VLÁKNA a TEXTIL

FIBRES AND TEXTILES

3

Volume 27.
September
2020

STU FCHPT

TECHNICAL UNIVERSITY OF LIBEREC
Faculty of Textile Engineering

Trenčianska univerzita Alexandra Dubčeka v Trenčíne
Fakulta priemyselných technológií v Púchove

VÚCHV

VÚTCH CHEMITEX

Spoločnosť priemyselnej chémie ZSVTS

CHEMOSVIT FIBROCHEM

Indexed in:
SCOPUS
Chemical Abstracts
World Textiles

ISSN 1335-0617
print version

ISSN 2585-8890
online version

Fibres and Textiles
Vlákna a textil

Published by

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

Vydáva

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

***Editor in chief** (Šéfredaktor)*: Anna Ujhelyiová

***Executive editor** (Výkonný redaktor)*: Marcela Hricová

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

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

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

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

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

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

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

***Typeset and printing** (Sadzba a tlač)*

FOART, s.r.o., Bratislava

Journal is published 4x per year
Subscription 60 EUR

Časopis vychádza 4x ročne
Ročné predplatné 60 EUR

Evidenčné číslo MKCR SR Bratislava EV 4006/10

IČO vydavateľa 00 397 687

Fibres and Textiles (3) 2020
Vlákna a textil (3) 2020
September 2020

Content

ASSESSING THE IMPACT OF SOCIAL MEDIA IN THE CONSUMER TREND TOWARDS SUSTAINABLE CLOTHING

Hana Algahni and Maha Abdullah Al-Dabbagh

King Abdulaziz University, Jeddah, Kingdom of Saudi Arabia
H1431j@gmail.com; mdabbaghs@gmail.com

Abstract: *There is a growing shift in demand towards sustainability in the clothing industry due to the negative impact the sector has on the environment with its push for excessive consumption of clothing, as well as the pace of change in clothing trends and fashion. Many factors have contributed to this, including the increased speed of production processes which have arisen as a response to higher demand for new products and the use of social media as a platform for promoting them. Relatively little is known about the harmful effects which clothing factories have on the environment, or the poor working conditions that employees have to endure. However, an increasing awareness of environmental issues and the consequences of excessive consumption in the fashion industry have begun a trend of new and innovative ways of consuming and producing fashion. It is encouraging that these new methods have helped reduce the negative impact on the environment and societies in general. Building on this cognizance, this study explores the possibility of channeling consumers' preferences towards sustainable clothing by highlighting and promoting alternatives through the use of social media. The study highlights the existing awareness Saudi consumers have regarding the concept of sustainable clothing, as well as the key factors affecting consumers' purchasing behavior. The study, using multiple focus groups, has identified the key deterrents to purchasing sustainable clothing including high price, lack of aesthetic design and unavailability of products at consumers' nearby stores. The study observed that consumers demand sustainable clothes that are attractively designed, of good quality and priced reasonably. In addition, consumers have stressed the need to be sufficiently informed about such clothes on social media.*

Keywords: *Sustainability, consumers, preserving the environment, social media.*

1 INTRODUCTION

Today, the world has become increasingly conscious of the need to protect the environment by using methods and techniques that reduce the environmental risks which threaten the survival of humanity and the decrease living standards, such as air and water pollution, global warming and other environmental risks. The fashion industry is a huge global concern and is principally one of the heaviest polluters in the world after oil. It is responsible for significant environmental problems associated with the production process due to its wide-scale use of toxic chemicals, which can adversely impact the natural environment and human health [1]. Further environmental and social problems have been caused by the rapid shift to the production of low-cost textiles and clothing in Asian and Middle Eastern countries. Additionally, cultivation of fiber crops (especially cotton) has increased significantly and has been subsequently accompanied by excessive production of pesticides and depletion of energy and natural resources. Meanwhile, the weaving of fabrics (textile production) requires using harmful chemicals throughout various stages of the production and manufacturing processes, including dyeing, bleaching and finishing.

Tracing the more recent origins of this industry, the 1900s can be said to have heralded the beginning of the 'fast fashion' era. During this period, companies started to expand the scale of products in response to changes in market demands and shopping behavior [2] which saw new styles of fashion being introduced approximately every week. This frequent introduction of new merchandise and speedy delivery of products was referred to as fast fashion, a name derived from "fast food" [3].

In terms of its delineation, the World Committee on Environment and Development (WCED) defines sustainability as development that meets the needs of the present generation without compromising the ability of future generations to meet their needs. However, it is worth noting that the majority of sustainability definitions typically include the triple bottom line concept, which incorporates the environment, people and the economy [4]. In order for this relationship to become a reality, consumers and companies must shoulder the burden by ensuring efficient consumption of natural resources, prevention of pollution and protection of the environment for future generations [5]. Governments, companies, corporates and individuals must collectively work together to achieve sustainable development for the economy and environment [5]. Companies have realized that fast fashion, while highly profitable, also raises considerable ethical issues [6]. Among those issues related to the fashion industry, there are a number of key environmental concerns such as: pollution of water and air, as a result of the use of toxic chemicals in the manufacture and production of clothing, and its serious impact on the health and safety of workers, in addition to 'fast fashion' products of poor quality which affect wear and longevity, thus increasing the amount of waste produced. The fashion industry is also linked with social issues, where many garment factory employees in developing countries work in highly polluted environments for more than 16-18 hours a day, while receiving low wages that do not meet basic family needs such as food, clothing, housing and medical care [7]. In this sense, many researchers, civil societies and individuals have become more conscious of the need to raise public awareness on ethical issues associated with fast fashion through magazines, journals and social media and to bring the public's attention to the value of sustainable fashion. However, in order for companies to produce sustainable fashion, consumers' behavior must be changed by means of channeling their preferences to products of sustainable fashion.

2 STUDY PROBLEM

The study problem can be summarized as follows:

1. Are consumers aware of the importance of sustainable fashion and its impact on the environment?
2. To what extent are Saudi consumers aware of fast fashion? How does fast fashion impact the environment?
3. Can social media be utilized to channel consumer preferences toward sustainable fashions?
4. Are there any obstacles impeding the expansion of sustainable fashion?

3 METHODOLOGY

The researcher used the descriptive method due to its consistency with the objectives of the study, which are to understand consumer opinion on the concept of sustainable clothes, and its role in preserving the environment. This has been done by examining the awareness of Saudi consumers toward sustainable clothes and their impact on the environment, as well as their awareness of fast fashion and its potential harm to the environment. The study has also sought to examine the potential of social media in channeling consumers' preferences towards sustainable clothing. Therefore, it was imperative to solicit the opinions of sample respondents by means of surveys, which were collated and analyzed in order to answer the study questions accordingly. From the data gathered, 506 responses were analyzed using the SPSS software. Surveys were verified before the testing process. Six focus groups were established to collect data on key obstacles preventing the purchase of sustainable clothes. A group of Saudi female respondents, aged 21-44 of various social and economic backgrounds, were targeted. The total number of female respondents, used in this study, was 34.

4 STUDY FINDINGS

Based on the objectives of the study, which were to ascertain the level of awareness, through social media, of the sample of Saudi consumers as it relates to sustainable clothing, the following findings were observed:

The study revealed the existence of limited knowledge among consumers on sustainable fashion and its importance in preserving the environment, with 47.1% of respondents saying they had never heard of the term. This lack of knowledge can be attributed to the fact that the term sustainable fashion and clothes are not widely spread among Saudi consumers, as, “sustainable fashion is a relatively new concept in the textile and apparel industry” [8]. Additionally, only 39.2% of consumers believed that their purchase of bio-based products would indirectly preserve the environment.

Social media channels such as Instagram, Twitter, Snapchat, WhatsApp, Facebook and YouTube play a key role in introducing Saudi consumers to sustainable clothing, as manufacturers are increasingly using these types of online media tools for marketing and advertising their products, due to the popularity of social media (particularly in Saudi Arabia), and its tendency to be used heavily and continuously in the country. In addition, manufacturers rely on social media to identify consumers' preferences, desires and trends, so as to target and improve the quality of their products.

As per the study findings (Figure 1), Instagram was ranked first among the type of social media platforms used by the sample of Saudi consumers with 51.1%, a figure that closely mirrored the findings of Wiberg's study [9]. The latter also revealed that Instagram is one of the most popular social media platforms used to follow brands of fast fashion in Swedish society. Based on this finding, the researcher believes that Instagram should be the main conduit used in attempting to raise consumer awareness on sustainable fashion.

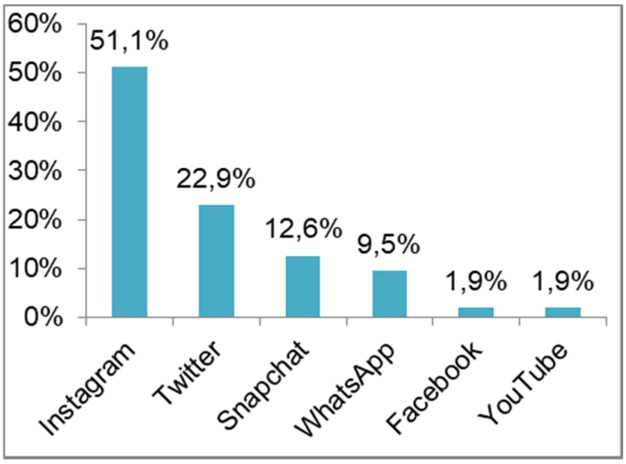


Figure 1 Analysis of sample responses of Saudi consumers highlighting type of social media used most frequently

Despite the importance of social media in introducing sustainable clothes to Saudi consumers, its impact has been relatively weak as the information provided to date has not helped to significantly increase awareness among consumers for sustainable clothes and their economic and environmental significance. Nor has it actively encouraged them to intensively purchase sustainable clothes. As per the results of the survey, 57.9% of Saudi consumers believed that social media had not managed to raise their awareness of the value of sustainable clothes. Additionally, 50.8% of Saudi consumers said that ads circulated through social media had not had the desired effect of tempting them into buying sustainable clothes. It was also noted that 85.4% of Saudi consumers said internet influencers' recommendations on social media had not prompted them to buy sustainable clothes. However, these findings contradict Al-Yaseen's study [10], which used statistic-based evidence to prove the positive impact of social media on consumer purchasing behavior in Jordan, in particular the power of social media based word of mouth by celebrities and friends. Lack of awareness among Saudi consumers with regards to sustainable clothes can be attributed to the nature of social media, in that it is a public and unspecialized medium. Moreover, Saudi consumers have little confidence in the information provided through social media due to the prevalence of false information on various platforms. They also display discernment of the fact that social media platforms are frequently used as tools to promote and market various products, many of which are not necessarily of high quality or value.

97.2% of Saudi consumers are aware of the problem of environmental pollution, which is considered a serious social and economic issue at the world level; yet they do not have sufficient information about the negative impact of the clothing industry on environment and in particular the impact of low-quality fast fashion. As per the survey, 68.9% of consumers were not aware that the clothing industry is one of the heaviest polluters in the world after oil, while only 37.8% of consumers were aware of the fact that fast fashion is made of environment-polluting materials.

Despite the economic, health, and environmental importance of sustainable clothes, they are still not regarded as being highly popular among Saudi consumers. This is due to the many obstacles hindering the spread of such clothing such as its high price, unavailability in nearby markets, and the availability of alternative clothes of lower quality at prices which are affordable to the different social classes.

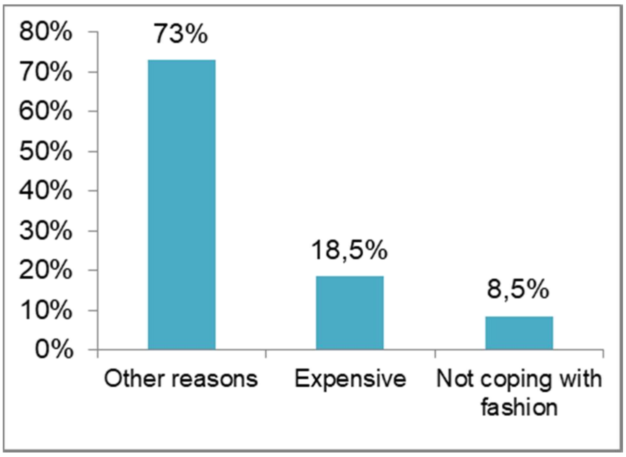


Figure 2 Analysis of Saudi consumers' responses for reasons that have resulted in them from refraining to purchase sustainable clothes

To generate greater demand companies must reduce the price of sustainable clothes, make them more easily available, improve their quality and increase awareness, focusing on emphasizing the health and environmental importance of this type of clothing, as this can help to create a positive narrative and increase consumer demand. To accelerate the sales of newly produced sustainable fashion, the willingness to purchase has to increase. Fashion consumers demand sustainable fashion with appealing design, high quality as well as varied product options [11]. Increased loyalty to trademarks or products is linked to increased consumer demand [12].

In brief, awareness among Saudi consumers of the importance of sustainable clothes and its impact on the environment is still nascent, while social media performs a secondary role in introducing sustainable clothes to consumers. Moreover, online platforms are limited to commercial marketing and advertising of these products. Numerous obstacles prevent the spread of sustainable clothes, including price, unavailability in nearby markets, and availability of alternative clothes of lower quality and at prices affordable to different social classes.

5 FOCUS GROUP FINDINGS

Based on the discussions from the focus groups in this study, the following factors were identified as those which influence consumer purchasing decisions:

- *Price* - This factor is more important than that of design and quality. For example, respondents in the first focus group indicated that "sustainable fashions are expensive so that they cannot buy them". Previous research has shown that a price higher than 10% above consumers' acceptable price range will not affect their purchasing decisions [11]. However, if the price is 25-30% higher than their acceptable price range, it will most likely result in the consumer refraining from making that purchase [13-15]. As sustainable fashion products usually have a higher price than other products, they are most likely to have an impact on purchasing decisions [16]. Previous studies have shown that price and quality are significant features being considered by consumers when making a decision, but priorities can change for some individuals when their surroundings change [17]. However, beliefs and behavior are a result of other factors playing a more important role in determining purchase behavior, which include price, value, trends and brand image [18].
- Most respondents in the focus groups believed that many sustainable clothes lack a sense of modern fashion and said they wanted sustainable products to be aesthetically pleasing and engineered with the attractive designs of the modern fashion lines. The conflict between fashion and environment was discussed by the focus groups and almost all respondents believed that it was difficult to have eco-friendly modern fashion and that therefore sustainable clothing often tends to be non-modern [19].
- *Quality* is an important factor influencing consumer purchasing decisions. All respondents in the focus groups agreed that sustainable fashion is of high quality and lasts for a longer period. A respondent in the fifth group has described sustainable clothes as practical as they are able to more easily withstand the effects of ironing and washing processes.
- Most respondents in the focus groups agreed that more information was needed on sustainable fashion, citing a lack of information as to why most consumers don't buy sustainable fashion. For example, a respondent in the first group mentioned that "there is lack of awareness among consumers that there is a category of clothing that is sustainable and that it has a positive impact on environment". Another respondent in the same group stressed that "many consumers are unaware of the benefits of these costumes". A respondent in the fifth group stated that, "nobody knows about sustainable clothing." Another respondent in the same group also confirmed that "sustainable fashion is not sufficiently promoted."
- Unavailability of sustainable clothes in the markets was cited as one of the main reasons behind weak purchasing in this sector. A respondent confirmed that these types of clothes are generally not available.
- Aspects related to the products are not the only factors influencing consumers purchasing decision; information and external factors such as peer pressure are also important [11]. This is supported by the comments made by a respondent in the fourth focus group who said, "A friend of mine has informed me about sustainable clothes… they are eco-friendly clothes made of natural materials. The main objective is to produce clothes that don't harm the environment." As for her familiarity with organic foods, she maintained, "I receive information about organic food from the social media, especially by social influencers. Journal and academic essays also give me more information".
- The other external factors influencing participants are the ways in which they acquire information on sustainable fashion, which varied widely among all participants. The majority of them are influenced by the various social media channels such as Instagram, Twitter, Snapchat and WhatsApp. One respondent believed that the best way to advertise sustainable clothes would be to hire celebrity brand ambassadors, going on to say that, "Usually, the objectives of ads for certain stores is to attract consumers. It is such a good idea to hire a celebrity brand ambassador to attract people to sustainable clothes".

