10] studied the flax fiber orientation in the skin and core layers, and, to quantify the impact of fiber bundles. They evidenced their presence in injected specimens and they focused on their effects on the tensile properties. They correlated this morphology with the tensile properties of the various areas. Finally, they investigated the initiation and propagation of cracks into the PP/flax composite in tensile mode by using in situ SEM observations.

In a composite eco-design approach, flax fibers could be good candidates for glass fiber substitution. However, their use in industrial applications could be restricted due to their scattered mechanical properties. Baley and Bourmaud [11] compared tensile properties of 50 batches of flax (*Linum usitatissimum*) fibers, cultivated in France between 1993 and 2011. Thus, 2954 fibers were tested in the same conditions according to the XP T 25-501-2 standard. Reliable specific data are suggested to be a basis for design calculation.

The aim of Sohn et al. study [12] was to develop a standard calibration model for determining shive content in retted flax by using near-infrared reflectance spectroscopy. Calibration samples were prepared by manually mixing pure, ground shive and pure, ground fiber from flax retted by three different methods (water, dew and enzyme retting) to provide a wide range of shive content from 0 to 100%. Partial least-squares (PLS) regression was used to generate a calibration model, and spectral data were processed using various pretreatments such as a multiplicative scatter correction (MSC), normalization, derivatives, and Martens' Uncertainty option to improve the calibration model.

Weisnerova and Weisner [13] applied computer image analysis to group together flax cultivars (*Linum usitatissimum L.*) according to their similarity in commercially important dry seed traits. Both the seed shape and seed-colour traits were tested on 53 cultivars from world germplasm collections. Four shape traits (Area, Perimeter, MeanChord, and MinFeret) and three colour traits (L*, a*, b* calculated from original RGB colour channels as CIE colour space coordinates) were computer extracted from digital images of 62349 seeds with 1200 seeds per cultivar in average. Cultivar clustering was generated by two independent methods of multivariate analysis.

Colour measurements are made of various kinds of flax retted by dew, water or enzymes [14]. Two sets of samples are analysed under different conditions using different spectrophotometers and by reflectance in the visible and near infrared spectral regions. Sample set one consists of 55 samples of various flax types retted by traditional dew and water methods and various experimental enzyme retted samples. Means and standard deviations of CIELAB colour values for each of the classes are displayed as spheroid plots. The enzyme retted fiber flax class forms a separate group that is substantially lighter and slightly yellower than dew retted flax [14].

3 METHODS

Sensory analysis is used to determine the quality of flax fibers, which can be described using the senses.

To determine the average length of a handful, 30 handfuls of chopped flax after determining the colour group are use. Each of the selected handfuls is spread on the table in an even layer and a sample weighing 25±1 g is taken from it. The average length of these handfuls is determined using a meter ruler with centimeter divisions.

During the measurement, individual fibers protruding in the handful are not taken into account. The test result is the arithmetic mean of the results of thirty measurements, calculated to the first decimal place, followed by rounding to an integer.

However, the sensory or organoleptic method has a significant disadvantage, which is its subjectivity. In order to avoid the dependence of the accuracy of quality assessment on the experience of experts and the identity of their senses, some manufacturers have begun to produce electronic devices that replace the human senses. Using such devices, you can get more accurate results when determining the quality indicator. In some cases, instead of methods of sensory analysis, instrumental express methods for determining the quality of raw materials and products are used. This is due to the fact that there are certain connections between some of the physical and mechanical properties of flax fibers. Some developed devices use this dependence.

Today, existing measuring devices from different manufacturers are very expensive and require training to work with them. But noteworthy are the hardware and software measuring systems based on the Arduino system, are much cheaper and allow you to measure the average length of flax fiber, fiber colour and other physical and mechanical quality indicators depending on the sensors used, circuit solutions, algorithm and algorithm processing of the received data.

According to modern technology, the long scutched fibers of different quality are obtained from a flax stalk. Long flax fibers are divided into numbers 8-14 in accordance with the State Standard of Ukraine 4015-2001. To determine the number of scutched flax according to the standard, it is necessary to calculate the sum of points that correspond to the arithmetic mean values of length, breaking load, flexibility of the fiber and its number by colour group. The study was performed using different batches of scutched flax fibers of different numbers, obtained from flax stock of *Charivnyi* variety of different degrees of aging. The average values of fiber quality are shown in Table 1.

For example, the developed automated method of measuring and calculating the average length of flax fiber is to pass a handful of fibers through a pair of cylindrical rollers and determine the height h_i of the longitudinal section in different areas along the length of the handful (Figure 1a). According to the obtained measurement data, the average fiber length is calculated, and the calculations are performed automatically in accordance with the compiled algorithm of the microcontroller. This method includes the preparation of a handful, its testing and determining the value by which the average length of flax is judged. The chosen method allows to increase the accuracy of estimating the average length of flax and will automate the process of testing and analysis of the results through the use of computer technology and elements of modern electronics.

The use of a pair of rolls to move the handful and measure the height of the sections allows to automate the test process by controlling the distance between the rolls at different times and using a set of these values to calculate the parameters needed to determine the average length of the handful. This system consists of a mechanical part (Figure 1b), an Arduino system (Figure 1c) and software. Such a system can work either separately or connected to a computer to provide automated measurement, perform the necessary calculations and save the measurement results. This device uses Arduino system with an ATmega328 microcontroller, a liquid crystal display with a working field of 2 lines of 16 characters, a stepper motor driver and a bipolar stepper motor. A variable resistance resistor is used as a sensor, the axis of which rotates depending on the lifting height of the measuring roller.

Table 1 Initial indicators of scutched flax fibers

№ of parties	Average values of quality indexes of different batches of fiber				
	The average length of a handful [cm]	Breaking load [daN]	Colour group	Flexibility [mm]	Linear density [tex]
1	75.8	29.1	2.2	42.7	12.5
2	70.1	26.8	1.7	43.5	9.9
3	71.7	32.3	2.9	42.8	13.0
4	72.0	29.3	3.0	37.4	12.5
5	59.9	31.7	2.2	41.9	12.7
6	78.2	26.4	2.2	43.1	10.9
7	54.7	28.2	3.0	43.1	10.7
8	65.4	31.5	2.4	38.7	12.5
9	88.6	29.7	1.9	34.8	13.7
10	54.1	37.4	3.2	46.5	11.3
11	80.0	32.0	3.0	40.5	14.7
12	55.2	22.2	2.6	65.6	7.1
13	64.9	24.5	3.1	49.0	8.9
14	63.3	24.6	3.0	45.2	11.0
15	71.2	20.1	1.8	51.9	10.2
16	80.1	33.1	1.9	41.4	13.5
17	69.5	27.4	1.8	49.0	11.9
18	77.3	40.3	1.9	32.5	19.8
19	69.5	32.6	2.3	40.3	14.4
20	42.0	27.6	2.1	50.1	10.4
21	54.1	24.4	2.9	54.3	8.9
22	41.1	15.2	3.0	70.0	7.2
23	63.2	21.6	2.2	50.3	9.7
24	72.8	24.3	2.4	54.2	8.9
25	45.0	5.0	2.9	82.1	6.0
26	41.5	18.4	2.8	55.8	7.9
27	64.3	24.7	1.5	46.9	9.0
28	66.0	25.5	2.0	50.2	9.4
29	57.8	28.1	2.8	50.1	9.6
30	69.1	17.1	1.5	47.0	10.3

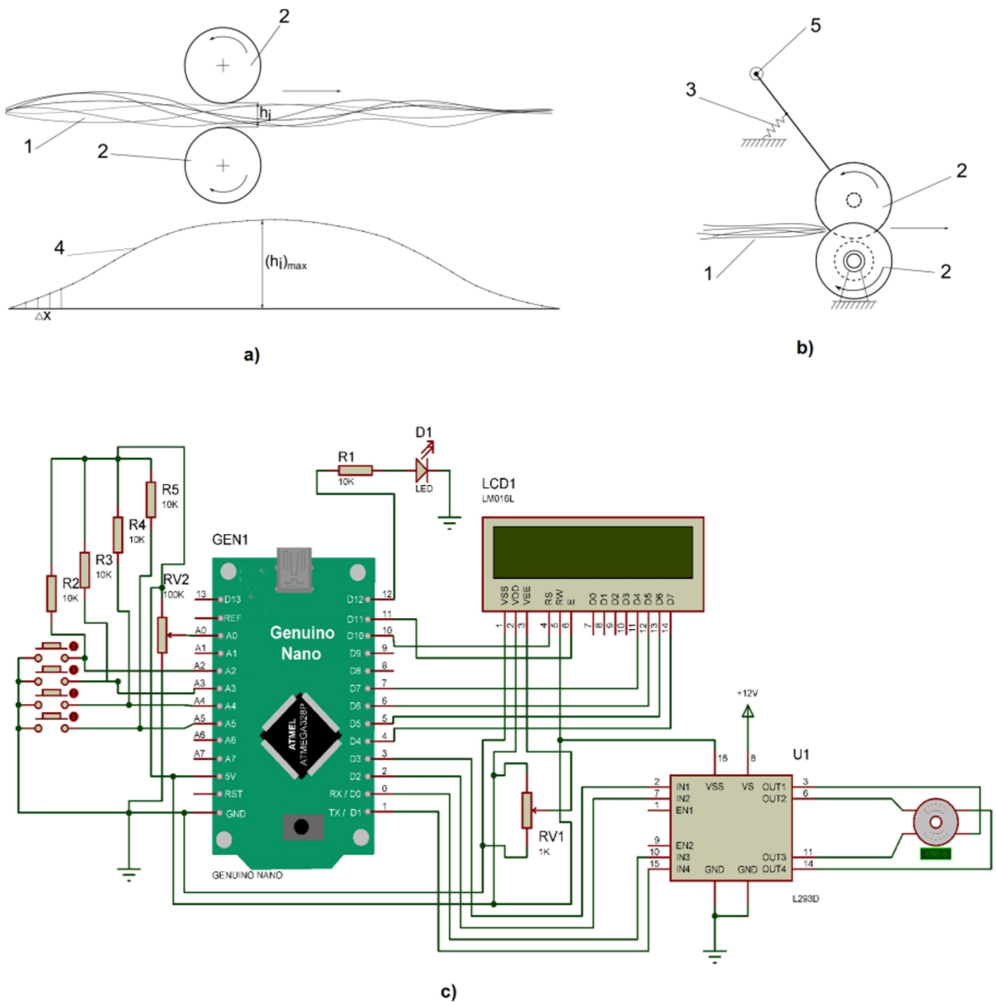


Figure 1 Scheme of the method of determining of the average fiber length. a) general scheme, b) kinematic scheme, (1 - fiber sample; 2 - roller; 3 - spring; 4 - a curve describing the measurement process, where *Δx* - the measurement interval, h_i - the i-th value of height [cm], $(h_i)_{max}$ - the maximum value of height; 5 - axis with analog sensor); c) electrical schematic diagram of the device

The implementation of this method involves the formation of a sample 1 of a certain mass, passing it between a pair of rotating rolls 2 and determining the height of the longitudinal section in different areas along the length of the handful at regular intervals (Figure 1b). These intervals should be such that the path x that the fiber has traveled during this time does not exceed 1 cm.

The area of the longitudinal section of the handful *S* is determined by the formula (1):

$$S = \Delta x \cdot \sum_{i-1}^{n-1} \frac{h_i + h_{i+1}}{2} \quad (1)$$

where: *S* - the area of longitudinal section [cm^2]; *n* – the number of measurements; *Δx* - measurement interval.

The average length $\overline{L}$ is determined by formula (2):

$$\overline{L} = \frac{S}{(h_i)max} \quad (2)$$

where: $(h_i)_{max}$ - maximum height [cm].

The sensor is a variable resistance resistor with a nominal value of 5 kΩ, the axis of which is connected to the moving axis of the device. Lifting the measuring roll allows you to change the resistance of the measuring resistor. The dependence of the resistance of the resistor on the lifting height of the roll was established experimentally (Figure 2). The established dependence is linear:

$$R = 29.9h - 11.64 \quad (3)$$

Practically to determine the lifting height of the measuring roll it is necessary to determine the resistance and calculate the height. For this calculation we use the inverse equation, which will look like this (4):

$$h = \frac{R + 11.04}{29.9} \quad (4)$$

where: *h* – the lifting height of the measuring roll [cm]; *R* – the resistance of the measuring resistor [Ω].

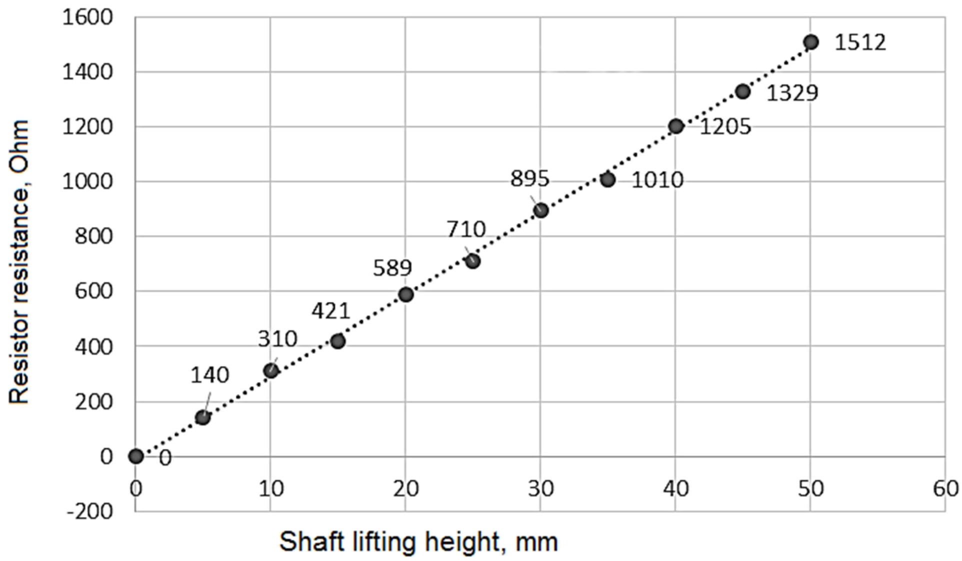


Figure 2 The dependence of the resistance of the resistor on the lifting height of the measuring roll

In this device, every second the voltage from the measuring resistor enters the analog-to-digital converter (ADC), from which the information goes to the microprocessor unit, where it is processed according to the developed algorithm (Figure 3) and output to a digital indicator as the average length of the test sample.

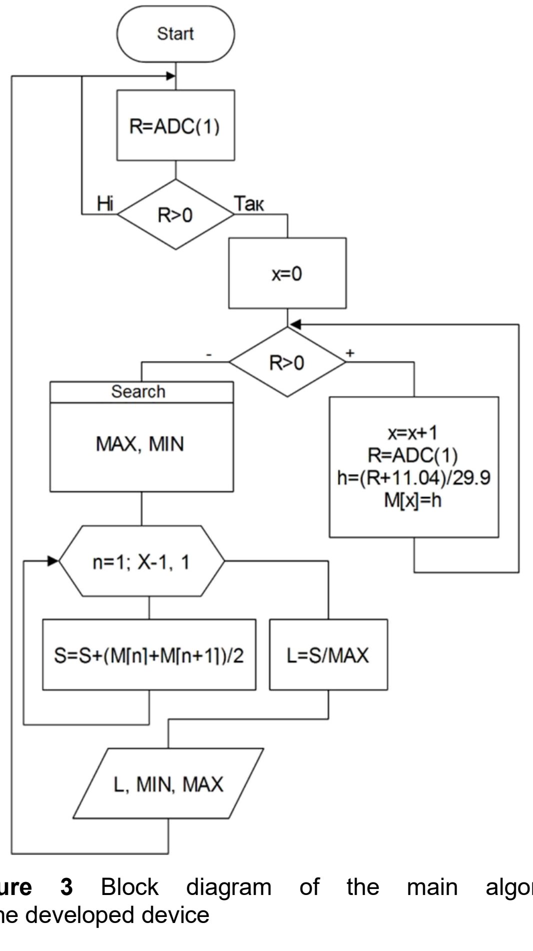


Figure 3 Block diagram of the main algorithm of the developed device

The use of the proposed method together with computer equipment with special peripherals or elements of modern electronics in practice will automate the process of measuring the length of flax, increase the objectivity of measurements and reduce the time for research.

Based on the results of theoretical research and analysis of patent sources, a digital autonomous device was created which allows to automatically measure and calculates the average length of the sample, to do statistical processing of the results.

The principle of operation of the developed device is based on measuring of the resistance of the measuring resistor, the axis of which is connected to the axis of the measuring roll.

The following example of the use of Arduino systems in measuring instruments can be presented in the developed automated method for determining the colour of flax fiber, which consists in the analysis of light reflected from the test sample (Figures 4 and 5).

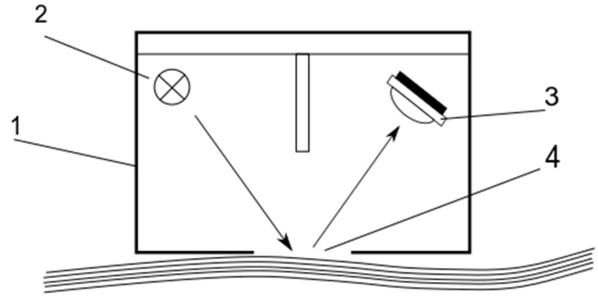


Figure 4 General scheme of the method of determining the colour of flax fiber; 1 - the case of the device; 2 - light source; 3 - photoresistor; 4 - fiber sample

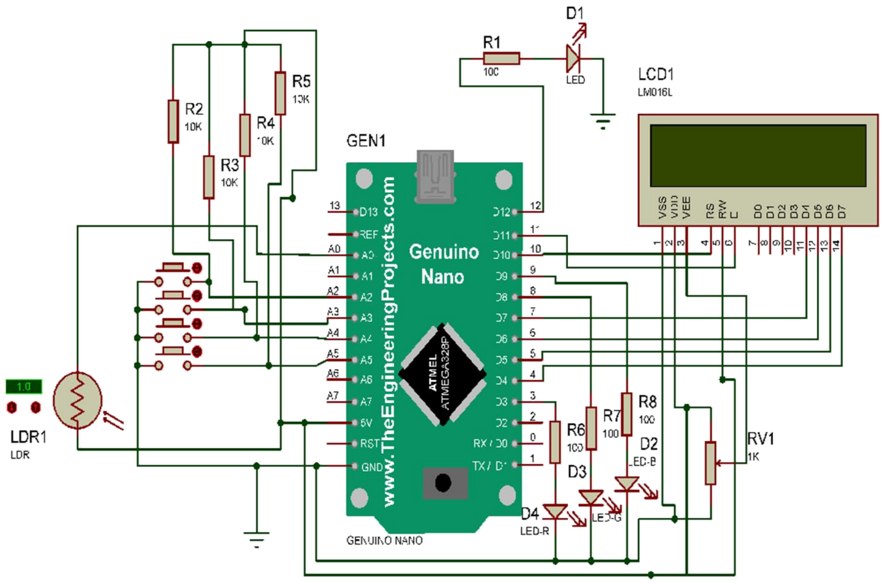


Figure 5 Electrical schematic diagram of the device for the method of determining the colour of flax fiber

This device uses an Arduino system with microcontroller ATmega328, liquid crystal display with a working field of 2 lines of 16 characters, RGB LEDs, photoresistor as a sensor that changes its resistance depending on the intensity of the light flux reflected from the sample.

During determining of the physical and mechanical parameters of flax fiber, the devices should be installed in a clean and dry place, away from heat sources and strong electromagnetic fields. For reliable operation of the device, the following conditions must be meet: a) storage temperature from -25 C to +70°C (from -13 to 158 F); b) operating temperature from -10 +60°C (from 14 to 140 F); c) relative humidity 5 to 95% non-condensing. The devices must be installed separately from other equipment. Adequate clearance should be provided for cooling them with vertical upward airflow. The temperature of the cooling air must be lower than the operating temperature of the device.

Design and research work and testing of devices were performed on the basis of the Institute of Bast Cultures of the National Academy of Agrarian Sciences of Ukraine. In the process of approbation (testing) of the equipment it is established:

a) results of measurements by the developed devices of samples of the fiber taken from one party and homogeneous on the physical and mechanical properties are stable and statistically controlled. The expected level of inconsistency of the obtained results is for the device for determining the average fiber length 0.02% and for the device for determining the colour of flax fiber 0.01%;
b) the calculated extended relative uncertainty of the measurement results for the developed devices is 4.22% and 4.7%, respectively;
c) the size of the measurement error of both devices is less than 5%.

The developed methodology of practical use of devices in the process of quality assessment of scutched flax fiber allows: to reduce the duration of the analysis on 40-45%; due to the obtained mathematical dependences to predict separate physical and mechanical parameters of the fiber; increase the objectivity of sample evaluation by increasing the number of measurements and their accuracy; reduce the cost of purchasing and maintaining of measuring equipment.

4 CONCLUSION

The use of Arduino systems in measuring devices will allow obtaining objective measurement results, reducing the time for research, significantly reduce the cost of devices, simplifying the design and adapting them to use in certain conditions. Such devices can work either individually or in conjunction with a computer with certain software.

5 REFERENCES

1. Waterbury M., Drzal L.: On the determination of fiber strengths by in-situ fiber strength testing, Journal of Composites, Technology and Research 13(1), 1991, pp. 22-28, https://doi.org/10.1520/CTR10070J
2. Charlet K., Eve S., Jernot J., Gomina M., Breard J.: Tensile deformation of a flax fiber, Procedia Engineering 1(1), 2009, pp. 233-236, https://doi.org/10.1016/j.proeng.2009.06.055
3. Baley C.: Influence of kink bands on the tensile strength of flax fibers, Journal of Materials Science 39(1), 2004, pp. 331-334, https://doi.org/10.1023/B:JMSC.0000007768.63055.ae

4. Andersons J., Joffe R.: Estimation of the tensile strength of an oriented flax fiber-reinforced polymer composite, Composites Part A: Applied Science and Manufacturing 42(9), 2011, pp. 1229-1235, https://doi.org/10.1016/j.compositesa.2011.05.005
5. Islam M., Ulven C.: A thermographic and energy based approach to define high cycle fatigue strength of flax fiber reinforced thermoset composites, Composites Science and Technology 196, 2020, pp. 108231-108233, https://doi.org/10.1016/j.compscitech.2020.108233
6. Romhany G., Karger-Kocsis J., Czigany T.: Tensile fracture and failure behavior of technical flax fibers, Journal of Applied Polymer Science 90(13), 2003, pp. 3638-3645, https://doi.org/10.1002/app.13110
7. Barton F., Akin D., Morrison W., Ulrich A., Archibald D.: Analysis of fiber content in flax stems by near-infrared spectroscopy, Journal of Agricultural and Food Chemistry 50(26), 2002, pp. 7576-7580, https://doi.org/10.1021/jf020367i
8. Tebmann M., Mohr S., Gayetskyy S., Habler U., Hanke R., Greiner G.: Automatic determination of fiber-length distribution in composite material using 3D CT data, EURASIP Journal on Advances in Signal Processing, 2010, article no. 545030, https://doi.org/10.1155/2010/545030
9. Depuydt D., Balthazar M., Hendrickx K., Six W., Ferraris E., Desplentere F., Van Vuure A.W.: Production and characterization of bamboo and flax fiber reinforced polylactic acid filaments for fused deposition modeling (FDM), Polymer Composites 40(5), 2019, pp. 1951-1963, https://doi.org/10.1002/pc.24971
10. Bourmaud A., Ausias G., Lebrun G., Tachon M.L., Baley C.: Observation of the structure of a composite polypropylene/flax and damage mechanisms under stress, Industrial Crops and Products 43, 2013, pp. 225-236, https://doi.org/10.1016/j.indcrop.2012.07.030
11. Baley C., Bourmaud A.: Average tensile properties of French elementary flax fibers, Materials Letters 122, 2014, pp. 159-161, https://doi.org/10.1016/j.matlet.2014.02.030
12. Sohn M., Barton F.E., Morrison W.H., Archibald D.D.: Application of partial least-squares regression to near-infrared reflectance spectroscopic determination of shive content in flax, Applied Spectroscopy 57(5), 2003, pp. 551-556, https://doi.org/10.1366/000370203321666588
13. Weisnerova D., Weisner I.: Computer image analysis of seed shape and seed color for flax cultivar description, Computers and Electronics in Agriculture 61(2), 2008, pp. 126-135, https://doi.org/10.1016/j.compag.2007.10.001
14. Akin D.E., Epps H.H., Archibald D.D., Sharma H.S.: Color measurement of flax retted by various means, Textile Research Journal 70(10), 2000, pp. 852-858, https://doi.org/10.1177/004051750007001002

APPLICATIVE AND RHEOLOGICAL PROPERTIES OF PLA MASTERBATCHES WITH CONTENT OF PLASTICIZER AND BIOPLASTICIZER

Z. Tomčíková[1], A. Ujhelyiová[2], K. Holcová[1], M. Hricová[2] and R. Plavec[2]

[1]*Research Institute for Man-Made Fibres a.s., Štúrova 2, 05921 Svit, Slovak Republic*
[2]*Slovak University of Technology in Bratislava, Faculty of Chemical and Food Technology, Institute of Natural and Synthetic Polymers, Radlinského 9, 81237 Bratislava, Slovak Republic*
tomcikova@vuchv.sk

Abstract: *Synthetic fibres prepared from standard types of polymers such as PP, PA and PET are no longer sufficient to cover all user requirements, therefore standard types of polymers are mixed and modified with various additives such as pigments, plasticizers, dispersants etc., and at the same time new types of polymers are being sought for fibres production. The effort of fibre producers and their processors is to meet the needs of users as much as possible. As there is currently a global problem with waste plastics, various solutions are being sought, either by recycling synthetic plastics or by looking for new biodegradable polymers. In recent years, much attention has been focused on polylactic acid (polylactide), which is biodegradable under certain conditions. In the present work, masterbatches prepared from two types of polylactic acid with 15% additive content will be studied. Polylactic acid is very brittle, which makes a problem in the preparation of fibres, so this article is focused on evaluating the PLA masterbatches containing plasticizers. In generally, plasticizers help to reduce the brittleness and increase the elasticity of the fibres. The applicative and rheological properties of the prepared PLA masterbatches were studied. The flow properties of masterbatches containing 15% non-biodegradable plasticizer with masterbatches containing 15% biodegradable plasticizer were compared.*

Keywords: *PLA masterbatches, applicative properties, rheological properties, plasticizer, bioplasticizer.*

1 INTRODUCTION

As a result of the corona crisis, global economic growth in 2020 recorded the slowest pace since the financial crisis ten years ago, including the textile industry. The total volume of fibres in 2020 was 120 million tons, of which 74 million tons were synthetic fibres, including staple fibres. Synthetic fibres achieved 5% growth due to the robust expansion of polyester fibres and staple fibres, while nylon rose slightly and both acrylic and polypropylene fibres weakened [1]. The pandemic led to a sudden surge in global demand for personal protective equipment, such as masks, gloves, gowns and bottled hand sanitizer resulting in increased solid polymer waste accumulation. The use of durable polymers is therefore a disadvantage [2-4]. The 21st century is focused on materials that will decompose in the natural environment, in soil or compost [5]. PLA offers unique properties of biodegradability, biocompatibility, thermoplastic processability and ecological safety [6, 7]. Plasticizers or dispersants are additives which increase the plasticity or decrease the viscosity of a material. They are the substances which are added in order to alter their physical properties. They decrease the attraction between polymer chains to make them more flexible [8, 9].

Permanent functional modifications of chemical fibres are most often ensured by adding a functional additive to the polymer mass of the fibre through the preparation of a masterbatch which is added to the base polymer in the spinning process. The masterbatch must have suitable rheological and applicative properties (it must not reduce the technological stability of the fibre preparation process). The masterbatch added in a defined ratio to the main polymer stream is melted, homogenized and spun into fibres together with the base polymer [10].

The paper presents the results of a study of the influence of two types of plasticizers and two types of PLA polymers on the applicative and rheological properties of prepared masterbatches. Four 15% masterbatches were prepared by mutual combination. The flow (applicative and rheological) properties mentioned above of masterbatches containing 15% non-biodegradable plasticizer with masterbatches containing 15% biodegradable plasticizer were compared. The obtained experimental results were evaluated from the point of view of the suitability of the flow properties prepared masterbatches for modified PLA fibre preparation.

2 EXPERIMENTAL AND METHODS

2.1 Materials

Polymers: polylactic acids: **PLA1** with MFI=24.6 g/10 min (210°C/2.16 kg) and **PLA2** with MFI=8.9 g/10 min (210°C/2.16 kg), both produced by Total Corbion PLA B.V.

Additives: plasticizer **PL** with MFI=6.0 g/10 min (210°C/2.16 kg) and bioplasticizer **BioPL** with MFI=8.9 g/10 min (210°C/2.16 kg) were used.

2.2 Preparation of PLA masterbatches

Before preparation of masterbatches the premixes have been prepared. The premixes consisted of a mutual combination of two PLA carriers (PLA1 and PLA2) and two types of additives (PL and bioPL). Both the polymers and the additives were milled and dried at 85°C for 4 hours before preparing the premixes.

PLA masterbatches were prepared on a laboratory Werner-Pfleiderer ZDSK 28 twin-screw extruder with vacuum zone and screw diameter of 28 mm. The preparation process of masterbatches had been carried out at a constant screws rotation speed 270 min^{-1} and constant extrusion temperature of 210°C. The output was four 15% masterbatches (Table 1).

Table 1 The masterbatches composition

Masterbatch No.	Name of masterbatch	Masterbatches composition [wt.%]		
		PLA carrier	PL	bioPL
1	PLA1/PL	PLA1	15	-
2	PLA1/bioPL	PLA1	-	15
3	PLA2/PL	PLA2	15	-
4	PLA2/bioPL	PLA2	-	15

2.3 Methods used

Applicative properties

The melt mass flow index (*MFI*) of masterbatches was evaluated using a Dynisco Kayness capillary rheo-viscometer according to Standard STN EN ISO 1133 Plastics: Determination of melt mass flow index and melt volume flow index of thermoplastic melts.

The filter index (*F*) is given in MPa/kg and represents the value of the fictitious pressure that would be achieved when filtering a melt of a masterbatch containing 1 kg of active ingredient through a system of precisely defined sieves. In our case, the methodology utilizes an experimental mixture of a PLA masterbatch and a basic testing polymer (polypropylene) in an exact concentration to check the dispersability of the plasticizer in the PLA masterbatch. PP polymer is used due to its low moisture content. The filter index of masterbatches was determined using a filtration single-screw extruder with a screw diameter of 25 mm and density of the filtration sieve with the smallest holes of 15 600 per cm^2. The filterability of the dispersion (filter index *F*) was then expressed as ratio of an increment of the pressure Δp [MPa] on the filter to a weight unit of the filtrate *m* [kg] at the definite filtration conditions when:

$$F = \left(\frac{\Delta p}{m}\right).\left(\frac{100}{c}\right) \quad (1)$$

where: *c* is pigment concentration in mixture.

Rheological properties

The rheology of 15% masterbatches of polymers PLA1 and PLA2 was tested on a Göttfert RG20 capillary rheometer by measuring the melt mass flow through the capillary with L/d = 30/1 (L - capillary length and d - capillary diameter in mm) as a function of varying pressure. It was operated in the temperature regime of 190°C and 210°C. The samples were dried at 80°C for 3 hours before measurement. According to Equations 2 and 3, the shear rate D [s^{-1}] and the shear stress τ [Pa] were calculated, where Q [mm^3.s^{-1}] is volume flow, R [mm] is capillary radius, ΔP [Pa] - pressure change, L [mm] - capillary length.

$$D = \frac{4Q}{\pi R^3} \quad (2)$$

$$\tau = \frac{R\Delta P}{2L} \quad (3)$$

These equations are applicable to materials that are called Newtonian fluids from a rheological point of view. From the calculated dependences of the shear stress from the shear rate, a seeming flow curves (without correction) were constructed.

Rabinowitsch correction was used to construct a true flow curve that takes into account the non-Newtonian flow pattern at the capillary wall, and the relationship for calculating the shear rate is transformed to:

$$D_{sk} = \frac{3n+1}{4n}\frac{4Q}{\pi R^3} \quad (4)$$

where: D_{sk} - the real shear rate, n - the flow behavior index or index of the deviation flow, Q - volume flow, R - capillary radius.

From the Ostwald de Waele law (5) for both seeming and real shear rate the flow consistency K [Pa.s] was calculated, which expresses the fluidity of the material (a high K value means high viscosity) and the non-Newtonian flow index n of polymer melts (masterbatches).

$$\tau = K.D^n \quad (5)$$

3 RESULTS AND DISCUSSION

Applicative properties of PLA masterbatches

Applicative properties give us the initial information about masterbatches. These include the flow characteristics of masterbatches - melt flow index and reciprocal value to the *MFI* - the viscosity, as well as the filterability value of masterbatches, which informs about their quality. Results of the evaluation of the applicative properties of prepared PLA masterbatches with additives PL and bioPL are presented in Table 2.