The findings obtained through the focus groups were consistent with the survey's findings in terms of lack of awareness among Saudi consumers on sustainable clothes and their role in protecting the environment. It was noted that the price factor is more important than that of design and quality. In addition, consumers believe that many sustainable clothes lack the element of attractiveness and say they want sustainable products to be of good quality, aesthetically pleasing and available at affordable prices. Thus, the results of this study are consistent with many other studies in highlighting the types of deterrents that hinder purchasing patterns in sustainable products, such as high price, quality issues, consumers' lack of awareness of value of sustainable products and unavailability of sustainable clothes in nearby markets [20]. The price barrier also impacts consumer purchasing behavior, as the majority of consumers believe sustainable clothes are expensive [7]. Moreover, the lack of information on sustainable clothes, and consumers' lack of understanding of certain marketing methods (i.e. posters) has led to an underestimating of the value of sustainable clothes [21]. The common beliefs that sustainable clothes are neither elegant nor modern, and based on older designs, are among the other factors influencing consumer behavior in this arena [22].

6 REFERENCES

1. Nielsen S.D.: Implementation of Supply Chain Sustainability in the Fashion Industry, IIIEE Master Thesis, 2012
2. Bhardwaj V., Fairhurst A.: Fast fashion: response to changes in the fashion industry, The International Review of Retail, Distribution and Consumer Research 20(1), 2010, pp. 165-173, https://doi.org/10.1080/09593960903498300
3. Byun S.E., Sternquist B.: The antecedents of in-store hoarding: measurement and application in the fast fashion retail environment, The International Review of Retail, Distribution and Consumer Research 18(2), 2008, pp. 133-147, https://doi.org/10.1080/09593960701868241
4. Preuit R.: Fashion and sustainability: increasing knowledge about slow fashion through an educational module, masters theses, Colorado State University, 2016, http://hdl.handle.net/10217/173475
5. McCann-Erickson Woprld Group: Can sustainability sell?, 2007,
6. Aspers P., Skov L.: Encounters in the global fashion business: Afterword, Current Sociology 54(5), 2006, pp. 802-813, https://doi.org/10.1177/0011392106066817
7. Choi T.-M., Cheng T.C.E. (Eds): Sustainable Fashion Supply Chain Management, Switzerland: Springer, 2015, https://doi.org/10.1007/978-3-319-12703-3
8. Pookulangara S., Shephard A.: Slow fashion movement: Understanding consumer perceptions – An exploratory study, Journal of Retailing and Consumer Services 20(2), 2012, pp. 200-206, https://doi.org/10.1016/j.jretconser.2012.12.002
9. Wiberg A.: Seeking loyalty on social media: A quantitative study examining the effects of brand information regarding sustainability efforts on brand loyalty and its antecedents in the fast-fashion industry, student thesis, Linnaeus University, School of Business and Economics, 2018, http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1215008&dswid=7453
10. Al-Yaseen M.F.M.: The Impact of using Social Media on purchasing behavior through the electronic spoken word, Master Thesis, Middle East University, Jordan, 2017
11. Leijon L., Dahlgren M.: Purchasing sustainable fashion: How to accelerate consumers' willingness to act and their actual actions, Student thesis, University of Borås, Faculty of Textiles, Engineering and Business, 2017, http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1144786&dswid=-5179
12. Meppelink B.: "Social networking websites and sustainable consumer practices": : a study of the way in which social networking websites can have a positive effect on sustainable consumer practices, MSc Thesis, Wageningen University, 2013
13. Bratt C.: Consumers' environmental behavior: generalized, sector-based, or compensatory? Environment and Behavior 31(1), 1999, pp. 28-44, https://doi.org/10.1177/00139169921971985
14. Chan T.Y., Wong C.W.Y.: The consumption side of sustainable fashion supply chain: Understanding fashion consumer eco-fashion consumption decision, Journal of Fashion Marketing and Management 16(2), 2012, pp. 193-215, https://doi.org/10.1108/13612021211222824
15. Miller C.: Levi's, Esprit spin new cotton into eco-friendly clothes, Marketing News 26(9), 1992, pp. 11-12
16. Kong H.M., Ko E., Chae H., Mattila P.: Understanding fashion consumers' attitude and behavioral intention toward sustainable fashion products: Focus on sustainable knowledge sources and knowledge types, Journal of Global Fashion Marketing 7(2), 2016, pp. 103-119, https://doi.org/10.1080/20932685.2015.1131435
17. Carlsson F., García J.H., Löfgren Å.: Conformity and the demand for environmental goods, Environmental and Resource Economics 47(3), 2010, pp. 407-421, https://doi.org/10.1007/s10640-010-9385-2
18. McNeill L., Moore R.: Sustainable fashion consumption and the fast fashion conundrum: fashionable consumers and attitudes to sustainability in clothing choice, International Journal of Consumer Studies 39(3), 2015, pp. 212-222, https://doi.org/10.1111/ijcs.12169
19. Solomon M.R., Rabolt N.J.: Consumer Behaviour in Fashion, Pearson Education Ltd. New Jersey, 2007
20. Hira A., Ferrie J.: Fair trade: Three key challenges for reaching the mainstream, Journal of Business Ethics, 63(2), 2006, pp. 107-118, https://doi.org/10.1007/s10551-005-3041-8
21. Cotelle R., Nury L., Terrisse P.: Les freins et leviers au développement économique des boutiques spécialisées en commerce équitable. Cabinet Solidere Conseil, 2011
22. Eder-Hansen J., Kryger J., Morris J., Sisco C., Watson D., Kiørboe N., Burchardi I.: The NICE consumer (Research Summary and Discussion Paper toward a Framework for Sustainable Fashion Consumption in the EU), Copenhagen, Denmark: Danish Fashion Institute, Business for Social Responsibility, 2012

INVESTIGATING THE TECHNOLOGICAL PROCESS OF ADHESION IN THE FABRICATION OF WEARABLE ANTENNAS

Snezhina Andonova[1], Gabriela Atanasova[2] and Nikolay Atanasov[2]

[1]Department of Mechanical Engineering and Technologies, Faculty of Engineering, South-West University "Neofit Rilski", 66 Ivan Mihailov Str., 2700 Blagoevgrad, Bulgaria
[2]Department of Communication and Computer Engineering, Faculty of Engineering, South-West University "Neofit Rilski", 66 Ivan Mihailov Str., 2700 Blagoevgrad, Bulgaria
andonova_sn@swu.bg

Abstract: *The process of designing and creating antennas on textile materials (TM) (built into the clothing) is an extremely interesting and innovative process. In modern conditions, in most cases, the conductive elements of the wearable antennas are made of a special conductive fabric (CF), which is connected to the main TM of the sewing product. The textile materials from which the garments are made are used as substrates for the wearable antennas. The efficiency of the adhesion process between the textile substrate and the conductive fabric is one of the main factors on which the quality of wearable antennas depends. The present work aims to study and analyze the technological features of the adhesion process (between CF and the substrate) in the fabrication of wearable antennas. As a result of the conducted research, dependencies between technological factors of the adhesion process in the fabrication of wearable antennas have been established. The obtained results make it possible to choose effective operating modes according to the priorities of the real work environment.*

Keywords: *process of adhesion, conductive fabric, wearable antenna.*

1 INTRODUCTION

In recent years, textile materials (TM) have been increasingly widely used: non-standard and innovative application. They are used to create a number of sensor systems in the field of health care [1]. TMs are also used as a basis for embedding electronic elements for various purposes. Electronic textile design is also part of the education of high school students' [2]. The application of TM as substrates for wearable antennas [3-7] is also increasingly common.

The process of designing and creating antennas on TM (built into the clothing) is an extremely relevant, interesting and innovative process. However, a number of cause-effect relations in this area are not sufficiently clear. This requires a lot of research and analysis to refine them.

In modern conditions, in most cases, the conductive elements of the wearable antennas are made of a special conductive fabric (CF), which is connected to the main TM of the sewing product. The textile materials from which the garments are made are used as substrates for the wearable antennas.

The efficiency of the adhesion process between the textile substrate and the conductive fabric is one of the main factors on which the quality of wearable antennas depends. Some research has been conducted in this area. For example, [8] discuss some of the problem areas in relation to adhesion to textile fibres and fabrics. Satisfactory adhesion to fibres and fabrics may be obtained when the material is dry, but failure of the adhesive joints may occur during aftercare treatments, e.g. washing and dry cleaning treatments [8]. In [9] is considered the understanding of adhesion between a synthetic polymer and a second material. The second material may be inorganic, such as glass, or it may be another polymer but is assumed to be smooth [9]. In [10] different views concerning polymer-to-polymer adhesion were considered. In [11] the recent research efforts on polymer adhesion with a special focus on adhesion mechanisms are considered. In [12] an overview of adhesive bonding processes and products and their various applications in the textile industry is made. These studies [8-12] consider the general principles of adhesion between polymers. They do not specify the processes of adhesion between the conductive fabric and the textile substrate in the fabrication of wearable antennas. A number of studies have been conducted on the possibilities for the application of various TMs as substrates in the manufacture of wearable antennas [3-6]. Wearable antennas made out of conductive fabric on textile substrates were reported in the past [4]. However, the processes of adhesion between the conductive fabric and the main TM (the substrate) in the fabrication of wearable antennas (WA) have not been sufficiently studied.

The present work aims to study and analyze the technological features of the adhesion process (between CF and the substrate) in the fabrication of wearable antennas.

2 DISCUSSION AND ANALYSIS

To achieve the aim, it is necessary to study a number of important technological parameters of the adhesion process between CF and TM, from which the sewing product is made.

2.1 Conditions to execute the experiment

An innovative TM registered with a patent [13] for an invention was selected for the TM from which the sewing product is made. It is a double woven fabric (for winter sports, hunting and tourism) "Hunter'12", produced by "E. Miroglio SA" - Sliven, Bulgaria. Its characteristics are described in detail in [13]. Extensive studies of the dielectric constant of this TM were performed for one and two layers [3]. This motivated the choice of this TM for the current study. The dielectric constant of this TM with a polymeric binder (PB) for different number of layers was also studied [3]. However, the parameters of the adhesion process between this TM and the conductive fabric in the fabrication of wearable antennas have been not clarified. This is a prerequisite for planning research in the present work.

The research is carried out with conductive fabric PT230, manufactured by SHZHOU WANHE Electronic CO., LTD. It contains the following components: polyester (70±3%), copper (16±5%), and nickel (14±2%). Its characteristics are: mass per unit area 80±10 g/m^2; thickness 0.08±0.01 mm; width 1080±10 mm. The used polymeric binder (PB) is a double interlining mesh with paper. One of the main factors determining the mechanism of adhesion is the melting temperature of PB. The quality of adhesion also depends on a number of technological parameters. For example, at a higher temperature of the iron heating plate, PB melts faster. After conducting numerous preliminary studies, other cause-effect relations have been established. For example, if the hotplate temperature is too high, the PB melts very quickly. Then, even at low pressure, PB displays on the front side of the conductive fabric. This leads to an unacceptable deterioration in the quality of WA.

Determining the temperature with thermal paper is not precise enough, as the temperature values are read at a certain interval. For this reason, a modern method is used to measure the temperature to create feedback with the studied materials. The temperature is read with a special PERMESS device. The temperature sensors are thermocouples.

The temperature Tp [°C], recorded between the iron plate and the conductive fabric and the temperature Tpb [°C], recorded between PB and the main TM (the substrate) differ significantly. This requires planning experiments to refine the technological parameters of the adhesion process for the selected TM.

For this purpose, Experiment I is planned to establish the time to reach different temperatures Tpb. The experiment was performed with a TEFAL steam iron. The adhesion processes are carried out without steam.

Experiment I was conducted in four stages. The conditions for the implementation of the first stage are:

- PB is placed on CF (CF is cut with dimensions slightly larger than the dimensions of the designed antenna);
- the scheme of arrangement of PB on the conductive fabric is given in Figure 1, where: 1 - ironing board; 2 - CF; 3 - PB; 4 - the paper on which the PB is; 5 - the iron plate;
- the temperature of the iron plate - 120°C;
- the time for carrying out stage 1 of Experiment I was determined after conducting a number of preliminary experiments - 2 s.

In step 2 of Experiment I, the paper 4 of Figure 1 is removed.

In step 3 of Experiment I, the CF is cut to the exact size of the conductive elements of the projected antenna.

The conditions for carrying out stage 4 of Experiment I are:

- the temperature of the iron plate - 120°C;
- the scheme of arrangement of the thermocouples when reading the temperature is given in Figure 2., where: 1 - ironing board; 2 - CF; 3 - PB; 4 - TM, from which the article is made (the substrate for the wearable antenna); 5 - plate of the iron; 6 - position of the sensors (thermocouples) for temperature reading;
- three variants were investigated (in the fourth stage of Experiment I): variant 1 - the time for reaching Tpb to 90°C; option 2 - the time to reach Tpb to 100°C; option 3 - the time to reach Tpb to 110°C.

It is assumed that some well-known companies have studied the processes of adhesion in the fabrication of wearable antennas. However, their results are confidential or commercial. In light of the above, no information was found about the temperature which PB (Tpb, °C) must reach in order to achieve quality adhesion. However, it is important to define the adhesion quality criteria.

The process of making WA is extremely innovative. There are many unresolved issues related to its implementation.

For example, after numerous preliminary studies, it has been found that the adhesion strength immediately after removing the iron is very low. The product needs to be cooled.

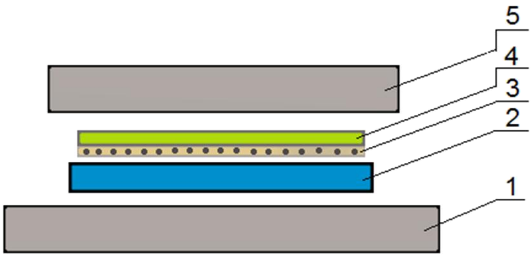


Figure 1 Arrangement of materials in step 1 of Experiment I

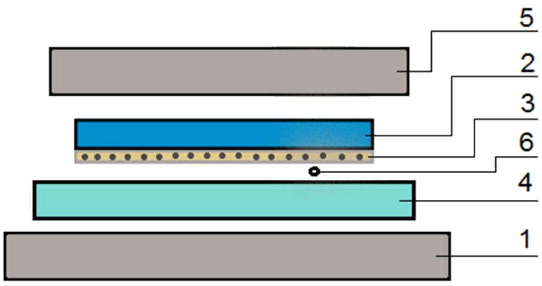


Figure 2 Arrangement of materials in step 4 of Experiment I

Then the adhesion strength is significantly higher.

It is logical that the quality of adhesion in the manufacture of WA also depends on washing and dry cleaning. This adhesion may depend on the exposure of the garment to direct sunlight, as well as on a number of other factors. In the present work, the resistance to adhesion after three washes was chosen as a quality criterion. The tests were performed after cooling the samples to ambient temperature. Washing was performed in a traditional program with an automatic washing machine at 30°C for 30 minutes. The choice of the washing temperature was made in accordance with the composition of the TM from which the product was made. It was found that in the samples made in variant 1, after the third wash, unravelling of the edges of the CF was observed. In some samples (for variant 1) separation of some ends of CF from the substrate was also observed. In the samples of variant 2 and variant 3, the ends of the CF were not unravelled and were not separated from the substrate. In variant 2 the energy and time consumption were lower. Therefore, as a criterion for qualitative adhesion, the following condition can be derived: Tpb=100°C.

During the preliminary experiments it was found that with increasing the pressure of the heating plate, the time to reach the required temperature of PB decreases. If the pressure is too high, it is possible for the PB to come out from the front of the CF. Therefore, more accurate consideration of the technological pressure factor is needed.

When working with the iron, the operator exerts a certain pressure. Considering this pressure is subjective. There is no possibility to measure and control this factor.

In the context of the above, Experiment II was planned, which was carried out on a fusing machine ATLAS-I. BALA-4-93 (stationary press type "drawer"). Thus, the pressure on the top plate becomes a controllable factor.

The conditions for conducting Experiment II are:

- the substrate, PB and CF are the same as in Experiment I;
- Experiment II is carried out in four stages;
- the technological parameters for carrying out stage 1, stage 2 and stage 3 of Experiment II are the same as in Experiment I;
- the technological parameters for the implementation of stage 4 of Experiment II are: a fusing machine ATLAS-I. BALA-4-93 (stationary press type "drawer"); pressure 44 N/cm^2; temperature of the press plate Tpp [°C] in three variants (variant 1 Tpp_1=120°C; variant 2 Tpp_2=130°C; variant 3 Tpp_3=140°C);
- stage 4 is finalized at T_{PB}=100°C.

2.2 Experimental results

The results obtained from the implementation of Experiment I and Experiment II are given in Tables 1 and 2. For both experiments, 3 repeated trials were made for each point in the experiment plan (m=3).

Table 1 Results from the conducted studies for duration of stage 4 of Experiment I

Study №, j	**Time t [s]**		
Variant №, i	t_1	t_2	t_3
V_1 Tpb=90°C	7.4	8.1	6.8
V_2 Tpb=100°C	12.6	13.1	11.9
V_3 Tpb=110°C	17.2	16.8	18.5

Table 2 Results from the conducted studies for duration of stage 4 of Experiment II

Study №, j	**Time t [s]**		
Variant №, i,	t_1	t_2	t_3
V_1 Tpp=120°C	8.9	10.1	9.1
V_2 Tpp=130°C	7.6	7.2	7.1
V_3 Tpp=140°C	6.2	6.4	5.3

2.3 *Discussion of experimental results*

It is necessary to check the reproducibility of the process, which is reduced [14, 15] to a check for consistency of dispersion (by Cochran's C test):

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

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

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

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

$$G_{C,I} = 0{,}5001; \quad G_{T,I} = 0{,}8709 \tag{3}$$

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

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

$$G_{C,II} = 0{,}5005; \quad G_{T,II} = 0{,}8709 \tag{4}$$

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

As a result of the conducted experiments, the relationship between the temperature which PB reaches and the time required for this was established (under the same other conditions of the experiment - Table 1).

The data in Table 2 show that as the temperature of the press plate increases, the adhesion time decreases.

For each of the investigated variants of Experiment II, the adhesion between the substrate and CF was very good. No defects were observed on the samples. Each of the studied samples can be considered as high quality. Therefore, the required amount of time and energy can be used as a criterion for efficiency. The results in Table 2 show that minimum time is required for variant 3 in step 4 of Experiment II. The difference in time required for variant 1 and variant 2 is small (3-4 s). The difference in energy required for variant 1 and variant 3 is relatively larger. On the other hand, raising the temperature of the press plate to 140°C will also lead to a significant increase in the temperature of the working environment. For these reasons, it is proposed to use variant 1 of Experiment II in the present work.

In general, the results obtained make it possible to select the adhesion conditions (upon receipt of WA) according to the specific performance requirements.

3 CONCLUSION

The present work investigates the conditions for the implementation of the adhesion process between CF and the substrate in the fabrication of WA. Innovative textile materials and modern methods and devices for temperature measurement are used.

A criterion for finalizing the adhesion process is proposed. A technological variant for performing the adhesion with a fusing machine is proposed. Thus, the pressure becomes a controllable factor.

Specific values of the time for the implementation of the adhesion process under different technological operating conditions have been established. The reproducibility of the conducted studies has been proven.

Dependencies between technological factors of the adhesion process in the fabrication of WA have also been established.

The obtained results make it possible to choose effective operating modes according to the priorities of the real work environment.

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

4 REFERENCES

1. Meng K., Zhao Sh., Zhou Y., Wu Y., et al.: A Wireless textile-based sensor system for self-powered personalized health care, Matter 2(4), 2020, pp. 896-907, https://doi.org/10.1016/j.matt.2019.12.025
2. Searle Kr., Litts Br., Kafai Y.: Debugging open-ended designs: High school students' perceptions of failure and success in an electronic textiles design activity, Thinking Skills and Creativity 30, 2018, pp. 125-134, https://doi.org/10.1016/j.tsc.2018.03.004
3. Andonova S.: Technological peculiarities of the production of a wearable antenna with innovative textile materials, Vlakna a textil (Fibres and Textiles) 27(1), 2020, pp. 3-6, http://vat.ft.tul.cz/2020/1/VaT_2020_1_1.pdf
4. Monti G., Corchia L., Tarricone L.: Fabrication techniques for wearable antennas, Proceedings of the 43rd European Microwave Conference 2013, Nuremberg, Germany, pp. 1747-1750, DOI: 10.23919/EuMC.2013.6687015
5. Al-Sehemi A., Al-Ghamdi A., Dishovsky N., Atanasov N., Atanasova G.: Wearable antennas for body-centric communications: design and characterization aspects, ACES Journal 34(8), 2019, pp. 1172-1181
6. Atanasova G., Atanasov N., Stefanov A., Andonova S., Avramov M., Kateva M.: Comparison of computed specific absorption rate induced in a homogeneous human body phantom using a wearable textile antenna for biomedical applications, Proceedings of 27th National Conference with International Participation "TELECOM 2019", 2019, Sofia, Bulgaria, pp. 94-97, DOI: 10.1109/TELECOM48729.2019.8994882

7. Atanasov N., Atanasova G., Stefanov A., Nedialkov I.: A wearable, low-profile, fractal monopole antenna integrated with a reflector for enhancing antenna performance and SAR reduction, IEEE MTT-S International Microwave Workshop Series on Advanced Materials and Processes for RF and THz Applications (IMWS-AMP) 2019, Bochum, Germany, pp. 67-69, DOI:10.1109/IMWS-AMP.2019.8880142
8. Holme I.: Adhesion to textile fibres and fabrics, International Journal of Adhesion and Adhesives 19(6), 1999, pp. 455-463, https://doi.org/10.1016/S0143-7496(99)00025-1
9. Brown H.R.: Polymer adhesion, Materials Forum 24, 2000, pp. 49-58
10. Voyutskii S., Vakula V.: The role of diffusion phenomena in polymer-to-polymer adhesion, Journal of Applied Polymer Science 7(2), 1963, pp. 475-491, https://doi.org/10.1002/app.1963.070070207
11. Awaja F., Gilbert M., Kelly G., Fox B., Pigram P.: Adhesion of polymers, Progress in Polymer Science 34(9), 2009, pp. 948-968, https://doi.org/10.1016/j.progpolymsci.2009.04.007
12. Stammen E., Dilger K.: Adhesive bonding of textiles: applications, chapter 9 in Joining Textiles, Principles and Applications, Woodhead Publishing Series in Textiles 2013, pp. 275-308, https://doi.org/10.1533/9780857093967.2.275
13. Rahnev I.: Patent for invention №66551/01.11.2016. BG 66551 B1, Double workwear fabric
14. Germanova-Krasteva D.: Textile Testing and Analysis, TU Sofija - University Press, Sofija, Bulgaria, 2012 (in Bulgarian)
15. Andonova S.: Investigation the influence of the cloth packs area on the temperature changes during the ironing process of cotton details, Tekstil I Obleklo 1, 2006, pp. 17-19 (in Bulgarian)

OPTIMIZATION OF THE THERMO-MECHANICAL FUSING PROCESS

Snezhina Angelova Andonova[1] and Silvia Baeva[2]

[1]*Faculty of Engineering, South-West University "Neofit Rilski", 66 Ivan Mihailov Str., 2700 Blagoevgrad, Bulgaria*
[2]*Faculty of Applied Mathematics and Informatics, Technical University of Sofia, 8 Kl. Ohridski Blvd, 1000 Sofia, Bulgaria*
andonova_sn@swu.bg; sbaeva@tu-sofia.bg

Abstract: *The thermo-mechanical fusing (TMF) process is one of the main technological processes in the garment industry. Research and analysis of it is especially important for the quality of garments. Some investigations were made to determine the effect of individual parameters on the TMF process. In order to achieve optimal quality indicators for TMF with energy and time saving, is create a mathematical model of the function connecting the output parameter with the input factors. This model describes the influence of the pressure, the temperature of the pressing plates and the mass per unit area of the basic textile materials on the duration of the TMF process. Obtaining an adequate mathematical model of the process creates real conditions for its optimization. The aim of the present work is to investigate and optimize the function describing the relationship between the output parameter and the input factors in TMF.*

Keywords: *optimization; thermo-mechanical fusing process.*

1 INTRODUCTION

The thermo-mechanical fusing (TMF) process is one of the main technological processes in the garment industry. Research and analysis of it is especially important for the quality of garments. From the study conducted, it can be summarized that some investigations were made to determine the effect of individual parameters on the TMF process [1-3]. The time for the implementation of the TMF process was studied [2, 4, 5]. The time-temperature dependence for different textile materials was investigated [4]. The conditions for feedback implementation with the processed textile materials at TMF were analyzed [4, 6]. However, the combined influence of the controllable factors, such as to satisfy the quality and performance criteria, has not been sufficiently studied. Globally, many elite companies have conducted research in this area, but their studies are commercial or confidential. In order to achieve optimal indicators for quality and productivity of a technological process, it is necessary to create a mathematical model of the function connecting the output parameter (*Y*) with the input factors (*X*) [7-9]. This requires conducting experiments with simultaneous variation of the studied factors [10]. In the work process [11] a mathematical model of the TMF process was created. This model describes the influence of the pressure, the temperature of the pressing plates and the mass per unit area of the basic textile materials on the duration of the TMF process [11]. Obtaining an adequate mathematical model of the process creates real conditions for its optimization [12, 13].

The present work aims to investigate and optimize the function describing the relationship between the output parameter and the input factors in TMF.

2 RESEARCH WORK

2.1 Conditions for conducting the study

In order to achieve the set goal, it is necessary to optimize the mathematical model (1).

Such values for the input parameters *X1, X2, X3* are sought for, for which the output parameter (function)

$$\begin{aligned} &Y(X_1 X_2 X_3) = \\ &= 22{,}4375 - 1{,}4375 X_1 - 5{,}8125 X_2 + \\ &+ 6{,}9375 X_3 - 1{,}8125 X_2 X_3 \to \min \end{aligned} \tag{1}$$

subject to:

$$\begin{cases} If \quad X_1 = \{-1;0;1\} \quad then \quad X_2, X_3 \geq 0; \\ If \quad X_2 = \{-1;0;1\} \quad then \quad X_1, X_3 \geq 0; \\ If \quad X_3 = \{-1;0;1\} \quad then \quad X_1, X_2 \geq 0, \end{cases} \tag{2}$$

where: $Y(X_1, X_2, X_3)$ - the time for implementation of the TMF process, which is a criterion for productivity; X_1 - coded value of the input parameter - pressure *P* [N/cm^2]; X_2 - coded value of the input parameter - temperature of the pressing plates *T* [°C]; X_3 - coded value of the input parameter - mass per unit area of basic textile materials *M* [g/m^2].

The levels of the input factors are given in Table 1 [11].

Table 1 Levels of factors

Factors	X_1 - Pressure [N/cm^2]		X_2 - Temperature of the pressing plates T [°C]		X_3 - Mass per unit area of basic textile materials M [g/m^2]	
Levels	***Natural***	***Coded***	***Natural***	***Coded***	***Natural***	***Coded***
$X_{oi} + J_i$	40	+1	150	+1	213	+1
X_{oi}	25	0	135	0	193	0
$X_{oi} - J_i$	10	-1	120	-1	173	-1
J_i	15		15		20	

Function (1) was studied at different combinations of input factor levels. The nine options listed in Table 2 were examined. In each option, one of the input factors is chosen to be a constant. The optimal value of the output parameter *Y* is sought by varying the other two input factors. Each factor taken as a constant, successively accepts the following levels: (+1), (0), (-1). The search for the optimal value is related to determining the minimum and maximum value of *Y*. The output parameter is the time for which the TMF process takes place. Therefore, the optimal value for *Y* will be Y_{min}.

2.2 Methods

Mathematical methods for analysis and evaluation are usually used to optimize technological processes [14-16], and their numerical realization is conducted with specialized software.

In the present article, the numerical realization of the proposed model of the optimization problem was rendered in software environments in the software product Maple. With its help the process of thermo-mechanical fusing is analyzed.

3D models of thermo-mechanical fusing process are designed in the environment of Maple. They illustrate the optimal options for carrying out this process.

2.3 Materials

When creating the mathematical model (1) [11] materials produced by the company NITEX-50 - Sofia were used for basic textile materials. They are 100% wool fabrics:

article EKSELSIOR, mass per unit area 173 g/m^2, warp threads count 52/2 Nm, weft threads count 37/1 Nm, warp threads density 122 pcs/10 cm, weft threads density 230 pcs/10 cm;

article RITZ, mass per unit area 193 g/m^2, warp threads count 52/2 Nm, weft threads count 37/1 Nm, warp threads density 175 pcs/10 cm, weft threads density 263 pcs/10 cm;

article KARDINAL, mass per unit area 213 g/m^2, warp threads count 52/2 Nm, weft threads count 37/1 Nm, warp threads density 370 pcs/10 cm, weft threads density 232 pcs/10 cm [11].