By comparing the applicative properties of the masterbatches (*MFI; η; F*) and the types of polymers used, it was found that masterbatches 1 and 2 have higher flow indices and lower coefficients of variation than masterbatches 3 and 4. This difference is due to different PLA matrix types (Table 2). The lower coefficients of variation of the masterbatches melts prepared on the PLA1 matrix demonstrate a more uniform flow through the capillary than the melts of the masterbatches prepared on the PLA2 matrix.

A comparison of the effect of plasticizers on the applicative properties showed a slight diluting effect of the PL plasticizer in both types of PLA matrix used. The plasticizer bioPL does not affect the *MFI* of the PLA1 matrix. The increase *MFI* of masterbatches 3 and 4 prepared on the PLA2 polymer matrix is due to the degradation of PLA2 during the melt-kneading process. Masterbatches prepared on a PLA1 matrix do not show this phenomenon. Comparison of CV_{MFI} and *MFI* of masterbatches 2 and 4 with bioPL content revealed degradation of PLA2, demonstrating a significant increase in CV_{MFI} from 8.7% (masterbatch 2) to 21.7% (masterbatch 4), as well as a 46% increase in *MFI* of masterbatch 4 over the base polymer PLA2 (Table 2).

A viscosity in the range of 400-900 Pa.s is desirable for the spinning process and is closely related to the desired mechanical properties of the fibres. The viscosity interval of the evaluated masterbatches corresponds to a flow index of 12.5 ÷ 27 g/10 min measured masterbatches.

The filterability of masterbatches is one of the most important properties of masterbatches, because it shows the degree of the additive dispersion in the matrix, what has the effect on the technological stability of the fibres preparation process. Masterbatches 3 and 4 containing PLA2 have low filter index (91 and 35 MPa/kg) indicating a high degree of the additive dispersion in the PLA matrix without the formation of larger agglomerates. From the point of view of filterability, the masterbatches can be used for the preparation of silk types of fibres with low fineness. Masterbatches 1 and 2 containing PLA1 have higher filter index and therefore meet the requirements for the preparation of fibres with higher finenesses - cotton and wool types. Filter index of studied masterbatches in the range of 35-185 MPa/kg is suitable for the preparation of fibres for research purposes.

It follows from the above that prepared PLA1 masterbatches with suitable applicative properties will not have a negative impact on the technological stability of the fibre preparation process. In PLA2 masterbatches, degradation of the PLA2 matrix can have a negative effect on fibre formation.

Rheological properties of PLA masterbatches

The rheological behavior of the melts of PLA masterbatches containing additives PL and bioPL were investigated in order to find the processing conditions in the spinning process. For PLA polymers the manufacturers recommend the processing temperatures of 190°C and 210°C, therefore these temperatures were used to take measure the rheological properties of the masterbatches.

From the measured and calculated values, the non-Newtonian flow index *n* (flow behavior index) and the flow consistency *K* of the PLA melts of the masterbatches were determined (Table 3). The results showed that masterbatches 1 and 3 containing plasticizer have higher values of flow behavior index (their behavior is closer to behavior of Newtonian fluids) and lower flow consistency (lower viscosities) compared to masterbatches 2 and 4 containing bioplasticizer. All of the above indicates their better processability in fibres preparation.

After editing by Rabinowitsch correction (RC), the flow consistency *K* decreased significantly at 190°C (most at masterbatch 4 - PLA2/bioPL from 63 631 to 19 864 Pa.s), at 210°C the decrease of the *K* was not so dramatic (at masterbatch 4 from 7 483 to 6 637 Pa.s).

Table 2 Applicative properties: melt mass flow index (*MFI*), viscosity (η) and their associated coefficients of variation (CV_X) and filter index (*F*) of prepared PLA masterbatches

Masterbatch No.	Name of masterbatch	MFI [a] [g/10 min]	CV_{MFI} [%]	η [a] [Pa.s]	CV_η [%]	F [MPa.kg^{-1}]
-	PLA1	24.6	5.1	469	5.2	-
1	PLA1/PL	26.5	9.1	437.3	9.7	185
2	PLA1/bioPL	24.6	8.7	470.4	8.3	107
-	PLA2	8.9	6.6	1 295.1	6.6	-
3	PLA2/PL	16.4	18.0	719.6	20.8	91
4	PLA2/bioPL	13.0	21.7	887.9	24.8	35

[a] 210°C/2.16 kg (τ = 19500 Pa), masterbatches were dried 2 h/70°C

Table 3 Regression parameters: the flow behavior index (*n*) and the flow consistency (*K*) from power model for melts of PLA masterbatches of additives PL and bioPL on polymer carriers PLA1 and PLA2, calculated without and with Rabinowitsch correction (RC)

Masterbatch No.	Name of masterbatches	190°C				210°C			
		without RC		*with RC*		*without RC*		*with RC*	
		K [Pa.s]	n	K [Pa.s]	n	K [Pa.s]	n	K [Pa.s]	n
1	PLA1/PL	15 127	0.386	13 293	0.386	1 474	0.586	1 340	0.586
2	PLA1/bioPL	42 915	0.260	19 553	0.334	4 827	0.486	4 308	0.486
3	PLA2/PL	45 891	0.264	19 698	0.345	3 257	0.518	2 921	0.518
4	PLA2/bioPL	63 631	0.226	19 864	0.341	7 483	0.450	6 637	0.450

The flow behavior index did not change at 210°C, which means that the non-Newtonian character of the flow at the capillary wall did not changed. When calculating the Rabinowitsch correction at 190°C, *n* increased for all premixes except premix 1, which means that the true melt flow of these premixes on the capillary wall is closer to the flow of Newtonian fluids and less dependent on shear rates than their apparent melt flow - without RC (Table 3).

PLA masterbatches of PL and bioPL additives are pseudoplastic fluids, it means with increasing shear rate the shear stress increases (Figures 1 and 2) and the viscosity (flow consistency) decreases (Figure 3). The pseudoplastic character of masterbatches is also proved by the flow behavior index, the value of which is lower than one (Table 3). Lower values *n* indicates a higher dependence of the shear stress on the shear rate at temperature 190°C than at temperature 210°C in the case of the evaluated masterbatches.

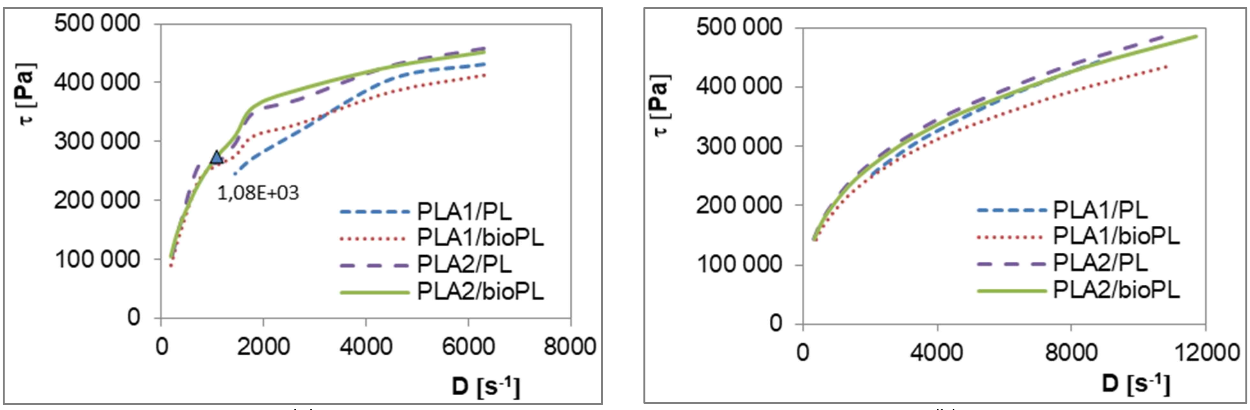
From the flow curves without Rabinowitsch correction at 190°C it can be seen that at a shear rate of about 1080 s^{-1} the flow curves of masterbatches 2, 3 and 4 intersect and the shear stress of the evaluated masterbatches at this point is the same (Figure 1a).

The masterbatches from PLA2 (3 and 4) have higher shear stresses compared to the masterbatches from PLA1, especially in the range of shear rates 2 000-3 000 s^{-1}. At high shear rates above 4 000 s^{-1}, PLA2 masterbatches have practically the same running independent of the plasticizer used.

The flow curves of PLA 1 masterbatches intersect at a shear rate of about 3 000 s^{-1}. With an increase in shear rates above 3 000 s^{-1}, the shear stress of masterbatch PLA1/bioPL was decreased and other hand the shear stress of masterbatch PLA1/PL was increases (Figure 1a). Lower shear stresses cause a lower screw load, so they are desirable in spinning process.

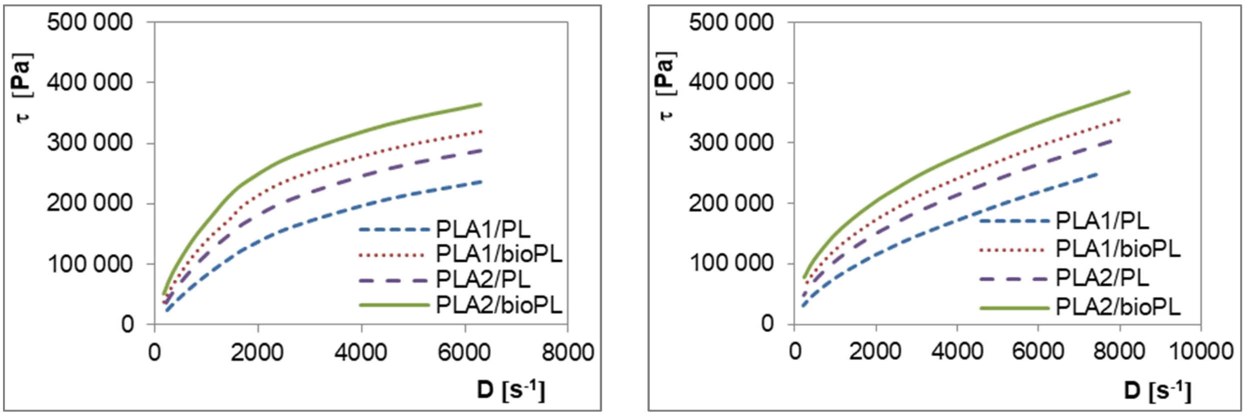
After adjustment by Rabinowitsch correction, the flow curves showed a less steep running and a shift to higher shear rates. The lowest shear stress at the same shear rates after RC was demonstrated for masterbatch PLA1/bioPL. The remaining masterbatches had practically the same course (Figure 1b).

At 210°C the shear stress is lower compared to the shear stress at 190°C at the same shear rates. The shear stress at 210°C increases in order: masterbatch 1 (PLA1/PL) < 3 (PLA2/PL) < 2 (PLA1/bioPL) < 4 (PLA2/bioPL) in both calculated cases with and without Rabinowitsch correction (Figure 2). The results showed that the type of plasticizer more significantly affects the rheological properties at temperature of 210°C than at 190°C, where more the type of PLA polymer not additives influenced of the flow properties of the melt.



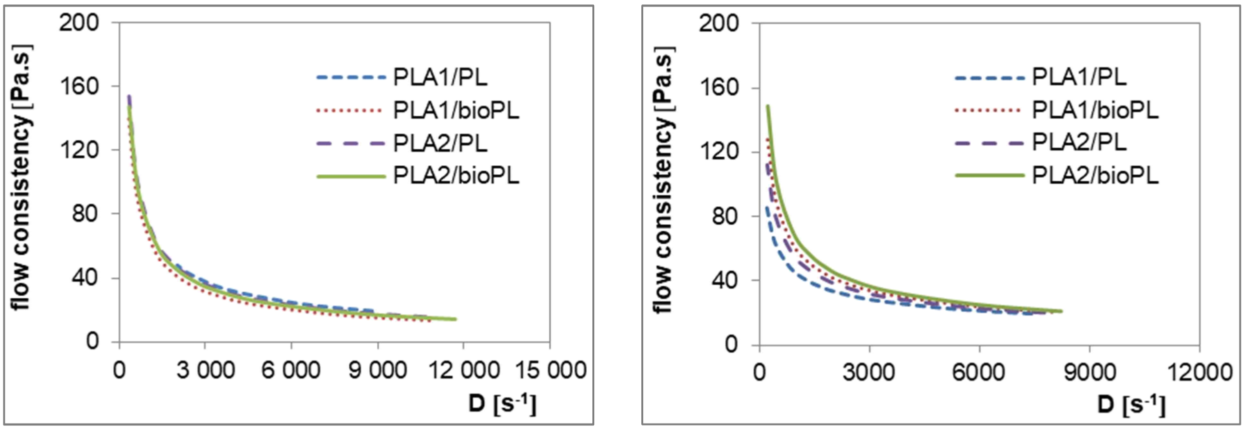
(a) (b)

Figure 1 Dependence of shear stress on the shear rate of PLA masterbatches with 15% additives (plasticizer PL, bioplasticizer bioPL) at temperature 190°C without (a) and with (b) Rabinowitsch correction



(a) (b)

Figure 2 Dependence of shear stress on the shear rate of PLA masterbatches with 15% additives (plasticizer PL, bioplasticizer bioPL) at temperature 210°C without (a) and with (b) Rabinowitsch correction



(a) (b)

Figure 3 The dependence of flow consistency (the real viscosity) on shear rate *K=f(D)* of PLA masterbatches with 15% additives (plasticizer PL, bioplasticizer bioPL) at temperature 190°C (a) and 210°C (b) after Rabinowitsch correction

In Newtonian fluids, the viscosity is only a material constant and does not depend on shear values, but only on the change in temperature. Because PLA masterbatches containing PL and bioPL are non-Newtonian pseudoplastic fluids with increasing shear rate, their viscosity decreases and changes with temperature (Figure 3).

From dependencies of flow consistency (the real viscosity) on shear rate *K=f(D)* of PLA masterbatches containing 15% additive at a melting point of 190°C in the whole range of shear rates the evaluated masterbatches have practically the same viscosities (Figure 3a). Slightly lower viscosity was observed for masterbatch 2 (PLA1/15%bioPL). At a melting point of 210°C, at low shear rates up to 3 000 s^{-1} the viscosity of masterbatches decreases following 4 > 2 > 3 > 1, which correspondent with shear rates of the evaluated masterbatches (Figure 2b).

The evaluation of the rheological properties of PLA masterbatches containing two types of additives PL and bioPL, shows that the PLA1/PL masterbatch is from rheological point of view the most suitable for fibre preparation because it has the lowest flow consistency and thus good material fluidity as well as has the highest value of flow behavior index *n*. At the same time, melt of masterbatch 1 achieves at 210°C the lowest shear stress and viscosity from of all evaluated masterbatches at the same shear rates.

4 CONCLUSION

The paper presents the results of masterbatches study, which consist of a mutual combination of two types of PLA polymers and two types of additives. The effect of the ingredients on the applicative and rheological properties of the masterbatches was investigated. The obtained experimental results were evaluated for the suitability of the masterbatches for the preparation of modified PLA fibres.

The results of the study showed that more the type of polymer as the type of additive used affects the applicative properties of the prepared masterbatches. Masterbatches prepared from PLA2 polymer have a lower *MFI* compared to masterbatches containing PLA1 polymer. Matrix degradation was detected in PLA2 masterbatches. A plasticizer PL showed a slight diluting effect of the in both types of PLA matrix used. The plasticizer bioPL does not affect the *MFI* of the PLA1 matrix. The filter index of all masterbatches is low; it is in the range of 35 - 185 MPa/kg, which means good dispersion of additives in the polymer matrix.

It follows from the above that the evaluated applicative properties of the studied PLA masterbatches will not negatively affect the technological stability of the fibre preparation process only degradation of the PLA2 matrix could have a negative effect on fibre formation.

The evaluation of the rheological properties of PLA masterbatches shows that the type of additive significantly affects the flow properties of masterbatches at 210°C, while at 190°C the flow properties of masterbatches are mainly influenced by the type of polylactic acid used.

The masterbatches containing plasticizer have higher values of the flow behavior index and lower flow consistency (lower viscosities) compared to masterbatches containing bioplasticizer, which indicates their better processability in fibre preparation. Due to better flow properties at temperature 210°C - lower shear stress and lower viscosity of investigated masterbatches, is a temperature regime 210°C more suitable for the processing of PLA masterbatches than temperature 190°C. Of all the masterbatches evaluated, the masterbatch prepared from PLA1 polymer and of plasticizer PL has the most suitable rheological characteristics. In terms of applicative and rheological properties, all masterbatches meet the technical conditions for the preparation of PLA fibres.