Material produced by the company Kufner-B121N77 was used for an auxiliary TM (interlining). The auxiliary TM is fabric, with mass per unit area 63 g/m^2, warp threads 100% PES, weft threads 100% PES [11].

3 RESULTS AND DISCUSSION

3.1 Research results

Research of the function (1) was performed for 9 options given in Table 2. While studying the first option, the function (1) acquires the form (3):

$$\begin{aligned} Y_{(X_2,X_3)} &= 22.4375 - 1.4375 - 5.8125X_2 + \\ &+ 6.9375X_3 - 1.8125X_2X_3 = \\ &= 21.0000 - 5.8125X_2 + 6.9375X_3 - \\ &- 1.8125X_2X_3 \end{aligned} \tag{3}$$

The three-dimensional image of the function (3) is given in Figure 1, where: X2ϵ[(-1)÷(+1)] and X3ϵ[(-1)÷(+1)].

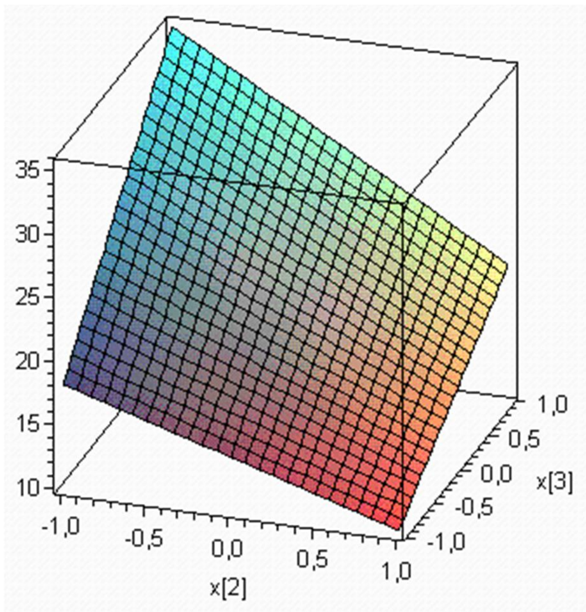


Figure 1 3D model of the function (1)

After the research it was found:

$$Y_{1max} = 35.5625 = f\,[X_2 = (-1),\ X_3 = (+1)] \tag{4}$$

$$Y_{1min} = 10.0625 = f\,[X_2 = (+1),\ X_3 = (-1)] \quad 5)$$

Figure 2 illustrates Y_{1max} and Y_{1min}.

The optimal value of Y_1 for the present study is Y_{1min}.

Therefore, the optimal levels of input factors for TMF in option 1 are: $X_1=(+1)$, $X_2=(+1)$, $X_3=(-1)$.

In a similar way, function (1) was studied for the other 8 options. The research results are given in Table 2. In Table 2 the function (1) is denoted by $Y_i = f\ (X_1, X_2, X_3)$, where $i=(1\div 9)$. Figures 3-10 illustrate the 3D models and the optimal values of the function (1) for the options 2-9.

3.2 *Discussion of the research results*

From the analysis of the obtained results it can be generalized that the function $Y_i(X_1, X_2, X_3)$ has an optimal value in option 1. The optimal value of function (1) is $Y_i(X_1, X_2, X_3)=10.0625$ *s* with natural values of the input factors: X_1**=***40 N/cm*^{2}, X_2*=150°C* and X_3*=213 g/m*^{2}.

Table 2 Optimal values of the function Y_i

Option №	Value of the input factor that is selected as a constant	Y_i (X_1, X_2, X_3)	$Y_{i\ max}$, [s]	$Y_{i\ min}$, [s]
1	$X_1=(+1)$	$Y_{(X_2,X_3)} = 21.0000 - 5.8125X_2 + 6.9375X_3 - 1.8125X_2X_3$	35.5625=f[X_2=(-1), X_3=(+1)]	10.0625=f[X_2=(+1), X_3=(-1)]
2	$X_1=0$	$Y_{(X_2,X_3)} = 22.4375 - 5.8125X_2 + 6.9375X_3 - 1.8125X_2X_3$	37.0000=f[X_2=(-1), X_3=(+1)]	11.5000=f[X_2=(+1), X_3=(-1)]
3	$X_1=(-1)$	$Y_{(X_2,X_3)} = 23.8750 - 5.8125X_2 + 6.9375X_3 - 1.8125X_2X_3$	38.4375=f[X_2=(-1), X_3=(+1)]	12.9375=f[X_2=(+1), X_3=(-1)]
4	$X_2=(+1)$	$Y_{(X_1,X_3)} = 16.6250 - 1.4375X_1 + 5.1250X_3$	23.1875=f[X_1=(-1), X_2=(+1)]	10.0625=f[X_1=(+1), X_2=(-1)]
5	$X_2=0$	$Y_{(X_1,X_3)} = 22.4375 - 1.4375X_1 + 6.9375X_3$	30.8125=f[X_1=(-1), X_2=(+1)]	14.0625=f[X_1=(+1), X_2=(-1)]
6	$X_2=(-1)$	$Y_{(X_1,X_3)} = 28.2500 - 1.4375X_1 + 8.7500X_3$	38.4375=f[X_1=(-1), X_2=(+1)]	18.0625= =f [X_1=(+1), X_2=(-1)]
7	$X_3=(+1)$	$Y_{(X_1,X_2)} = 29.3750 - 1.4375X_1 - 7.6250X_2$	38.4375=f[X_1=(-1), X_2=(-1)]	20.3125=f[X_1=(+1), X_2=(+1)]
8	$X_3=0$	$Y_{(X_1,X_2)} = 22.4375 - 1.4375X_1 - 5.8125X_2$	29.6875=f[X_1=(-1), X_2=(-1)]	15.1875=f[X_1=(+1), X_2=(+1)]
9	$X_3=(-1)$	$Y_{(X_1,X_2)} = 15.5000 - 1.4375X_1 - 4.0000X_2$	20.9375=f[X_1=(-1), X_2=(-1)]	10.0625=f[X_1=(+1), X_2=(+1)]

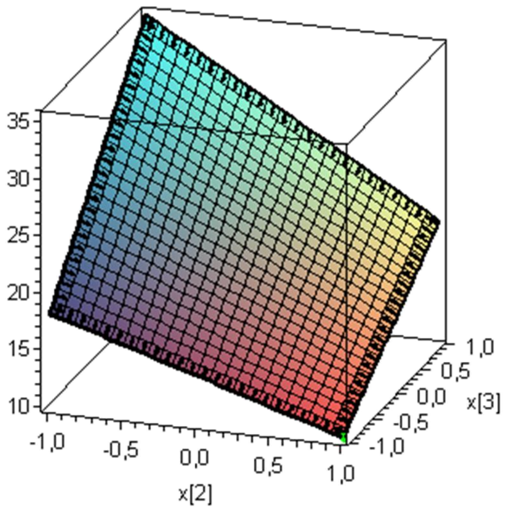


Figure 2 Optimal value of function (1) for option 1

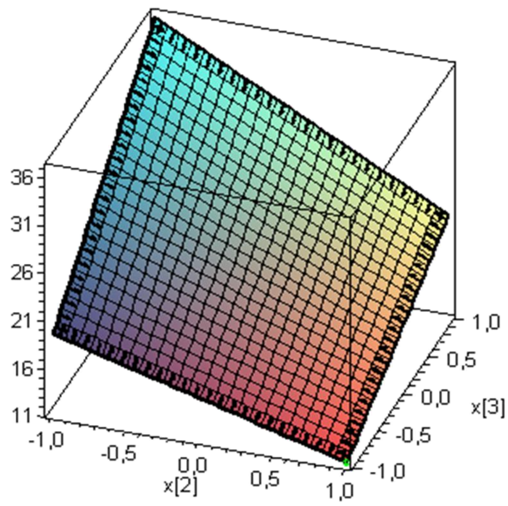


Figure 3 3D model and optimal value of function (1) for option 2

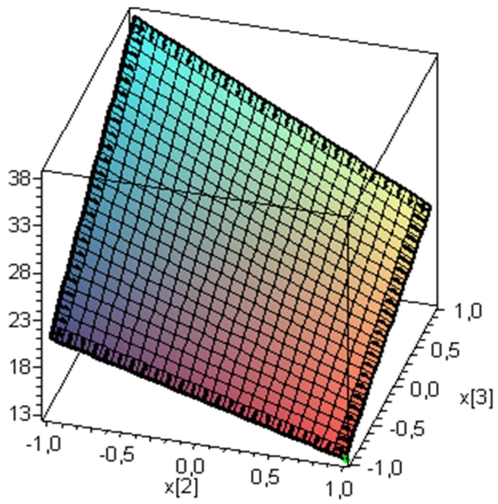


Figure 4 3D model and optimal value of function (1) for option 3

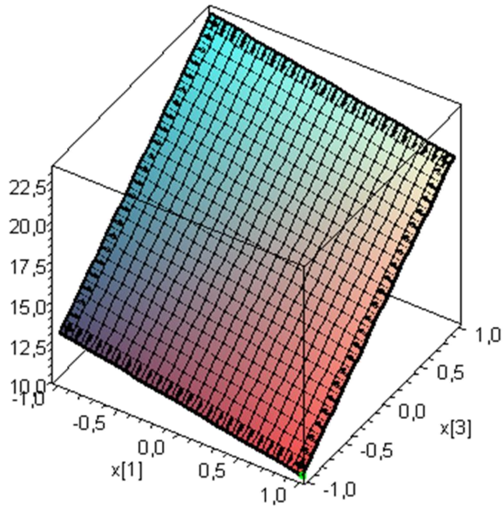


Figure 5 3D model and optimal value of function (1) for option 4

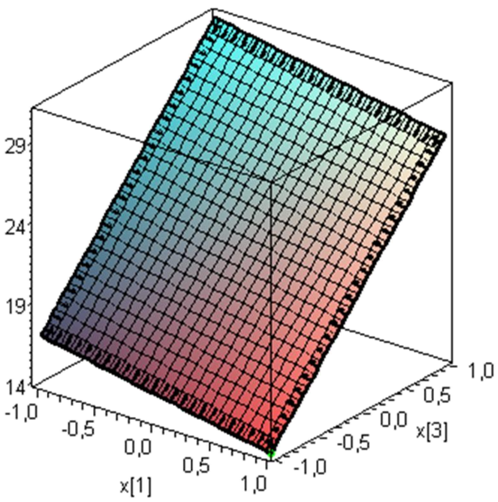


Figure 6 3D model and optimal value of function (1) for option 5

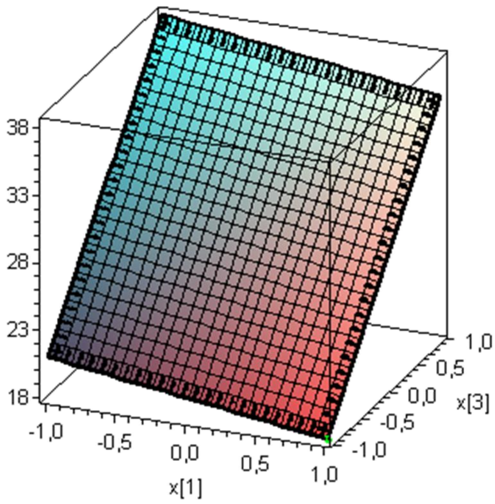


Figure 7 3D model and optimal value of function (1) for option 6

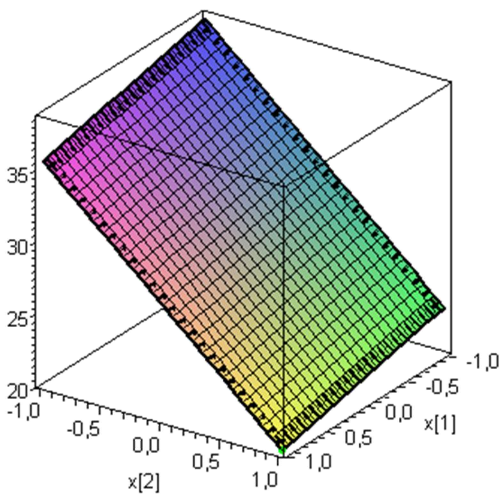


Figure 8 3D model and optimal value of function (1) for option 7

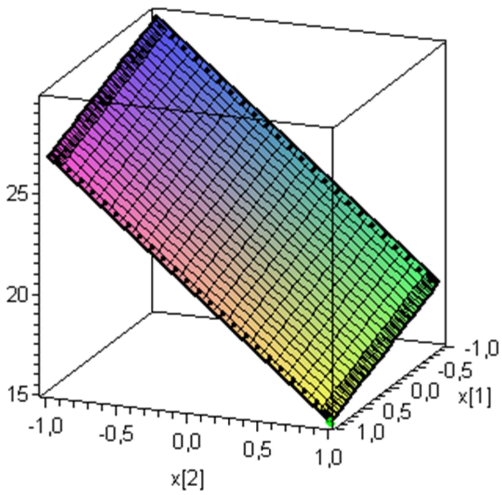


Figure 9 3D model and optimal value of function (1) for option 8

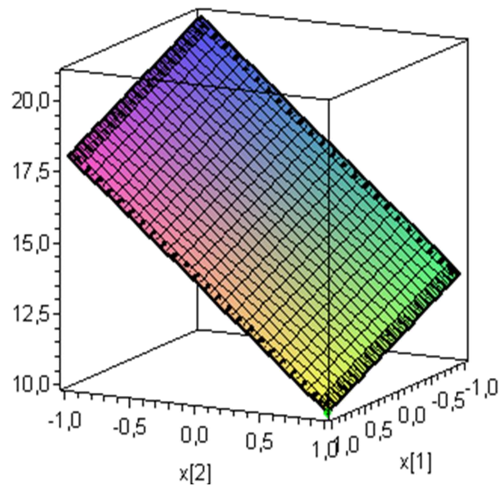


Figure 10 3D model and optimal value of function (1) for option 9

4 CONCLUSIONS

This work investigates the function connecting the output parameter with the input factors of the TMF process. A produce criterion is selected for the output parameter. This is the duration for the implementation of the TMF process.

Nine different options have been investigated. For each option one factor is selected, which is accepted as a constant, and the other factors change at a certain interval. The optimal values of the output parameter are determined for each option.

It was found that the optimal value of the output parameter (for the studied 9 options) *Yi=10.0625 s* is reached at the following values of the input factors: the pressure $P=40\ N/cm^2$, the temperature of the pressing plates *T=150°C* and the mass per unit area of basic textile materials $M=213\ g/m^2$.

3D images of the combinations of factor levels and the corresponding value of the output parameter for each option are designed. This makes it possible to easily and quickly find optimal combinations of input factors and the output parameter of the TMF process.

The present study has a wide applied-scientific significance. The application of mathematical methods for analysis, evaluation and optimization makes the conducted research scientifically based. The designed 3D images of the mathematical model of the process allow for making quick and efficient technological decisions in real production conditions.