ACKNOWLEDGEMENT: *This work was supported by the Slovak Research and Development Agency under the contracts No. APVV-17-0078 and No. APVV-14-0175.*

5 REFERENCES

1. Engelhardt A.: The Fiber Year 2020 - Deceleration along the textile chain, International Fiber Journal, July, 2020, Available from https://fiberjournal.com/the-fiber-year-2020-deceleration-along-the-textile-chain/, Accessed: 2021-04-23
2. European Environment Agency: Plastics, the circular economy and Europe′s environment - A priority for action, Report No 18, 2020, pp. 1-76, ISBN: 978-92-9480-312-2, ISSN: 1977-8449, doi: 10.2800/5847
3. Shanmugam V., Babu K, Garrison T.F., et al.: Potential natural polymer-based nanofibres for the development of facemasks in countering viral outbreaks, Journal of Applied Polymer Science 138(17), 2021, pp. 1-19, https://doi.org/10.1002/app.50658
4. Gumel A.M., Suffian M, Annuar M., Heidelberg T.: Current application of controlled degradation processes in polymer modification and functionalization, Wiley Periodicals, Journal of Applied Polymer Science 129(6), 2013, pp. 3079-3088, https://doi.org/10.1002/app.39006
5. Bauer J., et al.: PLA in the post-consumer-recycling stream, bioplastics Magazine 13(06), 2018, pp. 18-19, ISSN 1862-5258
6. Farah S., Anderson D.G., Langer R.: Physical and mechanical properties of PLA, and their functions in widespread applications - A comprehensive review, Advanced Drug Delivery Reviews 107, 2016, pp. 367-392, https://doi.org/10.1016/j.addr.2016.06.012
7. Dreier J., Castellón S.M., Bonten Ch.: Bio-foams made of modified polylactide, bioplastics Magazine 16(01), 2021, pp. 32-33, ISSN 1862-5258
8. Decai L., et al.: Preparation of plasticized poly(lactic acid) and its influence on the properties of composite materials, PLoS One 3(13), 2018, pp. 1-15, https://doi.org/10.1371/journal.pone.0193520
9. Cadogan D.F., Howick Ch.J.: Plasticizers, In: Ullmann's Encyclopedia of Industrial Chemistry, Wiley-VCH, Weinheim, 2000, https://doi.org/10.1002/14356007.a20_439
10. An.: New masterbatches for nonwovens, Man-Made Fiber Year Book 2013 64, 2013, p. 77

DEVELOPMENT OF THE MOBILE APPLICATIONS FOR USING IN APPAREL AND SHOES DESING

Oksana Zakharkevich, Julia Koshevko, Svetlana Kuleshova, Serhii Tkachuk and Anatolii Dombrovskyi

Khmelnitskyi National University, Department of Technology and Design of Garments, Institytska str. 11, 29016 Khmelnitskyi, Ukraine
zbir_vukladach@ukr.net; juliakoshevko@gmail.com

Abstract: *The globalization of the fashion clothing and footwear market, the significant influence of social networks and the speed of the spread of fashion trends require the presence of appropriate mobile technologies in the arsenal of a light industry specialist. Having analyzed the market of mobile applications in the field of shoe production, it has been singled out that there is the lack of applications that provide the calculation of details of shoe design and allow maintaining distance learning conditions for students in the industry. The similar conclusion was made for the field of apparel design. The aim of the study is to develop mobile applications to support the process of shoe and apparel design using computational and graphical methods of construction. The initial information on the construction of shoe and garment designs has been structured. The method of construction has been transformed into a tabular form by selecting elementary graphical operations; each one has been described by an attribute tuple. Modular synthesis of the structure for step-by-step presentation of information in the mobile applications has been applied. The implementation of step-by-step layering of structural modules by the principle of modular synthesis has been performed using the mechanism of on and off layers in the environment of the graphics editor. The method of semantic differential has been used to evaluate the developed mobile applications. The scales of the semantic differential for each attribute of the mobile applications have been represented as bipolar pairs expressed by adjectives or adverbs. The resulting psychographic profiles of the applications indicate a positive assessment by experts, as the coefficients correspond to the positive values of the Kansei words. The developed applications are intended for use by teachers and students of higher educational institutions, representatives of shoe/apparel companies, pupils and teachers of colleges, technical schools. The results of a survey of students and teachers have confirmed the need for the introduction of a mobile technology.*

Keywords: *mobile applications, design calculation, shoe details, garment parts, psychographic profile, modular synthesis.*

1 INTRODUCTION

The globalization of the fashion and footwear market, the significant influence of social networks and the speed of fashion trends require the presence of appropriate mobile technologies in the arsenal of a light industry specialist. The cost of ready-made applications is hundreds of times less than the cost of pattern-design systems (PDS) systems for clothing or footwear. The cost of their development and its duration is also significantly lower than the corresponding indicators of PDS. This allows providing the digitalization of small businesses, studios, showrooms, for which the purchase of industrial PDS is economically unprofitable. The use of applications does not require any costs for the purchase of equipment. The percentage of the population of any country in the world that uses mobile and tablet devices has reached its maximum level in recent years. Therefore, mobile technologies are relevant both for light industry enterprises and for educational institutions of all levels. This trend, as well as the presence of cameras in mobile and tablet devices, allows you to use them as a digital camera or even as a 3D scanner.

It should be noted that a designer of clothing or footwear, working in mass production, has long moved its workplace in the virtual space of computer-aided design systems. However, a student who is just mastering the profession and his teacher work manually or semi-manually. This is due to the peculiarities of studying the process of construction. To solve such problems, PDS is also a very expensive tool, which, moreover, does not have the necessary functionality. Calculators, although, are quite convenient for this type of task, but this calculation takes a long time, and the number of manipulations increases the risk of errors. An additional factor in favor of the use of mobile technologies is that there is the need in education to introduce distance learning, which is now faced by all educational institutions in the world due to the COVID-19 pandemic.

2 ANALYSIS OF PUBLISHED DATA AND STATING THE PROBLEM

The possibilities of using mobile applications for learning or as a tool in the learning process are widely covered in the scientific literature. Pedagogical and technological advantages of mobile learning are recognized by scientists and teachers [1]. Such studies have been conducted in various fields, such as: interactive learning environments for children [1, 2], training in clinical medicine [3, 4], language learning [5, 6], the study of physical phenomena using smartphones [7-10], etc.

Some advantages and disadvantages of using smartphones in training modules, such as learning identification skills in the field, are described in [11]. It should be stated that no evidence has been found that mobile technology has improved students' ability to apply their skills in the field. However, students have told that one of the advantages of mobile technologies is the ability to access the necessary educational information even in extracurricular activities.

In work [2] it has been found that learning with the use of tablets in comparison with traditional methods provides better learning outcomes for students and at the same time better meets the needs of teachers. Similar conclusions have been obtained as a result of studies presented in work [1], in which in addition to the use of smartphones, robots are used for training. That in total has provided significant optimization of mobile learning.

The most widely used mobile applications are in the field of language learning and teaching [5, 6] and this includes even the languages of formal programming languages [6]. Work [6] shows that such applications not only provide students with answers to their questions related to specific topics, but also provide an organization of the learning environment that supports the step-by-step learning process. Works [5, 6] are devoted to the analysis of various mobile applications used for learning foreign languages. The analysis has revealed that the quality and feasibility of individual tasks in different applications are not the same. However, as a rule, students who take part in research express a positive attitude towards such learning tools.

Mobile applications in the footwear industry, described in the scientific literature, are often associated with the production of smart shoes, such as shoes for the blind [12]. The developers have built sensors into the shoes, which transmit a signal through the Arduino board (Italy) to a smartphone that has an application for the Android operating system (the USA). The clear advantage of such an application is the ability to work without an Internet connection.

Another example of the use of mobile applications for smart shoes is the smart navigation technology described in [13], built into shoes for bikers and cyclists. The application for the Android operating system allows you to choose the best way to your destination. Studies dedicated to determining the best technologies for scanning the feet using mobile applications are presented in [14-16].

In [14] the approach to the estimation of the three-dimensional shape of the foot using a mobile application is described. The application algorithm finds a combination of shape parameters that best match the foot parameters that are determined from the photographic image of the foot. The mobile application offered in work [15] acts in a similar way: the photographic images of the foot are determined by six parameters of the foot, which users can use to select the right size shoes.

The aim of the study [16] was to determine the consistency between two 3D scanners, the software of one of which is actually a mobile application with the iOS operating system (the USA). The paper proves that the reliability of the data obtained using such a scanner is not lower than the average (along the Z axis), and high – in the directions of the X and Y axes.

Thus, based on the above, it is seen that the vast majority of mobile applications described by scientists are designed for the Android operating system [12, 13]. Only one application is offered for the iOS operating system [16].

The paper [17] presents different examples of using mobile applications during educational simulation of a design product, in managing students' remote independent work.

Scientific papers do not reflect the developments related to the direct design of shoe parts. However, similar studies have been performed in the field of clothing design [18, 19]. The paper [18] develops a prototype of a mobile application for calculating the parameters of the basic design of shoulder clothing and studies the market of mobile applications that are directly or indirectly related to the garment industry. Besides that, there is a number of papers dedicated to studies of fashion clothing market and its tendency to mobile shopping [20, 21].

In the paper [19] the mobile app for calculating the parameters of several different garments parts is presented. Both works [18, 19] provide the description of apps those might be used by professional patternmakers. Thus, the apps do not contain information on the method of drafting or its sequence.

In works [22, 23] the analysis of known methods of designing of top footwear details is performed. As a result, it has been found that computational and graphic methods of construction (copying and graphic system) are the most commonly used, and they are based on the use of conditional scanning of the block with the base lines applied to it. Baselines reflect the anatomical structure of the foot.

At the same time, the description of the method of construction of shoe parts is often an unstructured text, as in [24], and the methods themselves are not divided into separate operations, which makes it difficult for students to understand the task.

Thus, the analysis of literature sources indicates the need for additional research and systematization of known data for the introduction of mobile technologies in the process of designing shoe constructions as well as in apparel design.

The purpose and objectives of the study

The aim of the study is to develop a mobile application to support the process of shoe design using computational and graphic methods of construction which can be used both in production and in the learning process.

To achieve this goal, the following tasks were set:

- to analyze the market of existing mobile applications for use in the design and footwear manufacture (prototype search);
- to generate initial data for application development;
- to substantiate theoretically the principle of operation of the application;
- to develop a prototype of a mobile application;
- to perform testing and evaluation of the developed application.

3 MATERIALS AND METHODS

3.1 Analysis of the market of mobile applications in the footwear industry

For the general statistical set of mobile applications used in the manufacture and operation of footwear, we have accepted mobile applications, which are placed on the platforms of Google Play and App Store. The sample is formed by search results on the relevant platforms of mobile applications by keywords: shoes, shoes patterns, drafting shoes, smart shoes, etc. The total number of considered applications is 260 units: 201 Android applications from Google Play and 59 iOS from the App Store. It has been found out that the set of mobile applications developed for the Android operating system significantly outperforms mobile applications for iOS (77% vs. 23%).

According to the results of a review of mobile applications developed for the Android operating system and posted on Google Play, it has been found out that they can all be divided into 16 categories depending on the function they perform Figure 1. The most numerous are groups of applications that are actually catalogs of ideas for creating your own shoe models and applications of online shoe stores (32.02% each). For the purposes of designing and manufacturing shoes, you can use applications that scan the foot to determine its size (2.96%), shoe patterns (2.46%), design the appearance of shoes (2.46%). Other categories relate to the purchase or operation of footwear, as well as hobbies.

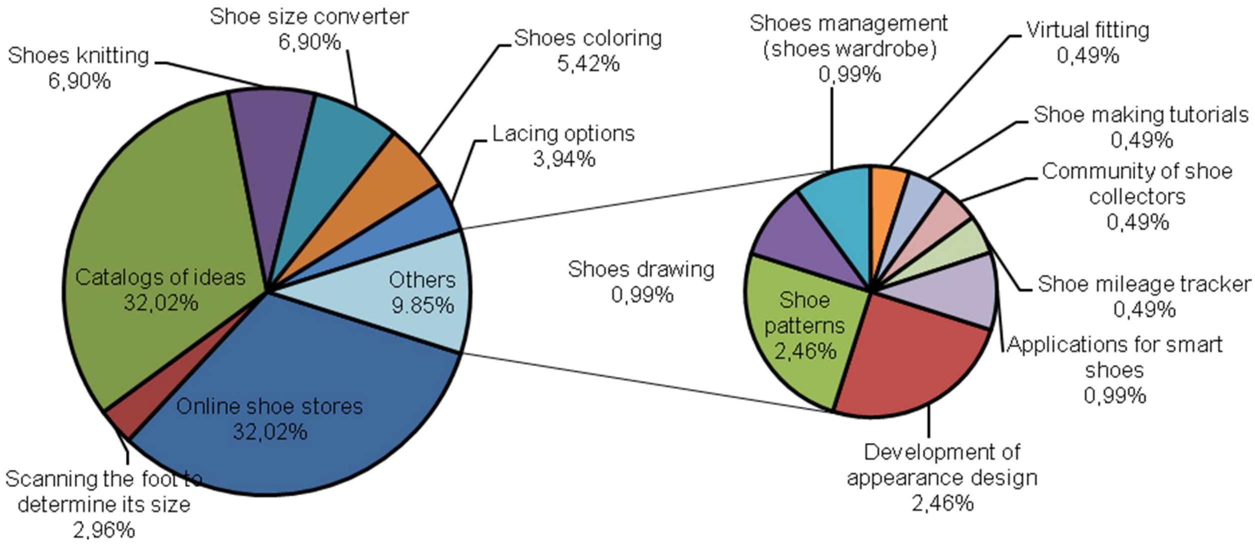


Figure 1 The ratio of the number of mobile applications of different groups used in the footwear industry (Android)

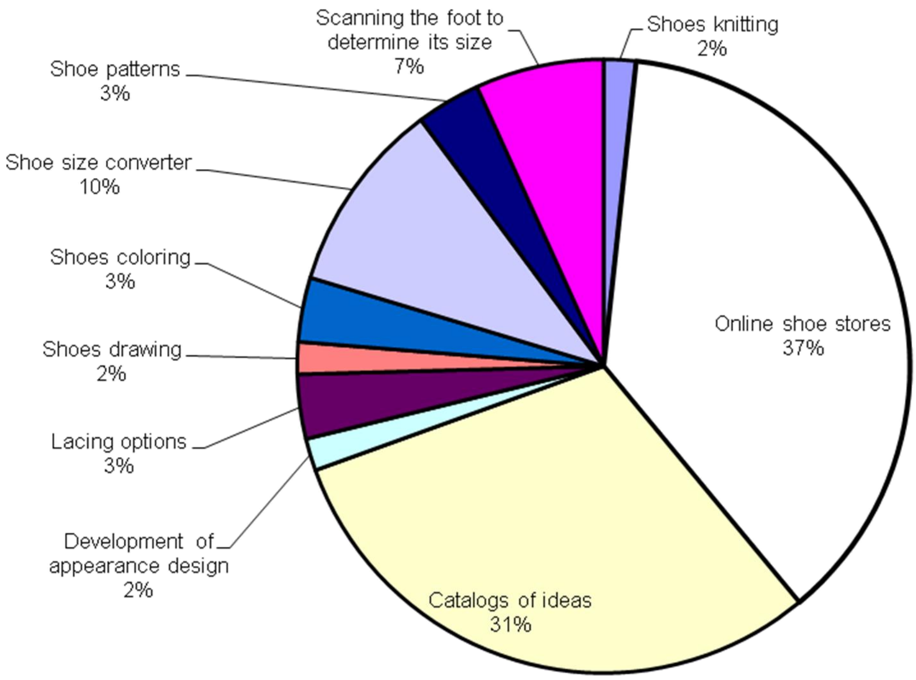


Figure 2 The ratio of the number of mobile applications of different groups used in the footwear industry (iOS)

Applications developed for iOS are represented by 10 categories (Figure 2). As in the case of Android, the largest categories are online shoe stores (37%) and catalogs of ideas (31%). From those categories which can be used for production or design of footwear, it is possible to allocate groups of footwear patterns (3%) and scanning the foot to determine its size (7%).

Figure 3 shows that the absolute value of each of the categories of mobile applications for Android exceeds the value of the corresponding category of applications for iOS.

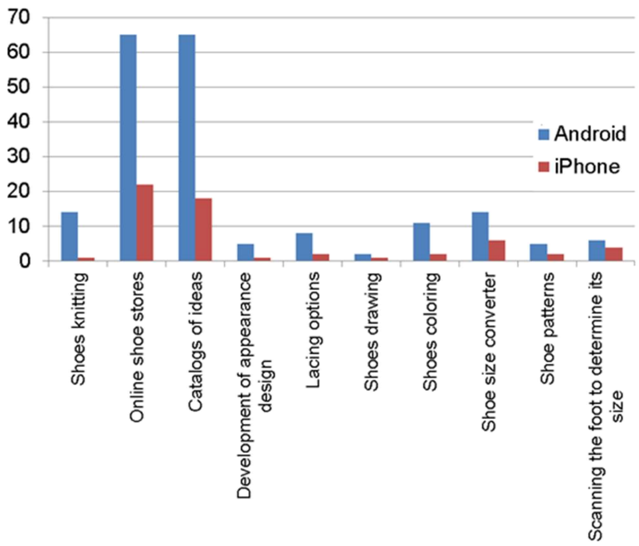


Figure 3 The ratio of the same categories of mobile applications designed for different operating systems

At the same time, the total value of the largest categories – online shoe stores and catalogs of ideas at times exceeds the values of other categories (Figure 4), and individual categories – even dozens of times.

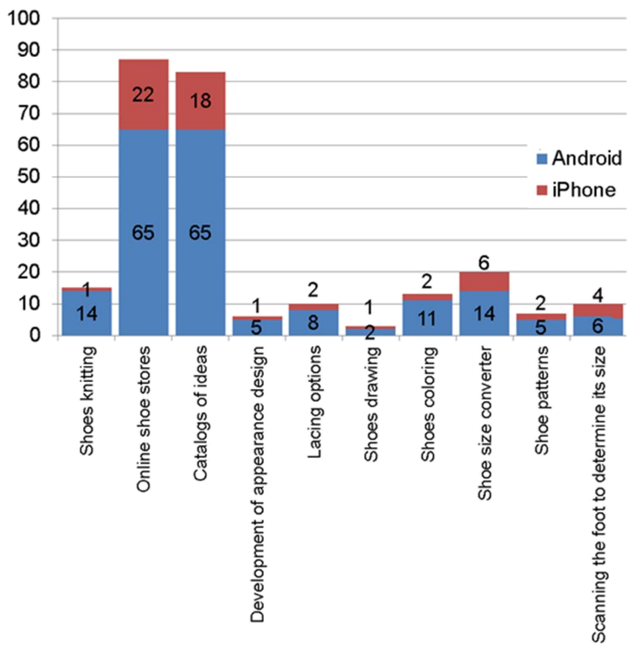


Figure 4 The ratio of categories of mobile applications

As revealed in the analysis of literature sources and publications, the greatest interest among the existing mobile applications on the market are applications-scanners feet, the main purpose of which is to determine the specific shape of the foot and its size, followed by selection of shoes in online stores. In addition to the applications described in the previously discussed scientific articles [14-16], the following applications are known on the market: Shoe-buddy (China) (SHOEGenius™, FOOTGenius™), ATLAS (Germany) (ATLAS Fußvermessungs), FootFact (Germany), FISCHER Scan -Fit (Austria), OrtoPie Scan (Peru).

3.2 The market of mobile applications in the apparel industry

The market of mobile applications in the apparel industry is fully described in [18, 19]. It was determined that there are 14 types of the mobile applications that are used in garment industry. All of them are considered to be very useful for the studying purposes. The main contribution to all of the categories large and small alike is made through the Android operating system. It was found out that "Pattern calculators" group is one of the smallest categories. It is represented by four applications (Chalk, JSK Patrones, Circle Skirt Calculator, Solo Patrones App) that were found in the search results and two applications those were developed and described in [18, 19].

Step by step sequence of pattern drafting is performed in the app "JSK Patrones". However, it provides ability to draft only the simplest construction design of garment. Thus, it was confirmed that there are no enough tools on the mobile apps market to provide clothing designers with ability to calculate the parameters of the clothing blocks and to learn the pattern drafting technique simultaneously.

4 DEVELOPMENT OF A PROTOTYPE OF A MOBILE APPLICATION

4.1 Formation of initial data for application development

The description of the technique is usually accompanied by several drawings showing several stages of construction, and sometimes the entire construction. Since the details of the shoes are relatively small, and in order to comply with the drawing rules of drawings' design, all symbols and lines must be of a certain size, the resulting drawing is quite cluttered, difficult to read even by a specialist. It is almost impossible to read such illustrations for a person who is just beginning his career in the profession.

Therefore, for use of the mobile application of calculation of details' design of footwear in the conditions of distance learning, it is expedient to illustrate all stages of design construction.

This mechanism is practically analogous to the process of modular synthesis of clothing designs developed in [25, 26]. According to the author's definition [25, 26], a structural module (SM) is a unified graphic element that has certain dimensional and parametric characteristics and provides functional and structural compatibility of graphic primitives in the design of the part.

Representation of each graphic element by generation from graphic segments provides ordering of sequence of graphic procedures in computer graphics. This system of structural modules is open and involves the addition of subsystems of the graphical representation of the respective modules in the form of layered construction of a complex drawing.

To achieve this task, the descriptive nature of the presentation of the method of design construction of the upper parts of the shoe is presented in the form of a system of structural modules of the upper parts (in the form of Table 1). The whole technique is divided into 58 elementary operations and corresponding structural modules. Each operation is characterized by a tuple of attributes: number in order; segment name (points, sections); calculation or specific value of the segment; direction of deposition (construction); features of graphic construction.

Table 1 System of structural modules of shoe upper parts

KM	Segment (point)	Size (formula)	Direction	Features of construction
1	2	3	4	5
1	OX	-	→	Horizontal with t. O
2	OY	-	↑	Vertical with t. O
3	$OB_к$	-	↑	Heel lift height
4	$B_кP$	$062L_{csp}$	→	From point Vk on the axis OX notch point P
5	p. M_1	-	-	p. M1 is the most protruding point of the sock part of the template. The lower heel angle of the conditional scan pattern of the pad (CSP) is combined with the point Vk, and the most protruding point of the lower contour of the template with the point P
6	p. M_2	-	-	Holding the template in p. Vk, lower the inner contour of the CSP to point P
7	M_1M_3	$0.5M_1M_2$	↓	The template is placed with the toe part in the M3 volume, and the heel part in the Vk point, and the lower contour of the CSP to the p. P is copied.

KM	Segment (point)	Size (formula)	Direction	Features of construction
8	$B_кB_к'$	5 mm	↑	With respect to p. P CSP is rotated so that the lower point of the heel contour coincides with p. Vk ′
9	O_1X_1	-	→	Through p. Vk 'and P
10	$O_1У_1$	-	⊥ O_1X_1	Tangent to the most convex point of the heel of the CSP
11	O_1I	0.23 L_{csp}	→ on O_1X_1	Perpendiculars to the O_1X_1 axis
12	O_1II	0.41 L_{csp}	→ on O_1X_1	
13	O_1III	0.48 L_{csp}	→ on O_1X_1	
14	O_1IV	0.68 L_{csp}	→ on O_1X_1	
15	O_1V	0.78 L_{csp}	→ on O_1X_1	
16	$B'_кB_п$	$0.15N_м$+25.15		$N_м$ - shoe size in the metric numbering system
17	$B'_кB_з$	$0.15N_м$+12.0		
18	K_1K_2	-	-	Intersection of the V baseline with the contour of the template
19	K_1K	$0.5K_1K_2$	↓ on K_1K_2	p. Vp and p. Vz are combined with p. K
20	p. M	-	-	Intersection of baseline IV with the upper contour of the CSP
21	p. L	-	-	Intersection of baseline III with the lower contour of the CSP
22	Mb	0.35 ML	↓ on ML	-
23	Mb'	0.5 ML	↓ on ML	bb' - the maximum allowable distance of the vamp line from the sock part of the CSP
24	$B_п1$	3 mm	→ on $B_пK$	-
25	p. 2	3 mm	← ⊥ CSP	At the point of greatest convexity of the heel of the CSP
26	$B'_к3$	2.5 mm	←	Points 1, 2, 3 are connected by a smooth curve, which is continued down relative to the CSP by the amount of allowance for the tightening strip
27	p. 4	-	-	Intersection of baseline I with $B_пK$
28	4-4'	6 mm	↓	-
29	p. 5	-	-	Intersection 1-4 'with baseline II
30	5-6	8 mm	← on 5-1	-
31	6-7	-	At an angle of 107° to 6-1	To the intersection with the upper contour of the CSP
32	7-8	1.5 mm	↓ on 6-7	-
33	8-9	50 mm	|| the upper contour of the CSP	-
34	p. C	-	-	The position of the deepening of the union, focusing on t and b and b '
35	p. H	-	-	The most convex point of the sock part of the CSP
36	HH_1	4 mm	↓	-
37	H_1H_2 - the line of inflection of the vamp	-	-	A right triangle is imposed so that one of its legs passes through p. H_1, the other through p. C, and the top of a right angle was located on the top contour of CSP (p. H_2)
38	Continuation H_1H_2	-	← → on H_1H_2	To the right of point H_1 along the contour of the sock part of the CSP by 11 mm and to the left of point H_2 to the intersection with the baseline I
39	C-10	15 м	→ || H_1H_2	-
40	10-11	9 mm	↓ on 9-10	-
41	11-11'	-	←|| $B_пK$	H_1H_2 - the bend line of the vamp
42	11'-12	2 mm	← on 11-11'	-
43	L-13	$0.5(O_1III-O_1II)$	← on the lower contour CSP	Half the distance along the lower contour of the CSP between the base lines II and III. Point 13 is connected with point 12
44	angle 8-6-1	45 mm	-	Rounding radius
45	angle 6-8-9	9 mm	-	Rounding radius
46	angle 8-9-11	22 mm	-	Rounding radius
47	angle 11-12-13	20 mm	-	Rounding radius
48	14-15	9 mm	←	-
49	15-16	1/2 the width of the tongue at the top	↓ on ⊥ H_1H_2	point 16 is connected with point C
50	angle 15-16-C	10 mm	-	Rounding radius
51	1-18	4 mm	-	Allowances for bending of the upper and front edges
52	1-17	13 mm	← angle 18-1-17= angle 18-1-4'	-
53	1-19	8 mm	↓	-
54	Thread fastening	2 mm	|| 11-12	Above point C
55	The line of the tongue cut	-	⊥ vamp bending lines	So that it was closed by the front edge of the ankle boots
56	Seam allowances	5-8 mm	-	Depending on the number of stitches
57	Tightening strap	-	-	Template curve with allowances
58	The contour of the vamp wing	At a distance of 8 mm	|| contour of the ankle boot	-

Each of the operations is illustrated by a separate drawing. Black color depicts graphic elements of the drawing, made during elementary operations, the sequence numbers of which precede the current one. Red shows graphical elements that were built during the current elementary operation. Some elementary operations are illustrated by two drawings (operations 8 and 37) to facilitate the perception of graphical information (Table 2).

The sequence of operations of designing the garment parts (by drafting method called RDM) is prepared in the similar way. It was illustrated separately for each garment style and part (Tables 3 and 4).

Table 2 Modular synthesis of the design of shoe uppers (selected fragments)

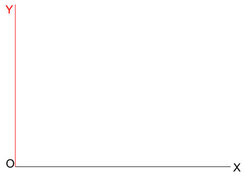
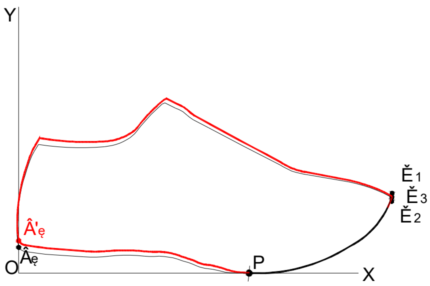
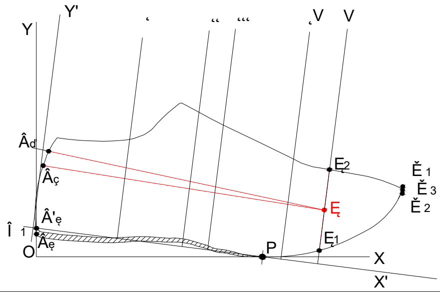
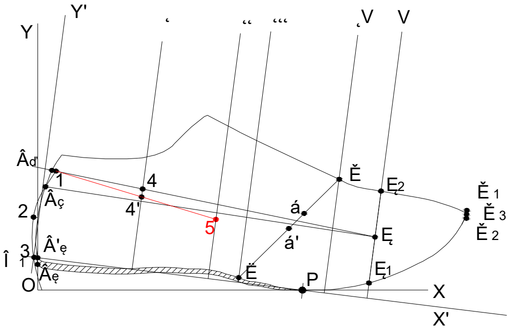
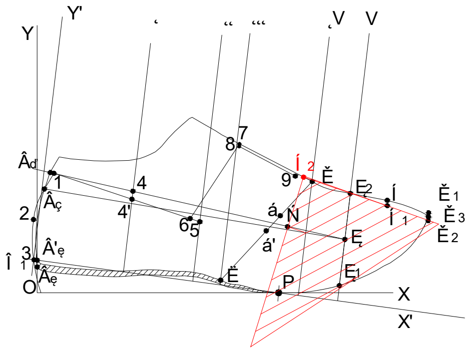
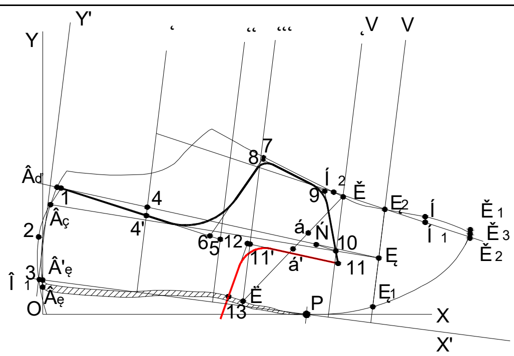
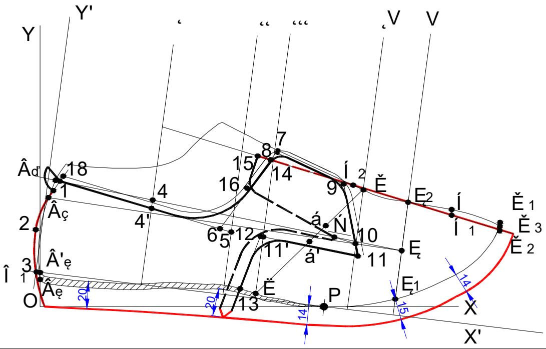
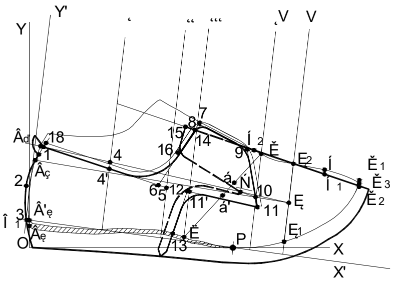
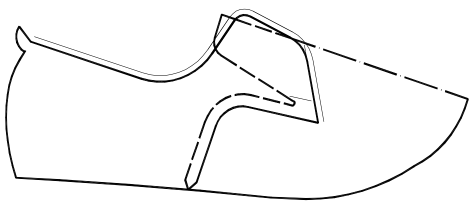
KM	Graphic illustration	KM	Graphic illustration
1		2	
8		19	
29		37	
47		57	
58		-	

Table 3 Modular synthesis of the basic design of a garment (selected fragments)