5 REFERENCES

1. Motejl V.: Machines and equipment in clothing production, SNTL, Praha, 1984 (in Czech)
2. Petrov H.: Research on the creation of high-performance technologies and equipment for the sticking of textiles, Edited by TU Sofija - University Press, Sofia, Bulgaria, Dissertation thesis, 1991 (in Bulgarian)
3. Andonova S.: Analysis of factors influencing the process of thermos-mechanical sticking in the sewing industry, Journal of Multidisciplinary Engineering Science and Technology 6(10), 2019, pp. 10884-10887, http://www.jmest.org/wp-content/uploads/ContentOctober2019.pdf
4. Andonova S., Stefanov A., Amudzhev I.: An investigation of the thermo-mechanical fusing process of innovative textile material, Industria Textila Journal, accepted
5. Colovic G. (Ed.): Determining time of technological operations in clothing production, chapter 3 in Management of Technology Systems in Garment Industry, 2011, pp. 43-79, https://doi.org/10.1533/9780857094049.43
6. Gries T., Lutz V., Niebel V., Saggiomo M., Simonis K.: Automation in quality monitoring of fabrics and garment seams, chapter 14 in Automation in Garment Manufacturing, The Textile Institute Book Series, 2018, pp. 353-376, https://doi.org/10.1016/B978-0-08-101211-6.00014-8
7. Watcharapanyawong K., Sirisoponsilp S., Sophatsathit P.: A model of mass customization for engineering production system development in textile and apparel industries in Thailand, Systems Engineering Procedia 2, 2011, pp. 382-397, https://doi.org/10.1016/j.sepro.2011.10.052
8. Quezada-García S., Espinosa-Paredes G., Polo-Labarrios M. A., Espinosa-Martínez E. G, Escobedo-Izquierdo M. A.: Green roof heat and mass transfer mathematical models: A review, Building and Environment 170, 2020, Article no. 106634, https://doi.org/10.1016/j.buildenv.2019.106634
9. Dimitrienko Yu.I., Dimitrienko I.D.: Modeling and simulation of textile composite plates under a punching load, Applied Mathematics and Computation 364, 2020, Article no. 124660, https://doi.org/10.1016/j.amc.2019.124660
10. Damyanov G., Germanova-Krasteva D.: Textile Processes: Quality Control and Design of Experiments, NY: Momentum Press, 2012, 240 p., ISBN: 9781606503874
11. Andonova S.: Mathematical modeling of the thermo-mechanical fusing process Vlakna a textil (Fibres and Textiles) 27(2), 2020, pp. 3-7
12. Wu L Yick K.I., Ng S.P., Yip J., Kong K.H.: Parametric design and process parameter optimization for bra cup molding via response surface methodology, Expert Systems with Applications 39(1), 2012, pp. 162-171, https://doi.org/10.1016/j.eswa.2011.07.003
13. Manusov V.Z, Matrenin P.V., Khasanzoda N.: Swarm algorithms in dynamic optimization problem of reactive power compensation units control, International Journal of Electrical and Computer Engineering 9(5), 2019, pp. 3967-3974, http://doi.org/10.11591/ijece.v9i5.pp3967-3974
14. Mital K., Mohan C.: Optimization methods in operation research and system analysis, 3rd edition, e-book, Springer, 2004, https://books.google.bg/books?id=_uMQQyWjoPoC&printsec=frontcover&dq=Optimization+approach&hl=bg&sa=X&ved=2ahUKEwji2cHIk6PrAhUmBhAIHYJNCuoQ6AEwBnoECAYQAg#v=onepage&q=Optimization%20approach&f=false

15. Yang X., Teo K., Lou C.: Optimization Methods and Applications, Springer, 2001, e-book https://books.google.bg/books?id=UwDqBwAAQBAJ&printsec=frontcover&dq=Optimization+approach&hl=bg&sa=X&ved=2ahUKEwjK4-aalaPrAhUNtYsKHbTzB-E4ChDoATACegQIAhAC#v=onepage&q=Optimization%20approach&f=false,
16. Pardalos P.: Approximation and Complexity in Numerical Optimization: Continuous and Discrete Problems, Springer, 2000, e-book, https://books.google.bg/books?id=cTatx1hWWEAC&pg=PA92&dq=Optimization+approach+approximation&hl=bg&sa=X&ved=2ahUKEwjG5KDamKPrAhUQt4sKHdvZBGs4ChDoATAAegQIABAC#v=onepage&q=Optimization%20approach%20approximation&f=false

OPTIMIZING A FUNCTION LINKING AN QUALITY CRITERION TO INPUT FACTORS ON THE THERMO-MECHANICAL FUSING PROCESS

Snezhina Andonova[1] and Silvia Baeva[2]

[1]Faculty of Engineering, South-West University "Neofit Rilski", 66 Ivan Mihailov Str., 2700 Blagoevgrad, Bulgaria
[2]Faculty of Applied Mathematics and Informatics, Technical University - Sofia, 8 Kl. Ohridski Blvd, 1000 Sofia, Bulgaria
andonova_sn@swu.bg

Abstract: *The subject of research in the present work are technological processes in the garment industry. Different quality criteria are established for each technological process. One of the major technological processes in the sewing industry is the process of thermo-mechanical fusing (TMF). Its optimization is not an easy task. This is due to the extreme complexity of the process. As a result of numerous studies, a mathematical model of TMF has been created. The model gives the relationship between input factors and a process quality parameter. The present work aims to optimize the function describing the relationship between the quality criterion and the input factors in TMF. A 3D graphical interpretation of the optimization has also been made.*

Keywords: *thermo-mechanical fusing process, optimizing.*

1 INTRODUCTION

The quality criteria in the garment industry are extremely many and varied [1]. Their research and optimization are important for the final look of the sewing product. Different quality criteria are established for each technological process. One of the major technological processes in the sewing industry is the process of thermo-mechanical fusing (TMF). A number of studies and analyzes of this process have been conducted. Various indicators have been used as quality criteria. For example, the compressibility of textile material (TM) during TMF is an important quality criterion [2-4]. In modern sewing technology, however, this problem is now very easy to overcome. For this purpose, the so-called "rough" cutting is used. The thermo-mechanical fusing process is carried out. Then the detail is cut fine (exactly). This ignores the problems with the compressibility of the TM during the TMF process. There is another significant problem with the TMF process. In case of incorrect setting of the process parameters, the color shade of the main textile material subjected to TMF changes. This change in the color shade of the individual parts will impair the quality of the sewing product as a whole. Therefore, it is appropriate to use the change in the specific color shade as a quality criterion after TMF. To achieve optimal indicators for the quality and productivity of a technological process, it is necessary to create a mathematical model of the function connecting the output parameter (*Y*) with the input factors (*X*) [5, 6]. This requires conducting experiments with the simultaneous variation of the studied factors.

In the works [7, 8] mathematical models of the TMF process are created. The mathematical model [7] describes the influence of input factors on a productivity criterion of the TMF process. The mathematical model [8] describes the influence of the pressure, the temperature of the pressing plates, and the mass per unit area of the basic textile materials on a quality criterion of the TMF process.

The present work aims to investigate and optimize the function describing the relationship between a quality criterion and the input factors in TMF. The change of the color shade of the textile material after TMF is used as a quality criterion.

Table 1 Levels of factors

Factors	X_1 - Pressure [N/cm^2]		X_2 - Temperature of the pressing plates T [°C]		X_3 - Mass per unit area of basic textile materials M [g/m^2]	
Levels	***Natural***	***Coded***	***Natural***	***Coded***	***Natural***	***Coded***
$X_{oi} + J_i$	40	+1	150	+1	213	+1
X_{oi}	25	0	135	0	193	0
$X_{oi} - J_i$	10	-1	120	-1	173	-1
J_i	15		15		20	

2 RESEARCH WORK

2.1 Conditions for conducting the study

As a result of numerous studies [2, 8, 9], the function connecting the quality criterion with the input factors of the TMF process has been created. This function is represented by (1):

$$\begin{aligned} Y(X_1, X_2, X_3) &= 1{,}255 + 0{,}3225.X_1 + \\ &+ 0{,}21.X_2 + 0{,}155.X_3 - 0{,}0175.X_1.X_2 - \\ &- 0{,}04.X_2.X_3 + 0{,}0175X_1.X_2.X_3 \end{aligned} \tag{1}$$

The optimization of the function is related to finding those values of X_1, X_2, and X_3 for which $Y\ (X_1, X_2, X_3)$ has a minimum or maximum value subject to:

$$\begin{cases} X_1 = \{-1;0;1\}; \\ X_2 = \{-1;0;1\}; \\ X_3 = \{-1;0;1\}, \end{cases} \tag{2}$$

where: $Y(X_1, X_2, X_3)$ - the change in the specific color shade of the textile material after TMF (a quality criterion); X_1 - the coded value of the input parameter - pressure P [N/cm^2]; X_2 - the coded value of the input parameter - the temperature of the pressing plates T [°C]; X_3 - the coded value of the input parameter - mass per unit area of basic textile materials M [g/m^2].

The coded and natural levels of input factors are given in Table 1 [8].

The study of function (1) was performed for 9 different options. The options are illustrated in Table 2. In each option, one of the input factors is assumed to be constant, and the other two factors vary (in the range of values given in Table 1). Each factor is taken as a constant and successively accepts the following levels: (+1), (0), (-1). The optimal values (minimum and maximum) of the output parameter Y for each option are sought. The output parameter is the change in the specific color shade of the textile material after TMF. In light of the above, Y_{min} is the optimal value of Y.

2.2 Methods

Statistical methods of analysis and evaluation are used to optimize a mathematical model [10-14]. In the present work, the optimization is performed with a specialized software product Maple. A 3D graphical interpretation of the model (1) in the environment of Maple was also made.

2.3 Materials

Materials produced by the company NITEX-50 - Sofia were used for basic textile materials. They are 100% wool fabrics: article EKSELSIOR; article RITZ; article KARDINAL, described in detail in [7].

The material produced by the company Kufner-B121N77 was used for interlining textile material (auxiliary textile material) [8].

3 RESULTS AND DISCUSSION

3.1 Research results

Function (1) is investigated for 9 different combinations of input factor levels. These 9 combinations (options) are illustrated in Table 2. When studying the first option:

- it is assumed that the coded value of X_1=(+1), then the natural values of X_2 and X_3 fulfil condition (3):

$$X_2,\ X_3 \geq 0 \tag{3}$$

- function (1) acquires the form (4):

$$\begin{aligned} &Y_1(X_2, X_3) = 1{,}255 + 0{,}3225.(+1) + 0{,}21.X_2 + \\ &+ 0{,}155.X_3 - 0{,}0175.(+1).X_2 - 0{,}04.X_2.X_3 + \\ &0{,}0175(+1).X_2.X_3 = 1{,}5775 + 0{,}1925X_2 + \\ &+ 0{,}155X_3 - 0{,}0225X_2.X_3 \end{aligned} \tag{4}$$

The 3D graphical interpretation of the mathematical model (4) is given in Figure 1, in which on the abscissa and the ordinate are given the coded values of X_2 and X_3, for which the condition (5) is fulfilled:

$$X_2 \epsilon [(-1) \div (+1)], \quad X_3 \epsilon [(-1) \div (+1)] \tag{5}$$

For the first option, the respective maximum and minimum values of the output parameter Y are obtained:

$$Y_{1max} = 1.9025 = f[X_2 = (+1),\ X_3 = (+1)] \tag{6}$$

$$Y_{1min} = 1.2075 = f[X_2 = (-1),\ X_3 = (-1)] \tag{7}$$

The optimal value of the output parameter Y for the first option is Y_{1min}. The optimal value of the function (1) for option 1 is given in Figure 2.

From the study, it can be concluded that the optimal levels of input factors for the TMF process for option 1 are: X_1=(+1); X_2=(-1); X_3=(-1).

Function (1) is investigated and analyzed in a similar way for the other options.

The results of the studies are given in Table 2. In Table 2 the function (1) is denoted by $Y_i=f(X_1, X_2, X_3)$, where i – option number.

In Figures 3-10 illustrates the 3D models and the optimal values of the function (1) for the options 2-9.

3.2 Discussion of the research results

For each of the considered options the natural levels of the factors at which the quality criterion has optimal values are presented (Table 3). Therefore, it can be generalized that function (1) has an optimal value for option 3, option 6 and option 9.

The optimal value of the function (1) is $Y_i(X_1, X_2, X_3)=0.4975$ at natural values of the input factors: X_1=10 N/cm^2, X_2=120°C, X_3=173 g/m^2.

Table 2 Optimal values of the function Y_i

Option №	Value of the input factor that is selected as a constant	$Y_i (X_1, X_2, X_3)$	$Y_{i\ max}$	$Y_{i\ min}$
1	$X_1=(+1)$	$Y_{(X_2,X_3)} = 1{,}5775 + 0{,}1925X_2 + 0{,}155X_3 - 0{,}0225X_2X_3$	1.9025=f[X_2=(+1), X_3=(+1)]	1.2075=f[X_2=(-1), X_3=(-1)]
2	$X_1=0$	$Y_{(X_2,X_3)} = 1{,}255 + 0{,}21X_2 + 0{,}155X_3 - 0{,}04X_2X_3$	1.58=f[X_2=(+1), X_3=(+1)]	0.85=f[X_2=(-1), X_3=(-1)]
3	$X_1=(-1)$	$Y_{(X_2,X_3)} = 0.9325 + 0{,}2275X_2 + 0{,}155X_3 - 0{,}0575X_2X_3$	1.2575=f[X_2=(+1), X_3=(+1)]	0.4925=f[X_2=(-1), X_3=(-1)]
4	$X_2=(+1)$	$Y_{(X_1,X_3)} = 1.465 + 0.305X_1 + 0.115X_3 + 0.0175X_1X_3$	1.9025=f[X_1=(+1), X_3=(+1)]	1.0625=f[X_1=(-1), X_3=(-1)]
5	$X_2=0$	$Y_{(X_1,X_3)} = 1.255 + 0.3225X_1 + 0.155X_3$	1.7325=f[X_1=(+1), X_3=(+1)]	0.7775=f[X_1=(-1), X_3=(-1)]
6	$X_2=(-1)$	$Y_{(X_1,X_3)} = 1.045 + 0.34X_1 + 0.195X_3 - 0.0175X_1X_3$	1.5625=f[X_1=(+1), X_3=(+1)]	0.4925=f[X_1=(-1), X_3=(-1)]
7	$X_3=(+1)$	$Y_{(X_1,X_2)} = 1.41 + 0.3225X_1 + 0.17X_2$	1.9025=f[X_1=(+1), X_2=(+1)]	0.9175=f[X_1=(-1), X_2=(-1)]
8	$X_3=0$	$Y_{(X_1,X_2)} = 1.255 + 0.3225X_1 + 0.21X_2 - 0.0175X_1X_2$	1.77=f[X_1=(+1), X_2=(+1)]	0.705=f[X_1=(-1), X_2=(-1)]
9	$X_3=(-1)$	$Y_{(X_1,X_2)} = 1.1 + 0.3225X_1 + 0.25X_2 - 0.035X_1X_2$	1.6375=f[X_1=(+1), X_2=(+1)]	0.4925=f[X_1=(-1), X_2=(-1)]

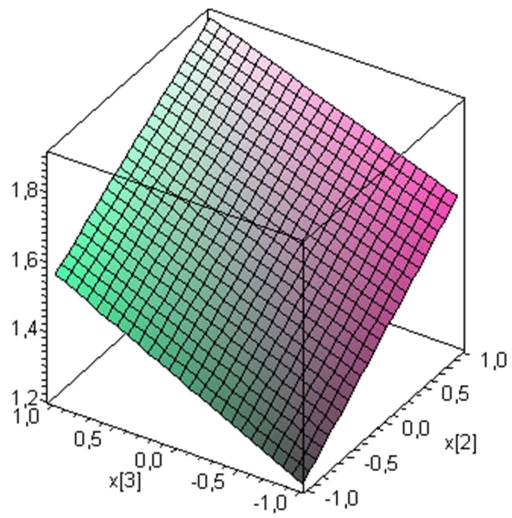


Figure 1 3D model of the function (4)

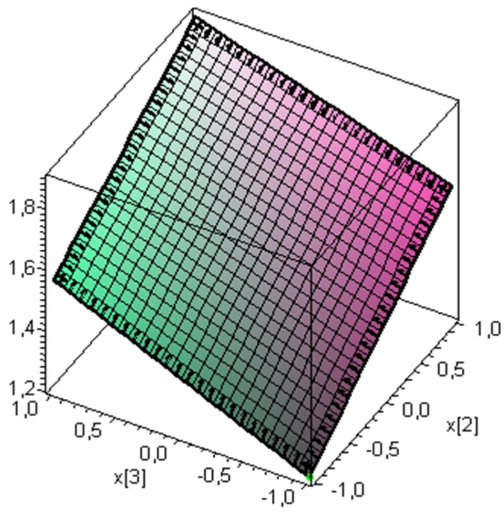


Figure 2 Optimal value of function (1) for option 1

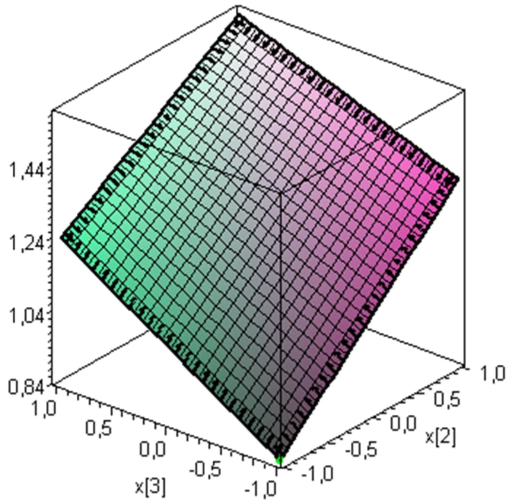


Figure 3 3D model and optimal value of function (1) for option 2

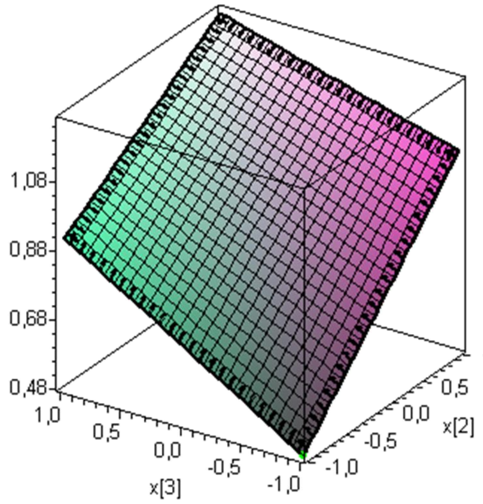


Figure 4 3D model and optimal value of function (1) for option 3

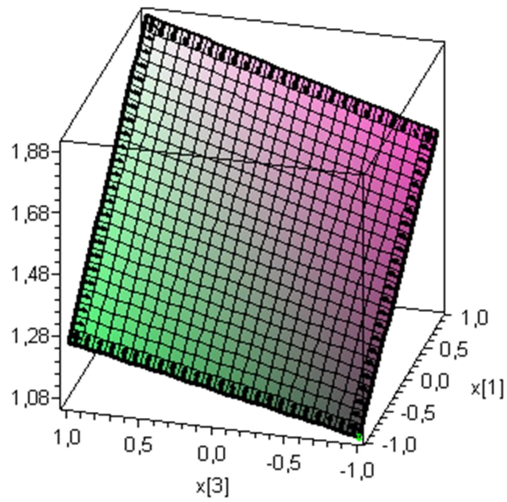


Figure 5 3D model and optimal value of function (1) for option 4

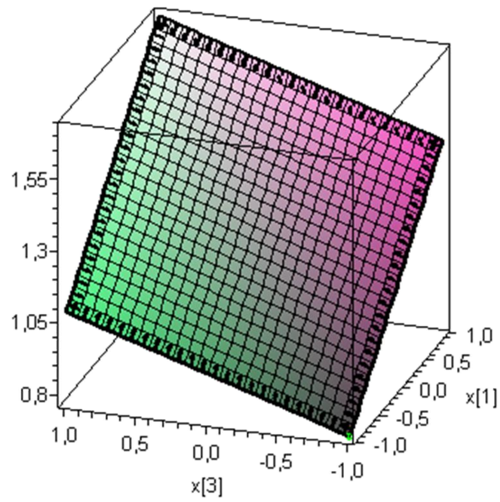


Figure 6 3D model and optimal value of function (1) for option 5

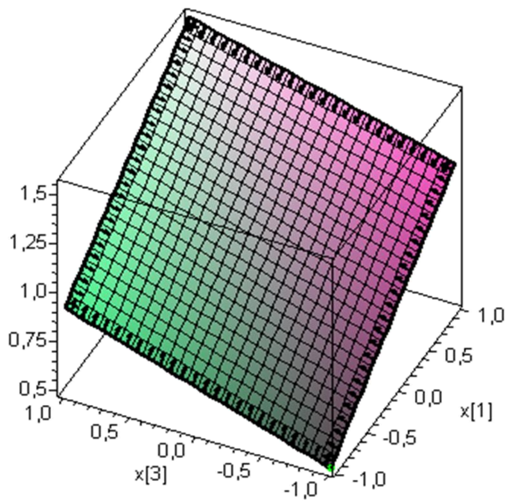


Figure 7 3D model and optimal value of function (1) for option 6

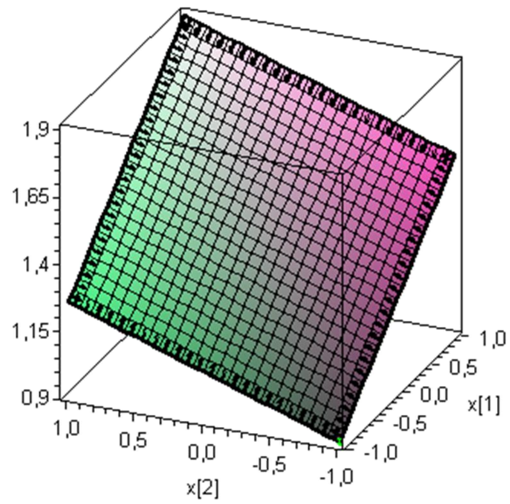


Figure 8 3D model and optimal value of function (1) for option 7

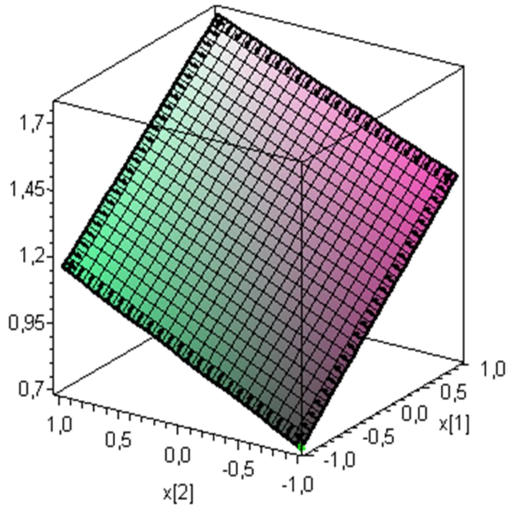


Figure 9 3D model and optimal value of function (1) for option 8

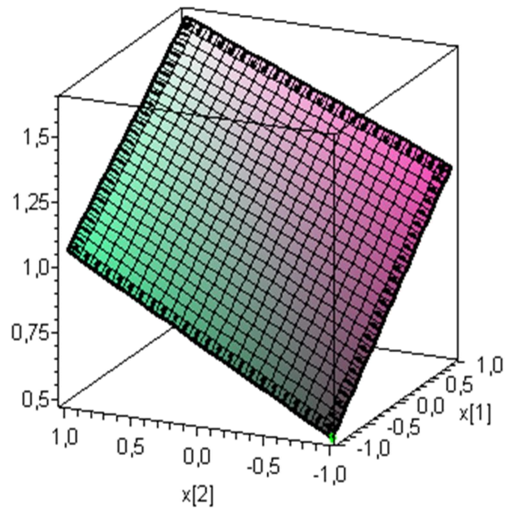


Figure 10 3D model and optimal value of function (1) for option 9

4 CONCLUSIONS

In the present work, the function connecting the output parameter with the input factors of the TMF process is investigated. A quality criterion is selected for an output parameter.

The change of the color shade of the main TMs after TMF was chosen as a quality criterion. The study aims to find those values of the input factors at which the output parameter has an optimal value. Nine different options of combinations of input factors were studied.

Table 3 Optimal combinations of the natural factor levels and the output parameter

Option №	Optimal values of the quality criterion Y_i (X_1, X_2, X_3)	X_1 [N/cm^2]	X_2 [°C]	X_3 [g/m^2]
1	1.2075	40	120	173
2	0.85	25	120	173
3	0.4925	10	120	173
4	1.0625	10	150	173
5	0.7775	10	135	173
6	0.4925	10	120	173
7	0.9175	10	120	213
8	0.705	10	120	193
9	0.4925	10	120	173

The following conditions are met for each option:

- one of the factors is considered a constant;
- the other factors belong to the range of values for which the mathematical model of the TMF process has been created;
- each factor, which is taken as a constant, sequentially takes the coded values: (+1), (0), (-1) (in three different options).

The optimal values of the quality criterion are determined for each option. The optimization is performed with a modern specialized software product Maple. The levels of the input factors at which the output parameter is optimal for the studied options are established. The optimal value of the selected quality criterion *Yi=0.4975* is reached at the following values of the input factors: the pressure *P=10 N/cm^2*, the temperature of the pressing plates *T=120°C* and the mass per unit area of basic textile materials *M=173 g/m^2*.

3D images of the combinations of factor levels and the corresponding value of the quality criterion for each option are designed.

The study illustrates the characteristics of the TMF process. Conditions are created for quick and easy finding of optimal combinations of input factors and output parameters in the real production. With the application of scientific methods, an effective solution to real technological problems in the garment industry has been proposed.

5 REFERENCES

1. Gries T., Lutz V., Niebel V., Saggiomo M., Simonis K.: Automation in quality monitoring of fabrics and garment seams, chapter 14 in Automation in Garment Manufacturing, The Textile Institute Book Series, 2018, pp. 353-376, https://doi.org/10.1016/B978-0-08-101211-6.00014-8
2. Andonova S.: Analysis of factors influencing the process of thermos-mechanical sticking in the sewing industry, Journal of Multidisciplinary Engineering Science and Technology 6(10), 2019, pp. 10884-10887, http://www.jmest.org/wp-content/uploads/ContentOctober2019.pdf
3. Petrov H.: Research on the creation of high-performance technologies and equipment for the sticking of textiles, TU Sofija - University Press, Sofia, Bulgaria, Dissertation thesis, 1991, (in Bulgarian)
4. Motejl V.: Machines and equipment in clothing production, SNTL, Praha, 1984 (in Czech)

5. Dimitrienko Yu.I., Dimitrienko I.D.: Modeling and simulation of textile composite plates under a punching load, Applied Mathematics and Computation 364, 2020, Article no. 124660, https://doi.org/10.1016/j.amc.2019.124660
6. Damyanov G., Germanova-Krasteva D.: Textile Processes: Quality Control and Design of Experiments, NY: Momentum Press, 2012, 240 p., ISBN: 9781606503874
7. Andonova S.: Mathematical modeling of the thermo-mechanical fusing process Vlakna a textil (Fibres and Textiles) 27(2), 2020, pp. 3-7
8. Andonova S.: An influence of fusing conditions on the change of color shade in the production of clothing, Tekstilec accepted
9. Andonova S., Stefanov A., Amudzhev I.: An investigation of the thermo-mechanical fusing process of innovative textile material, Industria Textila Journal, accepted
10. Wu L Yick K.I., Ng S.P., Yip J., Kong K.H.: Parametric design and process parameter optimization for bra cup molding via response surface methodology, Expert Systems with Applications 39(1), 2012, pp. 162-171, https://doi.org/10.1016/j.eswa.2011.07.003
11. Mital K., Mohan C.: Optimization methods in operation research and system analysis, 3rd edition, Springer, 2004, e-book, https://books.google.bg/books?id=_uMQQyWjoPoC&printsec=frontcover&dq=Optimization+approach&hl=bg&sa=X&ved=2ahUKEwji2cHIk6PrAhUmBhAIHYJNCuoQ6AEwBnoECAYQAg#v=onepage&q=Optimization%20approach&f=false,
12. Yang X., Teo K., Lou C.: Optimization Methods and Applications, Springer, 2001, e-book, https://books.google.bg/books?id=UwDqBwAAQBAJ&printsec=frontcover&dq=Optimization+approach&hl=bg&sa=X&ved=2ahUKEwjK4-aalaPrAhUNtYsKHbTzB-E4ChDoATACegQIAhAC#v=onepage&q=Optimization%20approach&f=false
13. Pappalardo E., Pardalos P., Stracquadanio G.: Optimization Approaches for Solving String Selection Problems, Springer, 2013, e-book, https://books.google.bg/books?id=y-u3BAAAQBAJ&pg=PA20&dq=Optimization+approach&hl=bg&sa=X&ved=2ahUKEwjK4-aalaPrAhUNtYsKHbTzB-E4ChDoATAFegQIBhAC#v=onepage&q=Optimization%20approach&f=false
14. Pardalos P.: Approximation and Complexity in Numerical Optimization: Continuous and Discrete Problems, Springer, 2000, e-book, https://books.google.bg/books?id=cTatx1hWWEAC&pg=PA92&dq=Optimization+approach+approximation&hl=bg&sa=X&ved=2ahUKEwjG5KDamKPrAhUQt4sKHdvZBGs4ChDoATAAegQIABAC#v=onepage&q=Optimization%20approach%20approximation&f=false

MATTRESS TOPPER WITH TEXTILE ECG ELECTRODES

Branko Babušiak[1], Maroš Šmondrk[1], Ľudmila Balogová[2] and Michal Gála[1]

[1]Department of Theoretical Electrical Engineering and Biomedical Engineering, Faculty of Electrical Engineering and Information Technologies, University of Žilina, Univerzitná 1, 010 26 Žilina, Slovak Republic
[2]VÚTCH-CHEMITEX, spol. s r.o., Rybníky 954, 011 68 Žilina, Slovak Republic
branko.babusiak@fel.uniza.sk; balogova@vutch.sk

Abstract: *The contribution focuses on construction design and verification of functionality of a mattress topper with incorporated textile ECG electrodes, designed for sensing, transmission and monitoring electrical activity of hearth (ECG) without direct contact with human skin. Sensoric part of the mattress topper consists of a system of active textile capacitive ECG electrodes made from electroconductive textiles incorporating microelectronics. The ECG electrodes are together with a grounding electrode integrated into construction of a cover of the mattress topper. The measuring segment comprises an independent control unit, receiving and processing the measured biomedical data and transmitting them to a computer for further processing. A prototype of a cover of the mattress topper has been developed on the base of an own proposal and its functionality has been verified experimentally by direct measurement of the ECG signal generated by a probant's body.*

Keywords: *textile electrode, capacitive sensing.*

1 INTRODUCTION

Electrocardiogram (ECG) sensing represents a traditional diagnostic method often used to monitor human health and diagnose potential cardiovascular diseases. The conventional method of ECG sensing uses electrodes and electroconductive gel in direct contact with skin surface of an examined person. A special feature of this type of measurement is high quality of measured signal due to low transfer resistance between the electrode and the skin (when using an electroconductive gel). On the other hand, long-term measurement is discomfortable and can cause allergic skin reaction in some cases.