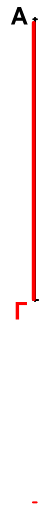
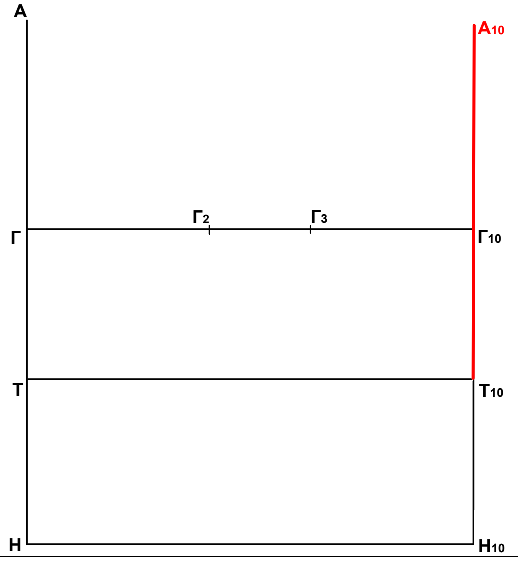
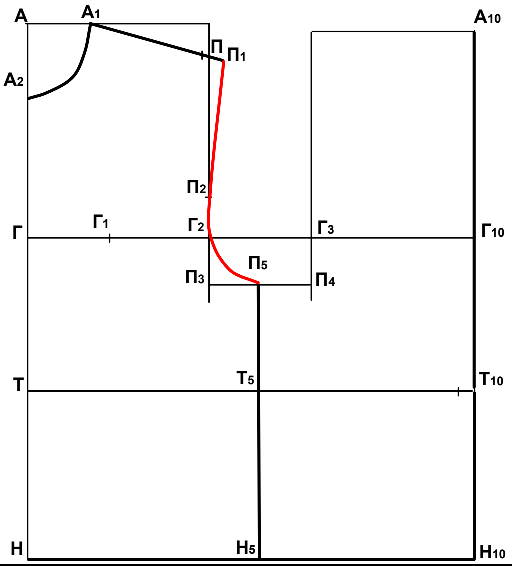
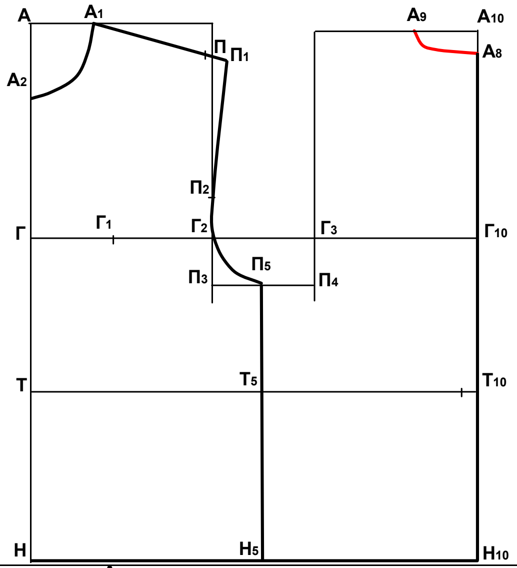
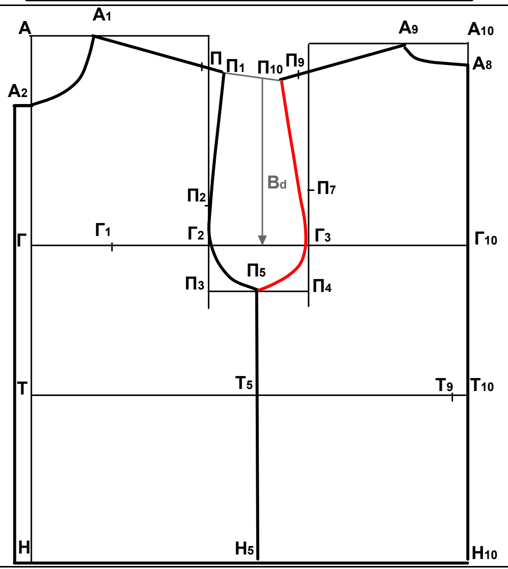
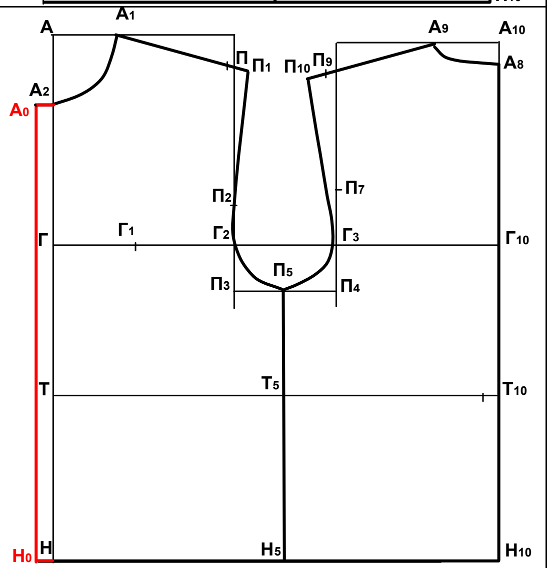
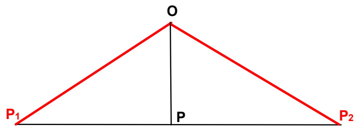
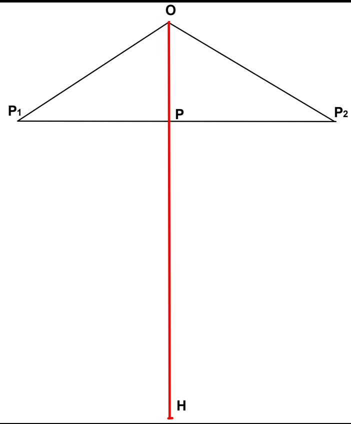
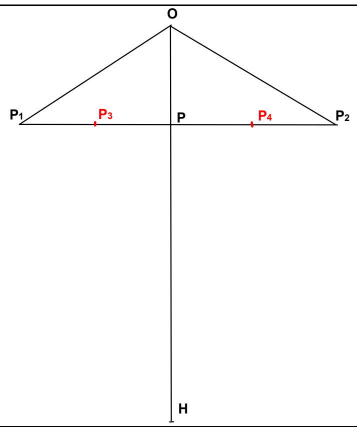
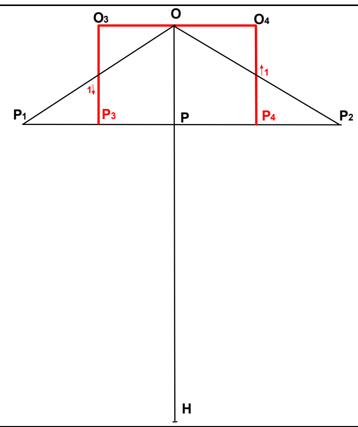
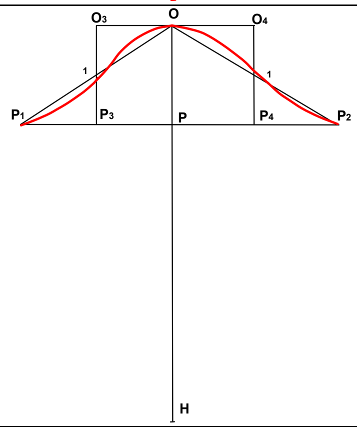
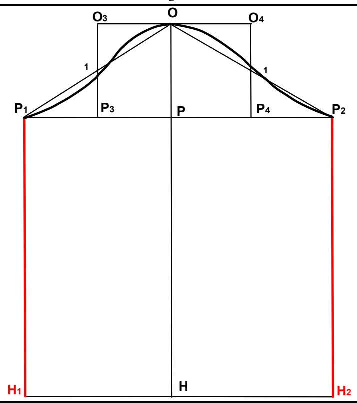
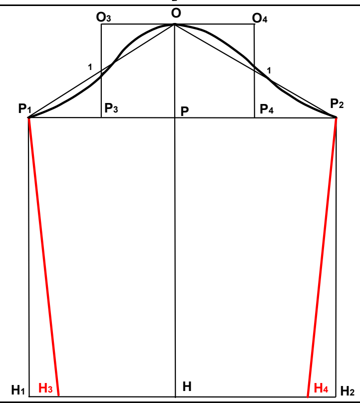
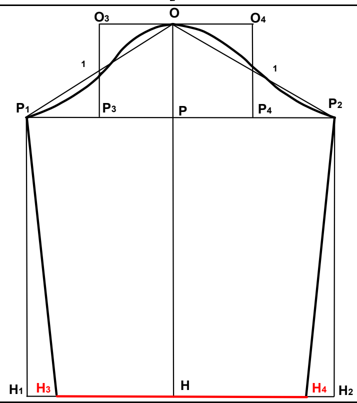
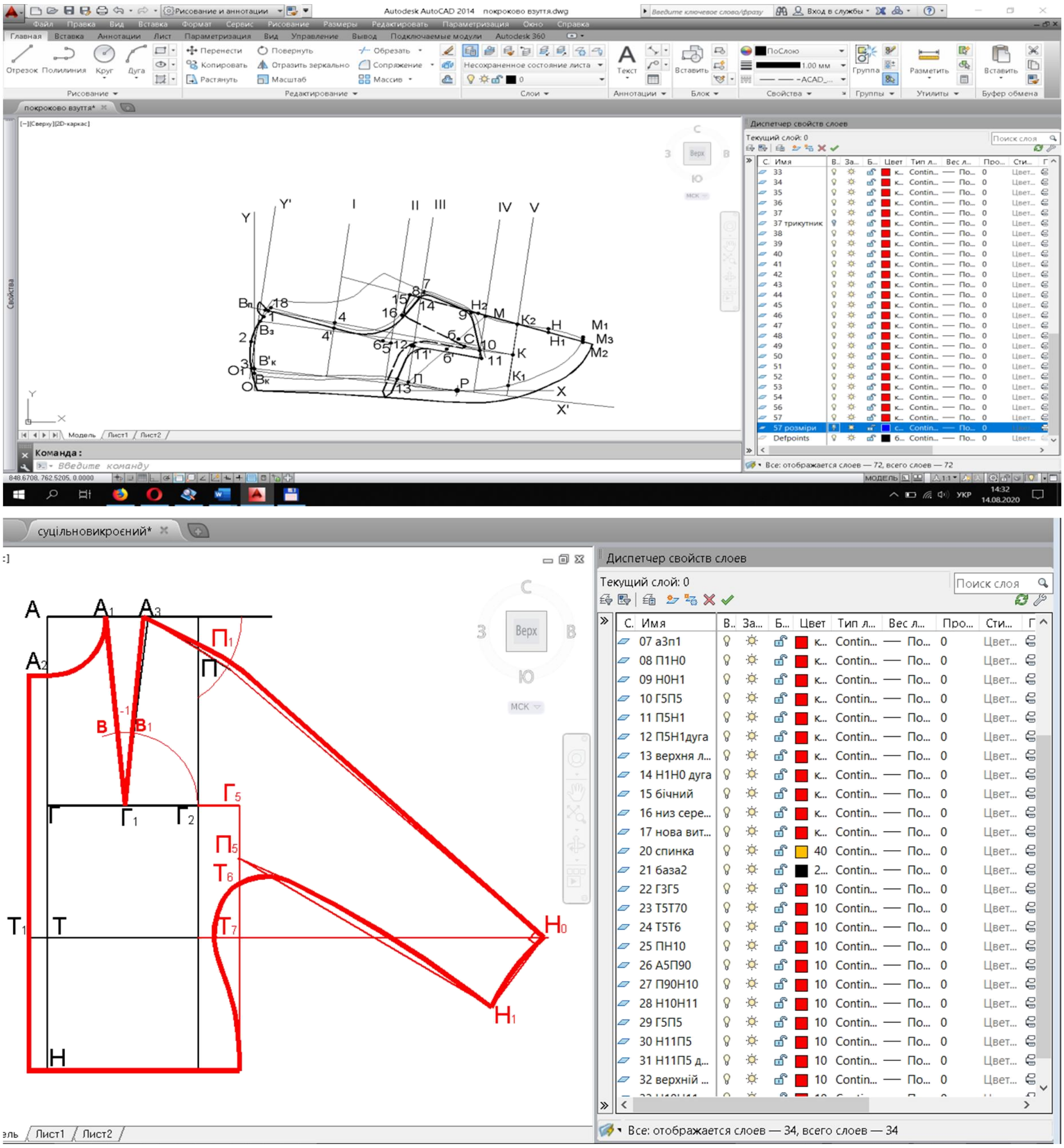
KM	Graphic illustration	KM	Graphic illustration
1		8	
20		23	
28		29	

Table 4 Modular synthesis of the basic design of sleeve

KM	Graphic illustration	KM	Graphic illustration	KM	Graphic illustration
1		2		3	
4		5		6	
7		8		9	

Implementation of step-by-step layering of structural modules on the principle of modular synthesis is performed using the mechanism of switching on and off layers in the field of the graphic editor AutoCAD (USA) Figure 5. The names of the layers correspond to the numbers of elementary operations (structural modules).

Thus, the necessary array of graphic and textual information for the development of the structure of the mobile applications is formed. The use of approaches to modular synthesis of structures allows us to provide the principle of step-by-step construction of shoe and garment parts.



a) b)

Figure 5 The mechanism of layering in the AutoCAD field for the formation of a modular synthesis of the drawing of the pattern design in the development of illustrations of the mobile application: a) shoes design; b) garment pattern design

4.2 Theoretical background of the principle of the applications operation

For the application to work, the concepts of "elementary operation" and "constructive module" are replaced by term "step", a more understandable one for ordinary users. This term defines the names of the applications being developed. In its essence, each step is an elementary operation of calculation and construction of the design of the details, represented by a graphic image of the structural module and a textual and digital description of the actions performed.

The number of graphic illustrations determines the number of Vertical Arrangement blocks selected as the main means of creating individual construction steps in a mobile application for the Android operating system developed in the MIT App Inventor (USA).

"SHOES Step-by-Step"

Each block of Vertical Arrangement contains the name of the elementary operation, a graphical representation of the structural module, the corresponding textual explanation (columns 3-4 of Table 1), as well as the calculation of the segment size (or a given default value) in mm.

The calculation is performed in steps 4, 7, 11-15, 16-17, 19, 22, 23, 43, 49 (Table 1). The content of the steps determines the necessary initial data that must be entered by the student before the calculation, as well as those data that must be entered during the construction.

The initial data include: Lcsp – the length of the conditional scan of the pad (CSP), mm; Nm – shoe size in the metric numbering system. The number of output values determines the number of blocks for entering text information (TextBox): two blocks that must precede the direct command of the calculation / start of construction. The information from these blocks will be used in steps 4, 7, 11 17.

Information to be entered during construction: the values of the segments K1K2 and ML, the distance along the lower contour of the CSP between the base lines II and III, the width of the tongue at the top.

These distances are measured directly on the drawing after performing the previous basic operations. Thus, in steps 19, 22, 43 and 49 you need to place additional blocks of text input.

<u>“RDMK Step-by-Step”</u>

Similar structure of Vertical Arrangement blocks was used to construct the mobile app “RDMK Step-by-Step”. The name RDMK corresponds to the name of the drafting method (that is RDM).

There are 16 steps for the construction of parts of top wear design. The initial data include 14 body measurements for the bodice, 6 body measurements for the sleeve, 4 amounts of eases for the bodice, and 2 amounts of eases for the sleeve (measured in cm).

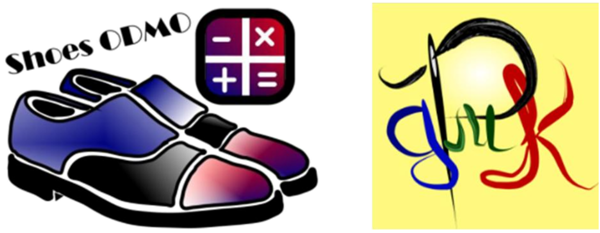
Information to be entered during construction: the values of the segments G1G2 (for the bodice) and L1L3 (for the sleeve). These distances are measured directly on the drawing after performing the previous basic operations (exactly as it was for the shoes design). Thus, additional blocks of text input are placed in steps 7 of sleeve construction and step 1 of the bodice construction.

The application gives users the option of completing the text fields by a shorthand method on the basis of what has been typed before. Otherwise, the fields will be autocompleted by zeros.

4.3 Software implementation of the mobile applications

An application for calculating the original design of shoes according to the method described in [18, 22]. Two application languages are used: Ukrainian and Russian. The applications (Figure 6) are intended for the use:

- by teachers and students of higher education institutions (HEIs) (fields of study: "Light industry technologies"; "Vocational education. Technology of light industry products"; "Fashion industry");
- by the representatives of shoe companies (“SHOES Step-by-Step”) or clothing designers / patternmakers (“RDMK Step-by-Step”);
- by students and teachers of colleges, technical schools of these specialties.



a) b)

Figure 6 Developed applications’ icons: a) “SHOES Step-by-Step”; b) “RDMK Step-by-Step”

To work with the application (“SHOES Step-by-Step”, the user enters the source data and presses the button "START CONSTRUCTION" (Figure 7a). The user is provided with an image of the construction drawing, a sequence of formulas, the names of the segments and their calculated values. Dialog boxes of the developed mobile application are presented in Figure 7. A significant number of stages (steps) of construction led to the need for the operator to go from the main page to any of the steps Figure 7b. In Figures 7c - 7e the steps of construction with a different set of attributes are shown. In Figures 7c - 7d the presence of the unit for calculating the value of the segment is shown. In Figure 7e calculation unit is missing. The block of explanations of features of graphic construction is shown in Figure 7c. In Figure 7g block of explanations is missing. In addition, in Figure 7c block for entering text information is presented.

If the user does not enter the source data, the input fields will be automatically filled with zeros. The developed application “SHOES Step-by-Step” is available for testing at:

https://play.google.com/store/apps/details?id=appinventor.ai_zbirvukladach.Shoes_copy&hl=en.

To work with the application (“RDMK Step-by-Step”), the user chooses style of the garment to be designed. The app allows calculating the parameters of garments with set-in sleeves and owlman style garment. The construction of owlman style may be performed only after completing computing the parameters of the basic bodice design (set-in sleeve).

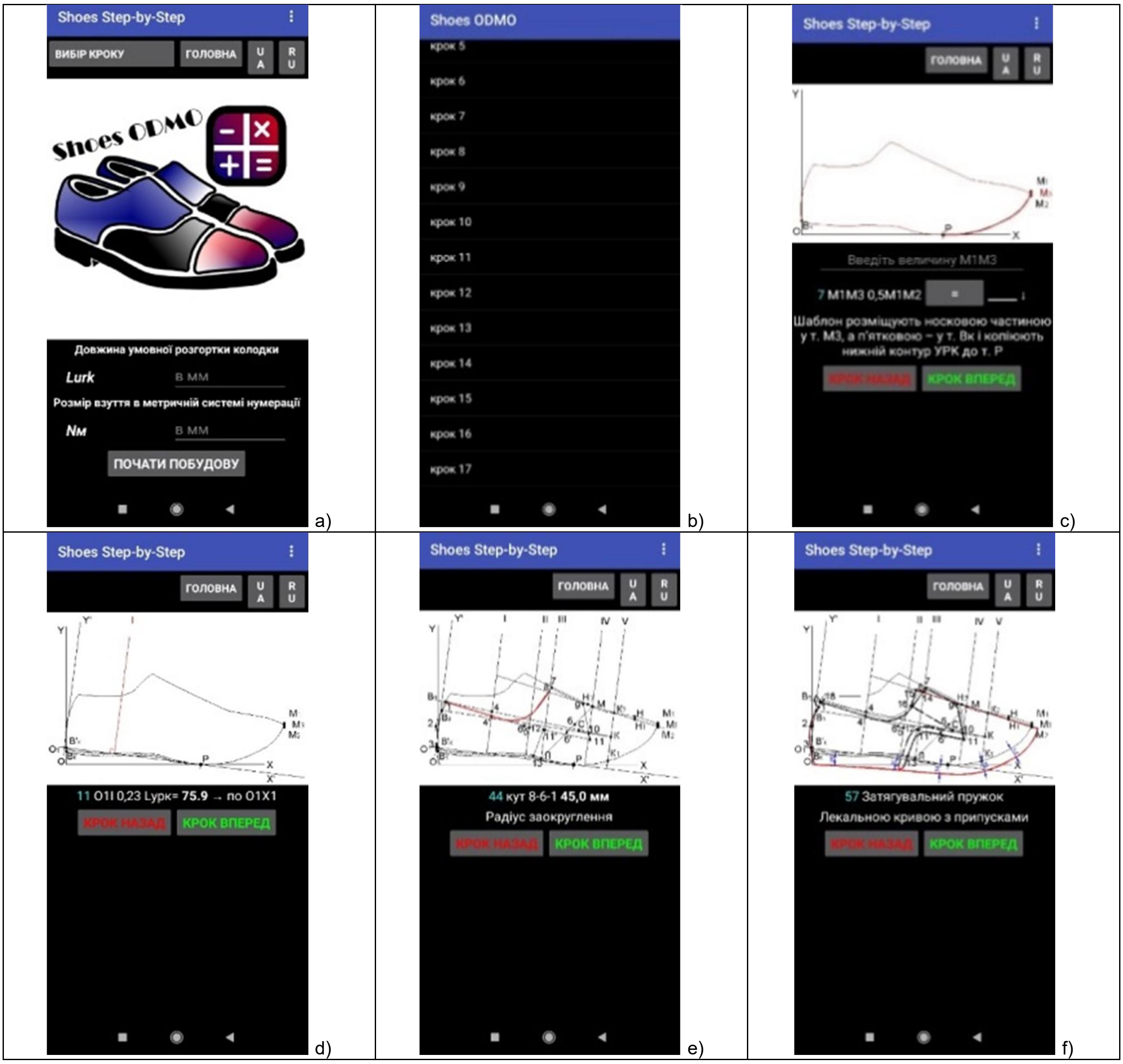


Figure 7 Dialog boxes for working with a mobile application "SHOES Step-by-Step": a) main page; b) choice of construction step; c) step 7; d) step 11; e) step 44; f) step 57

After that, the user chooses "BODICE" or "SLEEVE" button (Figure 8a) and enters the source data and presses the button "START CONSTRUCTION" (Figure 8b). The user is provided with an image of the construction drawing, a sequence of formulas, the names of the segments and their calculated values (Figure 8c). Dialog boxes of the developed mobile application are presented in Figure 8. A number of steps of construction led to the need for the operator to go from the main page to any of the steps in the similar way as it was shown for the application "SHOES Step-by-Step".

The developed application "RDMK step-by-step" is available for testing at: https://play.google.com/store/apps/details?id=appinventor.ai_zbirvukladach.RDMK.

4.4 Testing and evaluation of the developed application

The semantic differential method described in [23] was used to evaluate the developed applications. At the first stage of using this method, pairs of words with opposite meanings are formed, which form a semantic differential. Each pair of Kansei words is a bipolar pair for a separate attribute of the developed application: speed, accuracy, complexity, convenience, relevance (needs). The scales of the semantic differential for each attribute of the mobile application were represented as bipolar pairs expressed by adjectives or adverbs. The scales are presented in the form of horizontal rulers in the questionnaire.

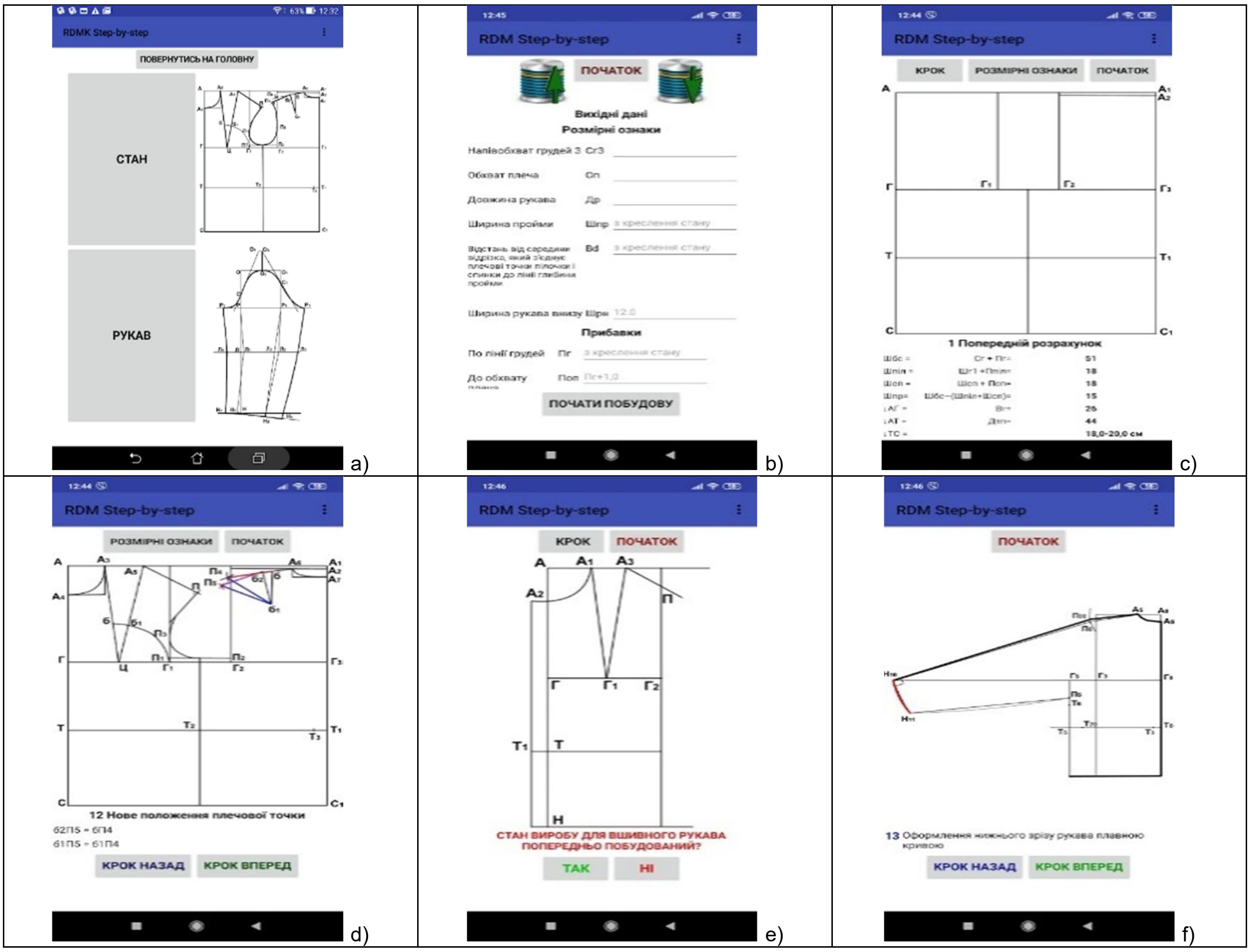


Figure 8: Dialog boxes for working with a mobile application “RDMK Step-by-Step”: a) main page; b) input data; c) step 1 12 (basic design, set-in sleeve); d) step 12 (basic design, set-in sleeve); e) step 1 (owlman style); f) step 13 (owlman style)

Each scale has seven gradations of values, which are expressed in numerical form (-3, -2, -1, 0, +1, +2, +3) Figure 9.

	-3	-2	-1	0	1	2	3	
slow								quick
complicate								simply
inaccurate								accurate
user-unfriendly interface								user-friendly interface
unnecessary								necessary

Figure 9 Semantic differential scales used for the survey

For ease of representation of Kansei words, all bipolar pairs were encoded with the first letters of words, which is common practice: SQ (Slow-Quick); CS (Complicated-Simple); AI (Accurate-Inaccurate); FU (User-Friendly interface – User-Unfriendly interface); NU (Necessary-Unnecessary).

At the next stage of the study, the applications were tested by experts and evaluated using a developed questionnaire. The first expert group consisted of 10 representatives of the footwear industry (students, teachers, representatives of the real sector of the economy) and 10 representatives of related specialties. The first group evaluated the app “SHOES Step-by-Step”. The second one consisted of 52 students, and 33 teachers, clothing designers, and patternmakers. The second group evaluated the app “RDMK Step-by-Step”.

As a result of the surveys, psychographic profiles of the developed mobile applications were obtained (Figures 10a-c). The profiles display the average values of the evaluation coefficients for each pair of Kansei words. As the coefficients correspond to the positive values of Kansei words, the results of the survey indicate that the experts approved the mobile application "SHOES Step-by-Step".

As it can be seen from Figure 10 experts working directly in the field of footwear production rated the application lower than specialists in related fields Figures 10a-b. This is due to the fact that experts pay considerable attention to the quality of the method of designing shoe parts, rather than the characteristics of the mobile application.

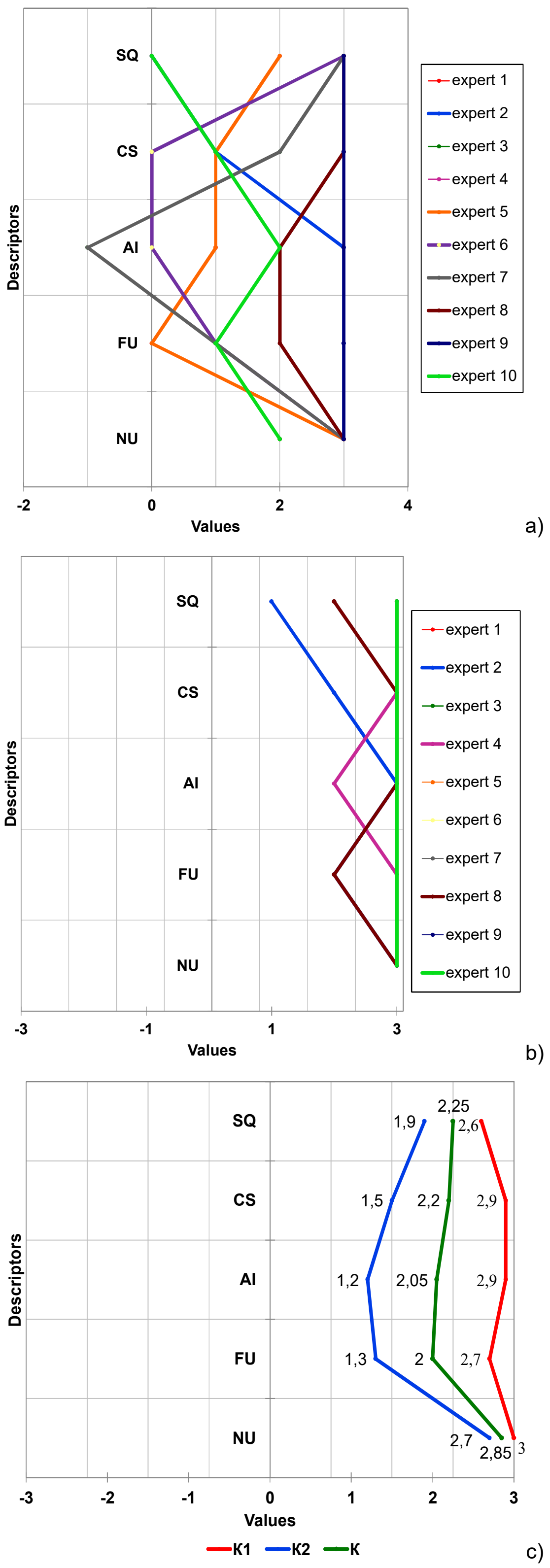


Figure 10 Psychographic profiles of the mobile application "SHOES Step-by-Step": a) expert group of 10 representatives of the footwear industry (students, teachers, representatives of the real sector of the economy) (group K1); b) expert group of 10 representatives of related specialties (group K2); c) the average values of the evaluation coefficients of the two expert groups (K)

At the same time, representatives of related specialties express their opinion more from the standpoint of beginners who assess the quality of the software product itself, through which training in shoe design takes place. However, a general tendency to a positive assessment persists in both groups Figure 10c.

As for the assessment of the mobile app “RDMK Step-by-Step”, the results of it are shown in the Figure 11.

As one can see from the Figure 11, the application is assessed mostly with marks related to positive meaning of Kansei Words (Figure 9). The average values of the evaluation coefficients of the two expert groups form psychographic profiles that have clearly identical form though experts of group K2 showed much more appreciation of the app.

5 DISCUSSION OF TEST RESULTS OF THE DEVELOPED MOBILE APPLICATIONS

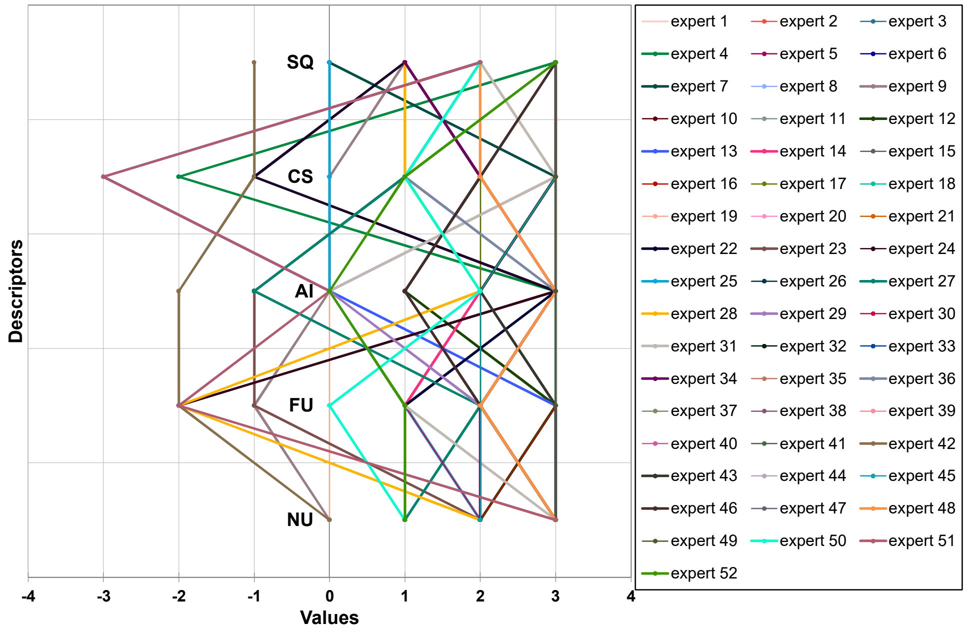
5.1 “SHOES Step-by-Step”

The positive assessment of the developed application "SHOES Step-by-Step" (Figure 10) is confirmed by the opinion of users from among the specialists of the footwear industry. The results of the survey showed that 90% of respondents were in favor of the use of mobile technologies in the process of calculating the shoes details. At the same time, 95% of experts preferred the tabular form of presentation of the method of parts construction (Table 1).