In recent years, capacitive sensing of ECG signal avoiding direct conductive contact between the electrode and the skin of an examined person is being developed. This unconventional method of capacitive sensing has been successfully integrated e.g. into office armchairs, car seats or beds [1, 2]. Monitoring of heart rate variability during sleep based on capacitively coupled textile electrodes on a bed was described by the scientists from Seoul National University, College of Medicine, Seoul, Korea. They developed and tested a capacitively coupled ECG measurement system on a bed using capacitively coupled electrodes and conductive textiles [3]. Scientists from Research and Development, Daimler AG Boeblingen, Germany developed a system of non-obtrusive ECG measurement by capacitive sensors in various patient fitments, e.g. stretchers, hospital beds, wheelchairs etc. They compared contact and contactless ECG measurements by shielded textile electrodes to display the potential of contactless monitoring of human vital functions [4]. Results of the experiments showed that the contactless recordings are of sufficient quality and that they can be used for further standard ECG analysis like QRS-complex detection.

An own proposal of a cover of a mattress topper incorporating a system of ECG electrodes based on electroconductive textiles is described in this contribution. The innovation is our developed application and evaluation device for displaying and archiving the ECG of a person lying on mattress topper.

2 DESIGN AND CONSTRUCTION

2.1 Capacitive measurement of ECG

Principle of capacitive ECG sensing is shown in Figure 1. An active ECG electrode constitutes one plate of a plate condenser and surface of human skin constitutes the second plate of the plate condenser. A dielectric layer is placed between these two plates; the most frequently this layer is a layer of cotton clothing in which a lying person is dressed during measurement. Capacity of such a condenser is calculated according to the formula:

$$C = \varepsilon_0 \varepsilon_r \frac{S}{d} \tag{1}$$

where: *S* is surface of condenser plate, *d* is distance between the condenser plates ε_0 is permittivity of vacuum and ε_r is dielectric permittivity.

If surface of an electrode is 25 cm^2 (5x5 cm), dielectric material is a cotton fabric with 0.5 mm thickness and 2.077 permittivity [5], capacity of the plate condenser will be approximately 92 pF.

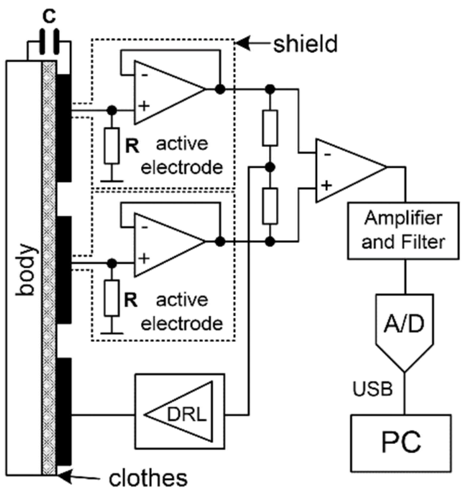


Figure 1 Block diagram of capacitive ECG sensing

The active ECG electrode incorporates a low-noise operational amplifier in connection of a voltage tracker. Static charge of the condenser is discharged by means of *R* resistor. Combination of *C* condenser with *R* resistor creates a filter whose limit frequency is calculated according to the formula:

$$f_c = \frac{1}{2\pi RC} \tag{2}$$

If value of the resistor will be 2 GΩ, then the limit frequency of the filter will be 0.87 Hz. Such a filter will enable to remove unacceptable biological artefact caused by breathing.

2.2 Textile sensors and ECG electrodes

An advantage of textile electrodes is pleasant hand, elasticity and ability to adapt to contours of a human body what enhances comfort of a man during ECG measurement. Several types of conductive fibres and textiles with various functional properties are available on the market at present. An electroconductive single jersey with specific electric resistance of 1.5 Ω/10 cm has been used in construction of the textile ECG electrodes. This single jersey is made from 100% fibre with core from polyamide and shell from pure silver. The single jersey is 0.2 mm thick and weighs of 180 g/m^2. The electroconductive fabric was used to prepare eight textile sensors (Figure 2a) with dimensions of 5x5 cm (negative electrodes) and one textile sensor with dimensions of 5x30 cm (positive electrode). The sensors constitute a sensing component of the active ECG capacitive electrodes. Electronics of the ECG electrodes has been placed on a flexible board and connected conductively with the textile sensor. The electrically conductive knitted fabric, which was used to prepare the textile sensors, was also used to shielding the electronics (Figure 2b). Construction of the ECG electrode is shown in Figure 2.

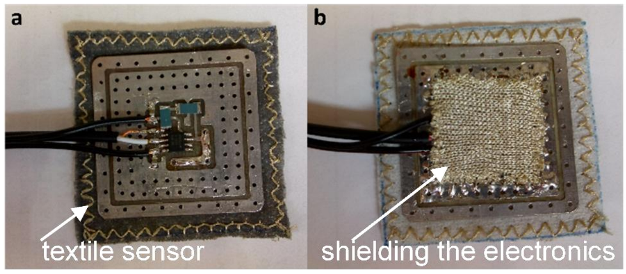


Figure 2 Active ECG electrode. Setting of the electronic components from the back side of the electrode (a), shielding the electronics by a conductive fabric (b)

2.3 Proposal of a cover of the mattress topper

Sensoric component of the cover of the mattress topper are active ECG capacitive textile electrodes (8 pcs) with incorporated microelectronics (marked 1 up to 8) and a reference active ECG capacitive textile electrode (marked 0). Setting of the electrodes on the upper face side of the cover of the mattress cover is shown in Figure 3. A passive DRL electrode, placed on the cover of the mattress topper as well, is used to supress technical artefacts, primarily interferences from the electrical power network. The ECG electrodes constitute an eight lead system of ECG measurement, where the electrodes No. 1-8 are negative electrodes and electrode No. 0 is a positive one. Connection of the electrodes is placed under the cover of the mattress topper and terminated by 25 outlet connector connected to the control unit.

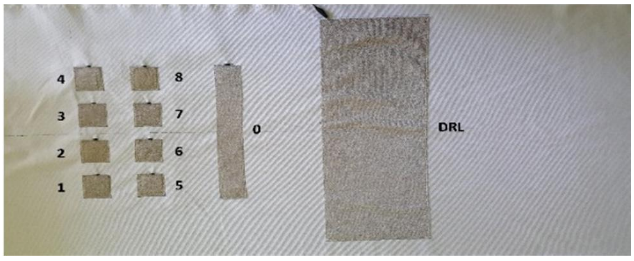


Figure 3 A prototype of the cover of the mattress topper

The control unit collects signals from the electrodes, performs further analogical processing, digitalisation of the signals and their transmission to a computer by means of universal serial bus (USB) interface. A basic component of the control unit is an integrated eight-channel circuit ADS1198, 16-bit analogue-digital (AD) transducer with internal reference and adjustable amplification and sampling frequency. The ADS1198 chip is controlled by ATmega328P microcontroller by means of serial peripheral interface (SPI). The microcontroller provides communication with a personal computer by means of universal asynchronous receiver transmitter (UART), which is converted to the USB interface by FT232RL converter. A prototype of the control unit and its connection to the cover of the mattress topper is shown in Figure 4.

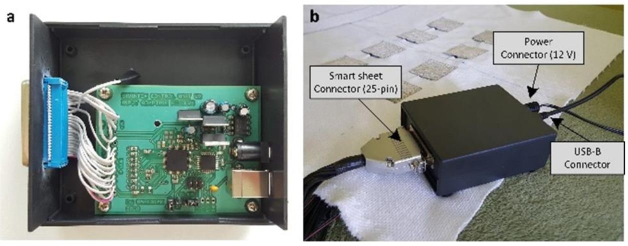


Figure 4 A prototype of the control unit (a) and its connection to the cover of the mattress topper

3 RESULTS AND DISCUSSION

Functionality of the cover of the mattress topper has been evaluated on a person lying on his back for 1 hour (Figure 5). The subject wore nightdress made from 100% cotton fibre. Sampling frequency was adjusted to 250 Hz. Amplification was adjusted to value 6 for all channels with the exception of channel No. 2 and No. 3.

Figure 5 A probant lying on the developed mattress topper

Signal in these channels exceeded the range on amplification 6 and therefore amplification in these channels was reduced to 4. DRL circuit was active and signal for DRL circuit was derived from all input channels. Raw ECG record is shown in Figure 6. The channels are arranged in lines, i.e. channels No. 1 and No. 2 are shown in the first line. It is obvious from the figure that signals in the channels are influenced by noise differently and show also different offset. This phenomenon is caused by local differences in distribution of electrical potential on the skin, accumulation of static charge and different pressure of the electrodes.

Although DRL circuit has been used and electronics of the active electrodes have been shielded, the output signals comprise considerable noise on the frequency of 50 Hz as it is evident from the power spectral density (PSD) in Figure 7.

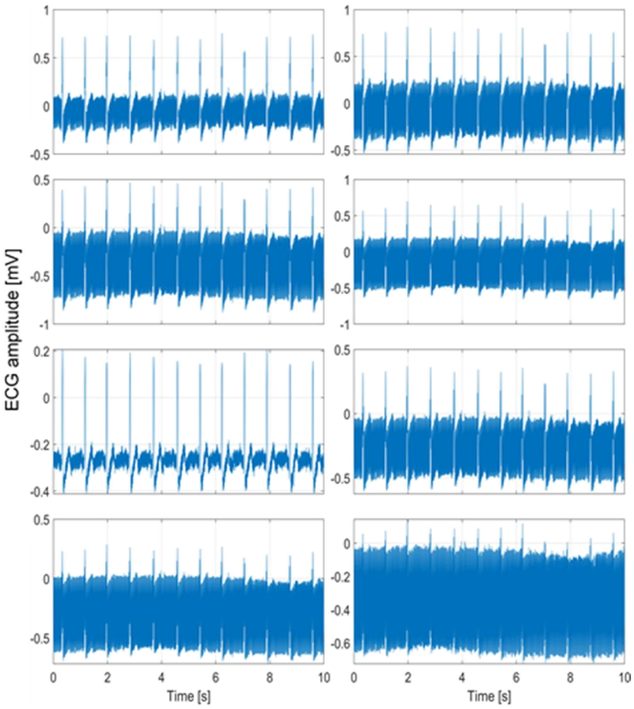


Figure 6 Raw eight-channel ECG record measured from the cover of the mattress topper

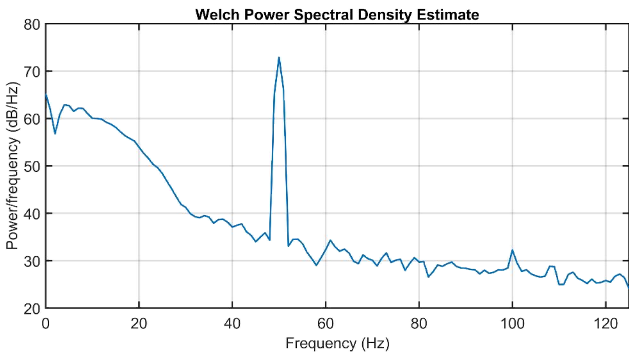


Figure 7 Power spectral density (PSD) of the channel

A narrow-band filter for 50 Hz, applied to all channels, has been proposed to reduce the noise. ECG record after application of the filter is shown in Figure 8.

The main problem is electrostatic charge and movement artefacts. The movement artefact causes saturation of the operational amplifier inputs and it can take even several seconds until the signal has been stabilised again. Solution of this problem consists in application of a special electronic circuit grounding temporarily inputs of the operational amplifier as soon as a signal gets outside the measuring range [6].

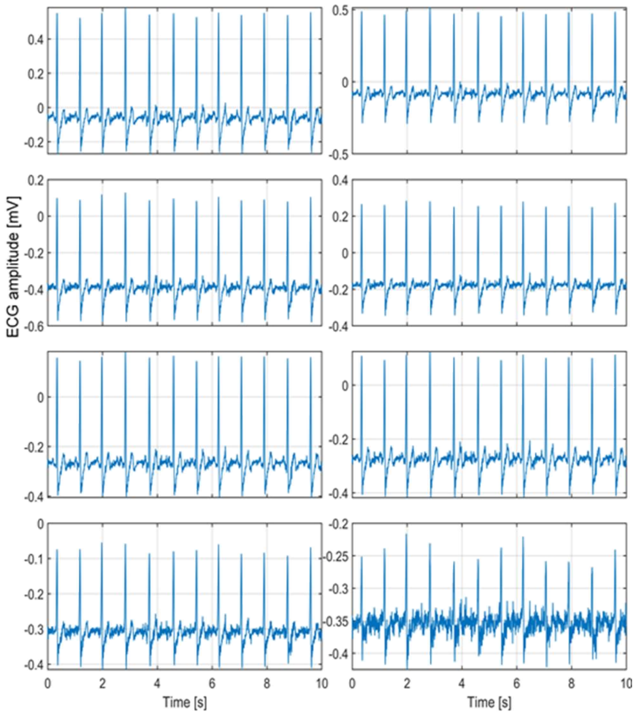


Figure 8 Filtered eight-channel ECG record measured from the cover of the mattress topper

4 CONCLUSION

The proposed prototype of the cover of the mattress topper enables ECG monitoring on capacitance principle in lying position. This method of measurement is comfortable in comparison with the standard sensing – it is not necessary to apply any electroconductive gel, attach the electrodes, power cables and carry data collection unit. These advantages enable comfortable ECG monitoring not only in the hospitals but also remote monitoring in the home environment. Further enlargement of functionalities of the designed mattress topper will be implementation of textile position sensors into construction of the topper. Their task will be to monitor movement of a patient and improve sensing of ECG signal from the textile active ECG electrodes. We are currently working on the protection of textile ECG electrodes from damage during maintenance by washing, chemical cleaning and mechanical damage, e.g. abrasion.