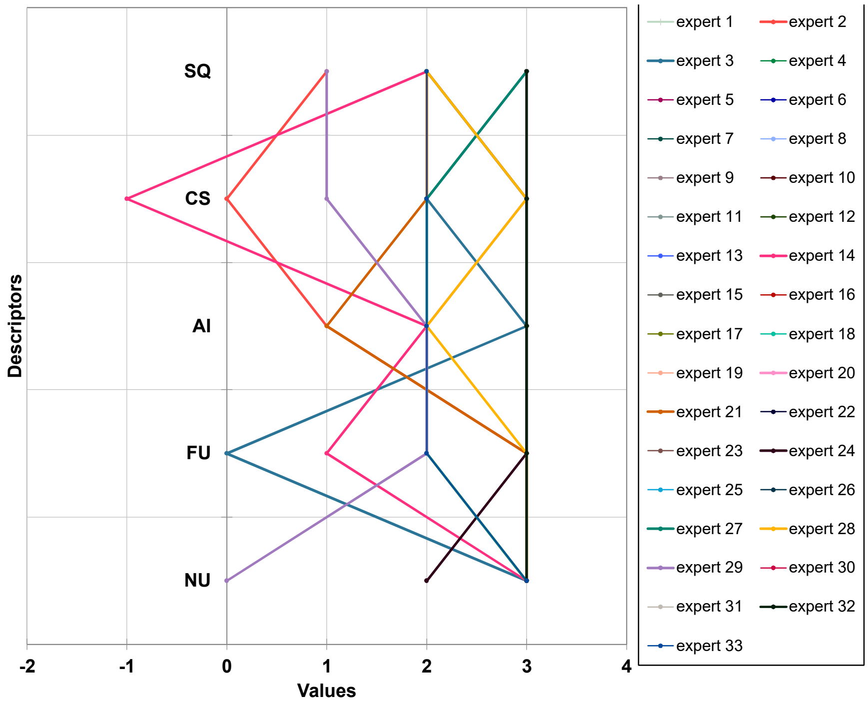
The structure of the proposed method of calculation and construction of shoe parts is radically different from the solutions known in the field [22–24], as none of them uses mobile technology. A known solution from a related field, namely a mobile application for calculating the parameters of the basic design of shoulder clothing [18, 19], is not accompanied by step-by-step illustrations and explanations.

The results of this work can be extended to all methods of designing shoe parts, which are based on calculation and graphic methods of construction. However, currently the application is used only for one specific technique. The calculation is performed only in millimeters. To use the application, the user must have at least a superficial knowledge of specialized terminology: conditional scan of the pad, the metric numbering system of shoe sizes, the names of the details of the shoe upper, and so on.

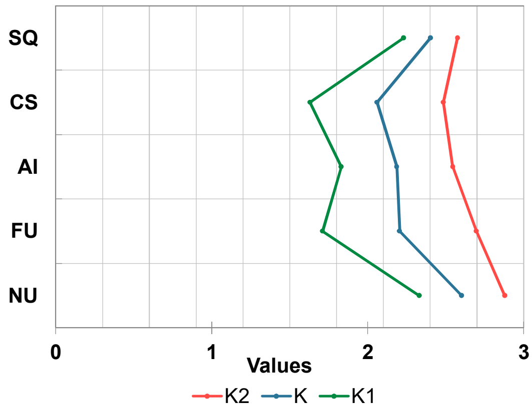
As one can see from the Figure 11, the application is assessed mostly with marks related to positive meaning of Kansei Words (Figure 9). The average values of the evaluation coefficients of the two expert groups form psychographic profiles that have clearly identical form though experts of group K2 showed much more appreciation of the app.



a)



b)



c)

Figure 11 Psychographic profiles of the mobile application "RDMK Step-by-Step": a) expert group of 52 students (group K1); b) expert group of 33 teachers (group K2); c) the average values of the evaluation coefficients of the two expert groups (K)

This solution of the application provides adequate and accurate construction of the structure only if the input data is entered correctly. The calculation blocks do not contain operators for checking the entered data and the obtained results. Adding such an operator would ensure the accuracy of the constructed structure, and not just error-free reproduction of the sequence of actions.

After successful testing of the application in higher educational institutions, it is advisable to ensure its operation in English. In addition, it is necessary to add the ability to perform calculations of the parameters of the details of the bottom of the shoe, as well as the details of the lining, back, toe, etc. Such functions are easily implemented using the above sequence of actions. The description of the modular synthesis is ensuring reproductivity of the results of study.

The development of this study is to create an algorithm not only for calculation, as in this case, but for the automated construction of patterns of shoe parts. Such an algorithm would allow the formation of files with patterns that are calculated and built to the size of the direct user of the application. The implementation of the construction mechanism should be combined with the results of 3D-scans of the foot using a specialized application to obtain accurate source data. Today, the technology is being actively developed in many works [14-16], but the results of scans still cannot be used to create a conditional scan of the pad. Their results are mainly used only to determine the size of shoes.

6 DISCUSSION OF TEST RESULTS OF THE DEVELOPED MOBILE APPLICATIONS

6.1 "SHOES Step-by-Step"

The positive assessment of the developed application "SHOES Step-by-Step" (Figure 10) is confirmed by the opinion of users from among the specialists of the footwear industry. The results of the survey showed that 90% of respondents were in favor of the use of mobile technologies in the process of calculating the shoes details. At the same time, 95% of experts preferred the tabular form of presentation of the method of parts construction (Table 1).

The structure of the proposed method of calculation and construction of shoe parts is radically different from the solutions known in the field [22–24], as none of them uses mobile technology. A known solution from a related field, namely a mobile application for calculating the parameters of the basic design of shoulder clothing [18, 19], is not accompanied by step-by-step illustrations and explanations.

The results of this work can be extended to all methods of designing shoe parts, which are based on calculation and graphic methods of construction. However, currently the application is used only for one specific technique. The calculation is performed only in millimeters. To use the application, the user must have at least a superficial knowledge of specialized terminology: conditional scan of the pad, the metric numbering system of shoe sizes, the names of the details of the shoe upper, and so on.

This solution of the application provides adequate and accurate construction of the structure only if the input data is entered correctly. The calculation blocks do not contain operators for checking the entered data and the obtained results. Adding such an operator would ensure the accuracy of the constructed structure, and not just error-free reproduction of the sequence of actions.

After successful testing of the application in higher educational institutions, it is advisable to ensure its operation in English. In addition, it is necessary to add the ability to perform calculations of the parameters of the details of the bottom of the shoe, as well as the details of the lining, back, toe, etc. Such functions are easily implemented using the above sequence of actions. The description of the modular synthesis is ensuring reproductivity of the results of study.

The development of this study is to create an algorithm not only for calculation, as in this case, but for the automated construction of patterns of shoe parts. Such an algorithm would allow the formation of files with patterns that are calculated and built to the size of the direct user of the application. The implementation of the construction mechanism should be combined with the results of 3D-scans of the foot using a specialized application to obtain accurate source data. Today, the technology is being actively developed in many works [14-16], but the results of scans still cannot be used to create a conditional scan of the pad. Their results are mainly used only to determine the size of shoes.

6.2 "RDMK Step-by-Step"

Most of the concerns expressed for the application "SHOES Step-by-Step" are to be applied to the app "RDMK Step-by-Step". That is due to the similarity of the applications designs as well as methods of garment and shoes construction.

In addition, the automated construction of patterns using mobile applications has not been implemented yet neither in apparel design nor in footwear industry. This is due to the significant variety of sizes, shapes, models and patterns of parts. Technologies of this kind require the use of artificial intelligence and machine learning systems.

7 CONCLUSIONS

According to the results of the review of mobile applications, which are related to footwear industry and presented on the digital distribution platforms Google Play and App Store, it was found that all of them can be divided into 16 categories. The most numerous are groups of applications, which are actually catalogs of ideas and applications of online shoe stores (32.02%). It was found that the absolute value of each of the categories of mobile applications for Android exceeds the value of the corresponding category of applications for iOS. This result corresponds to the general distribution of the number of users of devices with the specified operating systems (Android – 74.25%, iOS – 25.15%). No applications for calculating the design parameters of shoe parts were found on any of the platforms.

It was confirmed that there are no enough tools on the mobile apps market to provide clothing designers with ability to calculate the parameters of the clothing blocks and to learn the pattern drafting technique simultaneously.

The necessary array of graphic and textual information for the development of the structure of the mobile applications is formed in the form of a system of structural modules of shoe uppers. Each structural module is illustrated with a separate drawing, which allows you to clearly distinguish between individual construction steps.

On the basis of the systematized initial information the means for creation of separate steps of construction in the mobile application for the Android operating system – the Vertical Arrangement block is chosen. Ensuring the principle of step-by-step construction of shoe and garments parts is achieved through the use of modular synthesis of structures.

The novelty of the current study lays in using the modular synthesis as a description of any step-by-step construction. The same description and way to construct the pattern with help of a mobile app might be used for any pattern draft technique, even for those lay beyond the apparel or footwear design.

Software implementation of the mobile applications, performed in the field of visual programming, allows the use of mobile technologies in the process of designing shoes and garments.

As a result of the evaluation of the mobile applications by the methods of Kansei Engineering, the need for the introduction of mobile technologies during the training of specialists in the footwear and apparel industries was revealed. This need is justified by the positive values of the average evaluation coefficients in the psychographic profiles: 2.25/2.60 (quick); 2.2/2.2 (simple); 2.05/2.19 (accurate); 2/2.06 (convenient); 2.85/2.4 (necessary).

The mobile applications developed during the current study are available at Google Play. Thus, the results of the study might be used in a practical way by both industries and education representatives.

8 REFERENCES

1. Kim Y., Smith D.: Pedagogical and technological augmentation of mobile learning for young children interactive learning environments, Interactive Learning Environments 25(1), 2017, pp. 4-16, https://doi.org/10.1080/10494820.2015.1087411
2. Zaranis N., Kalogiannakis M., Papadakis S.: Using mobile devices for teaching realistic mathematics in kindergarten education, Creative Education 4(7), 2013, pp. 1-10, http://dx.doi.org/10.4236/ce.2013.47A1001
3. Mackaya B.J., Andersona J., Hardingb T.: Mobile technology in clinical teaching, Nurse Education in Practice 22, 2017, pp. 1-6, https://doi.org/10.1016/j.nepr.2016.11.001
4. Lumsden C.J., Byrne-Davis L. M.Th., Mooney J.S., Sandars J.: Using mobile devices for teaching and learning in clinical medicine, Archives of Disease in Childhood - Education and Practice 100(5), 2015, pp. 244-251, http://dx.doi.org/10.1136/archdischild-2014-306620
5. Rosell-Aguilar F.: A taxonomy and framework for evaluating language learning mobile applications, Calico Journal 34(2), 2017, pp. 243-258, https://doi.org/10.1558/cj.27623
6. Pereira C.H., Terra R.: A mobile app for teaching formal languages and automata, Computer Applications in Engineering Education, 2018, https://doi.org/10.1002/cae.21944
7. Khaddage F., Lattemann C.: iTeach We Learn Via Mobile Apps "a Case Study in a Business Course", In R. McBride & M. Searson (Eds.), Proceedings of SITE 2013-Society for Information Technology & Teacher Education International Conference, pp. 3225–3233. New Orleans, Louisiana, United States: Association for the Advancement of Computing in Education, Retrieved June 19, 2020 from https://www.learntechlib.org/primary/p/48591/
8. Mouzaa Ch., Barrett-Greenlyb T.: Bridging the app gap: An examination of a professional development initiative on mobile learning in urban schools, Computer & Education 88, 2015, pp. 1-14, https://doi.org/10.1016/j.compedu.2015.04.009
9. Shraim Kh., Crompton H.: Perceptions of using smart mobile devices in higher education teaching: A case study from Palestine, Contemporary Educational Technology 6(4), 2015, pp. 301-318, https://www.researchgate.net/publication/283214572_Perceptions_of_Using_Smart_Mobile_Devices_in_Higher_Education_Teaching_A_Case_Study_from_Palestine
10. Koshevko J., Kushevskiy N.: Design of energy-saving technology of shaping and fixing the shape of headdresses parts, Eastern-European Journal of Enterprise Technologies 3/6(81), 2016, pp. 16-25, https://doi.org/10.15587/1729-4061.2016.71242

11. Thomas R.L., Fellowes M.D.E.: Effectiveness of mobile apps in teaching field-based identification skills, Journal of Biological Education 51(2), 2017, pp. 136-143, https://doi.org/10.1080/00219266.2016.1177573
12. Chandekar T., Chouhan R., Gaikwad R., Gosavi H., Darade S.A.: Implementation of obstacle detection and navigation system for visually impaired using smart shoes, International Research Journal of Engineering and Technology (IRJET) 4(4), 2017, pp. 2125-2129, https://www.irjet.net/archives/V4/i4/IRJET-V4I4444.pdf
13. Deshmukh G., Gawade V., Godse V., Londhe N., Gawari D.: Smart navigational shoes for bikers/cyclists, International Journal of Computer Applications 180(41), 2018, pp. 6-10, https://doi.org/10.5120/ijca2018917062
14. Parrilla E., Ballester A., Solves-Camallonga C., Nacher B., Puigcerver S., Uriel J., Pierola A., Gonzalez J.C., Alemany S.: Low-cost 3D foot scanner using a mobile app, Footwear Science 7(1), 2015, pp. 26-28, https://doi.org/10.1080/19424280.2015.1038308
15. Cheung K.Y., Reth D., Song C., Li Z., Li Q., Xu W.: BigFoot: A Mobile Solution toward Foot Parameters Extraction, IEEE 16th International Conference on Wearable and Implantable Body Sensor Networks (BSN), Chicago, IL, USA, 2019, pp. 1-4, https://doi.org/10.1109/BSN.2019.8771077
16. Alfaro-Santafé J., Gómez-Bernal A., Lanuza-Cerzócimo C., Alfaro-Santafé J.V., Pérez-Morcillo A., Almenar-Arasanz A.J.: Three-axis measurements with a novel system for 3D plantar foot scanning: iPhone X, Footwear Science 12(2), 2020, pp. 123-131, https://doi.org/10.1080/19424280.2020.1734867
17. Borisenko D.: Use of mobile applications for developing design products in training of future experts in design, Information Technologies and Learning Tools 68(6), 2018, pp. 47-63, https://doi.org/10.33407/itlt.v68i6.2224 (in Ukrainian)
18. 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. 24-34, http://scinn.org.ua/sites/default/files/pdf/2019/N3/Zhylenko.pdf
19. Zakharkevich O., Poluchovich I., Kuleshova S., Koshevko J., Shvets G., Shvets A.: "CloStyler" - mobile application to calculate the parameters of clothing blocks, IOP Conference Series: Materials Science and Engineering, 1031, 2021, 012031, https://doi.org/10.1088/1757-899X/1031/1/012031
20. Liang Y., Liu C.: Comparison of consumers' acceptance of online apparel mass customization across web and mobile channels, Journal of Global Fashion Marketing 10(3), 2019, pp. 228-245, DOI: 10.1080/20932685.2019.1619469
21. SangHee A.: Effects of mobile shopping tendencies and information search on the shopping mall satisfaction and repurchase intention: focusing on fashion clothing, Journal of Digital Convergence, 18(8), 2020, pp. 469-478, https://www.koreascience.or.kr/article/JAKO202024852036088.pdf
22. Nadopta T., Liba V.: Clarification of the position of the base lines for the design of shoe uppers based on anthropometric studies of the adult population of Ukraine, Bulletin of KNUTD 2(52), 2010, pp. 85-89, https://er.knutd.edu.ua/handle/123456789/6367 (in Ukrainian)
23. Nadopta T.: Analysis of methods for designing shoe uppers, Bulletin of Khmelnytsky National University, 2(3), 2007, pp. 112-116, (in Ukrainian)
http://journals.khnu.km.ua/vestnik/zmisthtmt.htm
24. Begnyak B.: Workshop on designing and designing shoes: a textbook, Khmelnytsky: KhNU, 251, 2013 (in Ukrainian)
25. Slavinskaya A.: Fundamentals of modular clothing design, Monograph, Khmelnytsky, KhNU 167, 2007 (in Ukrainian)
26. Slavinska A.: Methods of typical clothing design, Textbook, Khmelnytsky: KhNU, 159, 2008 (in Ukrainian)
27. Kuleshova S.G., Zakharkevich O.V., Koshevko J.V., Ditkovska O.A.: Development of expert system based on Kansei Engineering to support clothing design process, Vlakna a textil (Fibres and Textiles) 24(3), 2017, pp. 30-41, http://vat.ft.tul.cz/Archive/VaT_2017_3.pd

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