ACKNOWLEDGEMENT: *This contribution has been supported by the Slovak Research and Development Agency on the basis of contracts No. APVV-14-0519, APVV-16-0190 and APVV-18-0167.*

This contribution has been supported by the project "Research on technologies and products for smart and technical textiles (VY-INTECH-TEX)" ITMS: 26220220134, under financial support by the European Regional Development Fund (ERDF) and the Ministry of Education, Science, Research and Sport of Slovak Republic, contract no. 137/2010/2.2/OPVaV.

Podporujeme výskumné aktivity na Slovensku / Projekt je spolufinancovaný zo zdrojov EÚ

5 REFERENCES

1. Lim Y.G., Hong K.H., Kim K.K., Shin J.H., Lee S.M., Chung G.S., Baek H.J., Jeong D-U., Park K.S.: Monitoring physiological signals using nonintrusive sensors installed in daily life equipment, Biomedical Engineering Letters 1(1), 2011, pp. 11-20, https://doi.org/10.1007/s13534-011-0012-0
2. Lim Y.G., Lee J.S., Lee S.M., Lee H.J., Park K.S.: Capacitive measurement of ECG for ubiquitous healthcare, Annals of Biomedical Engineering 42(11), 2014, pp. 2218-2227, https://doi.org/10.1007/s10439-014-1069-6
3. Lee H.J., Hwang S.H., Yoon H.N., Lee W.K., Park K.S.: Heart rate variability monitoring during sleep based on capacitively coupled textile electrodes on a bed, Sensors 15(5), 2015, 11295-11311, DOI: 10.3390/s150511295
4. Chamadiya B., Mankodiya K., Wagner M., Hofmann U.G.: Textile-based, contactless ECG monitoring for non-ICU clinical settings, Journal of Ambient Intelligence and Humanized Computing 4(6), 2013, pp 791-800, https://doi.org/10.1007/s12652-012-0153-8
5. Lesnikowski J.: Dielectric permittivity measurement methods of textile substrate of textile transmission lines, Przeglad Elektrotechniczny 88(3A), 2012, pp. 148-151
6. Spinelli E., Haberman M., Garcia P., Guerrero F.: A capacitive electrode with fast recovery feature, Physiological measurement 33(8), 2012, pp. 1277-1288, https://doi.org/10.1088/0967-3334/33/8/1277

POLYPROPYLENE AND POLYAMIDE FIBRES CONTAINING PHOTOLUMINESCENT PIGMENTS

Ľudmila Balogová, Katarína Ščasníková and Mária Húšťavová

Research Institute for Textile Chemistry (VÚTCH) – CHEMITEX, spol. s r.o., Rybníky 954, 011 68 Žilina, Slovak Republic
balogova@vutch.sk

Abstract: *This article is focused on evaluating the efficiency of special protective photoluminescent pigments in polypropylene (PP) and polyamide (PA) fibres and textiles. The polypropylene and polyamide fibres have been prepared during our research by an innovative spinning technology using progressive polymer dispersions (concentrates) containing 0.01 wt.% and 0,1 wt.% of the photoluminescent organic pigment UVB, EOB3 and H-KSN. Processability of the developed fibres has been evaluated in the construction of single jersey fabrics. Degree of efficiency of the photoluminescent pigments in PP and PA fibres and fabrics has been evaluated objectively by change of color expression by means of the color coordinate b* in CIE LAB color space using ULTRASCAN XE spectrocolorimeter according to the standard STN ISO 105-J03 and by optical expression of the photoexcitation initiated by absorption of photons of electromagnetic radiation under UV lamp with a LED bulb. Intensity of optical excitation during detection under UV light creates an individual pattern enabling clear identification of the photoluminescent fibres in order to protect products against counterfeiting and ensure their authenticity and originality. There are mentioned also the results from evaluation of selected human-ecological properties of PP fibres containing the photoluminescent pigments and further possibilities of their application in the textile and clothing products.*

Keywords: *photoluminescent pigments, photoluminescent PP and PA fibres, photoexcitation, originality protection.*

1 INTRODUCTION

The long-lasting problem of the high amount of counterfeit products in the market and the growing trend of direct annual losses from infringements of intellectual property rights of trademark owners and legitimate OEMs are forcing manufacturers to look for new ways and solutions to be a step further than counterfeiters, to protect their name, brand, but especially the quality of their products. In addition to originality, counterfeits in most cases do not meet the requirements for the protection of human health, safety and quality of materials used, and in many cases are harmful to health [1, 2].

Photoluminescent dyes and pigments, which exist in organic and inorganic form, are mainly used to control the protection of the originality of the products [3]. One of the solutions is the application of photoluminescent pigments to textile fibres. These identification elements can be incorporated into textile and clothing products and will ensure the protection, originality and authenticity of products on the market. Optical excitation of photoluminescent pigments when detected under an ultraviolet (UV) lamp creates an individual spectral pattern that allows clear authentication of the product.

The effects which involve energy absorption and subsequent light emission are generally classified as luminescence [4]. Light is created as a result of the excitation of the electrons or molecules from their standard state by the radiation of this obtained excess energy during the transition of electrons to the original state. Such excitation of electrons can be caused by many ways, for example, by irradiation a textile with ultraviolet, infrared, visible or other radiation [5, 6]. For textile products made of unmodified polymer fibres, it is possible to ensure the protection of their originality by using security protection patterns made of photoluminescent polymer fibres in products, e.g. by embroidering the manufacturer's logo on the finished product, resp. by integrating the security label. Verification of patterns under a UV lamp will reveal hidden security patterns confirming the authenticity of the document [7].

This article focuses on the solution how to protect the product originality by using the polypropylene (PP) and polyamide (PA) fibres and progressive dispersions (concentrates) with a content of 0.01 and 0.1 wt.% of special protective photoluminescent (PL) blue organic pigments UVB, EOB3 and H-KSN and verification of their application in selected textile products.

2 EXPERMENTAL PART

2.1 Materials used

As part of our own research, the following types of shaped fibres with a fineness of 170 dtex were prepared:

a) *PP fibres* with content of PL blue pigment *UVB* with a concentration of 0.01 and 0.1 wt.%;

b) *PP fibres* with content of PL blue pigment *EOB3* with a concentration 0.01 and 0.1 wt.%;

c) *PA fibres* with content of PL blue pigment *UVB* with a concentration of 0.01 and 0.1 wt.%;

d) *PA fibres* with content of PL blue pigment *EOB3* with a concentration 0.01 and 0.1 wt.%;

e) *PA fibres* with content of PL blue pigment *H-KSN* with a concentration 0.01 and 0.1 wt.%;

f) shaped standard (unmodified) PP and PA fibres without photoluminescent (PL) pigment content.

PP and PA fibres were used to produce single jersey (100% quality component). An overview and designation of the prepared knitted fabrics is given in Table 1. The textile processability of the prepared PP and PA fibres was good without defects.

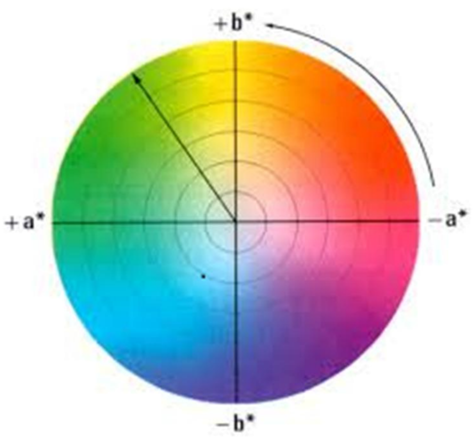
Table 1 Identification of fibres and knitted fabrics prepared from standard and photoluminescent PP and PA fibres

Fibres	Knitted fabrics
PP/FT/standard	PP/P
PP/UVB/0.01%	PP/UVB/0.01/P
PP/UVB/0.1%	PP/UVB/0.1/P
PP/EOB3/0.01%	PP/EOB3/0.01/P
PP/EOB3/0.1%	PP/EOB3/0.1/P
PA/FT/standard	PA/P
PA/UVB/0.1%	PA/UVB/0.1/P
PA/EOB3/0.1%	PA/EOB3/0.1/P
PA/H-KSN /0.1%	PA/H-KSN/0.1/P

2.2 Methods for evaluating the effectiveness of radiation intensity

The research solution for evaluating the efficiency of radiation intensity of photoluminescent blue organic pigments UVB, EOB3 and H-KSN (containing 0.01 and 0.1 wt.% of protective photoluminescent pigment) of developed PP and PA fibres and textiles prepared from them was performed by two methods:

- *objectively by changing the color expression* defined by the color coordinate b* in the CIE LAB color space on the ULTRASCAN XE according to the STN ISO 105-J03 standard. The color coordinate b* defines the shades between yellow and blue and it is a symbol for all differences between the two colors (2 color points or the coordinates of 2 color points). The intensity of the blue radiation depends on the shift of the measured value b* in the a, b diagram according to the b-axis (Figure 1a). Shifting the b* coordinate to positive values (+b*) causes the transition of the color to an area that approaches to the spectrum of yellow color. Shifting the b* coordinate to negative values (-b*) causes the color transition to an area that approaches to the blue color spectrum. The lower (more negative) the measured value of b*, the more significant the intensity of the blue light emission of the tested sample [8].
- *optical demonstration of photoexcitation* (radiation emission) initiated by the absorption of photons of electromagnetic radiation under a UV lamp with an LED lamp Nitecore CU 6 Chameleon (Figure 1b). When using a UV lamp, a physical effect is observed. The fiber / textile material containing 0.01 and 0.1 wt.% the photo-luminescent pigment emits more blue light than the pigment-free fabric.



a)

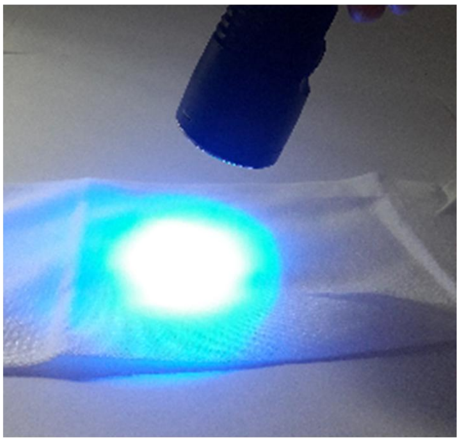

b)

Figure 1 CIELAB color space (a) and optical expression of blue light when using a UV lamp (b)

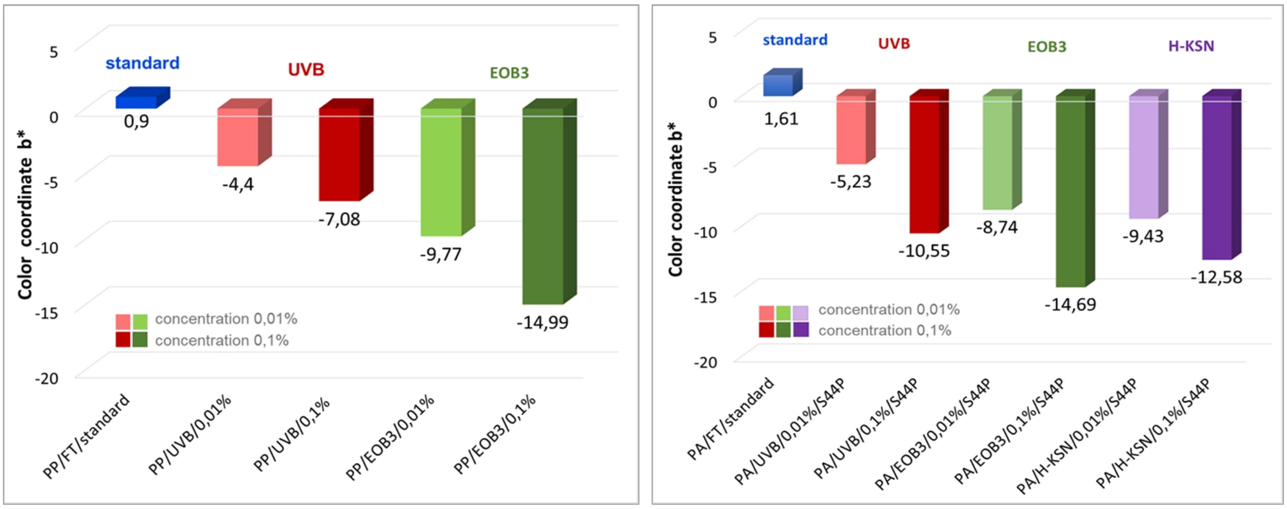
3 RESULTS AND DISCUSSION

3.1 Evaluation of the efficiency of radiation intensity of photoluminescent PP and PA fibres

The degree of effectiveness of PL pigments was evaluated in the developed PP and PA fibres without content (standard) and with a content of 0.1 and 0.01 wt.% of PL pigments UVB, EOB3 (PP fibres) and UVB, EOB3, H-KSN (PA fibres) using an objective instrumental method by determining the change in color expression which is defined by the color coordinate b* on the PP/PA fibres coils. The results are shown in Figure 2. PP fibres with a content of 0.1 wt.% PL pigment EOB3 has a 110 % higher intensity of blue light emission than PP fibres with the same content (0.1 wt.%) of PL pigment UVB and also 50% higher than PP fibres with content of 0.01 wt.% PL pigment EOB3. The most significant intensity of blue light emission was achieved in PP fibres with a content of 0.1 wt.% PL pigment EOB3. The color coordinate "b*" of these fibres is at the level -14.99.

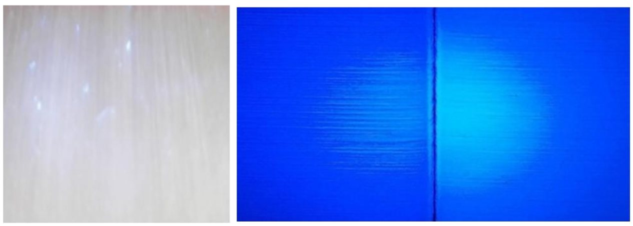
As with PP fibres, it was confirmed that the PA fiber with a content of 0.1 wt.% of PL pigment EOB3 has a higher intensity of blue light emission than PA fiber with the same content (0.1 wt.%) of PL pigment UVB (40% higher) resp. H-KSN (17% higher) and as a PA fiber with a content of 0.01 wt.% of PL pigment EOB3 (68% higher). The most significant intensity of blue light emission was achieved with PA fiber containing 0.1 wt.% of PL pigment EOB3. The color coordinate b* of this fiber is -14.69.

PP and PA fibres and fabrics with and without PL pigment are white in daylight and cannot be recognize with the naked eye. When using a UV lamp, a physical phenomenon is observed. Textile material containing PL pigment emits more light than fabrics without PL pigment. On the prepared textile materials containing PL pigment an optical excitation emitting a blue color was observed with the naked eye, which allows significant identification of the product containing the photoluminescent additives.



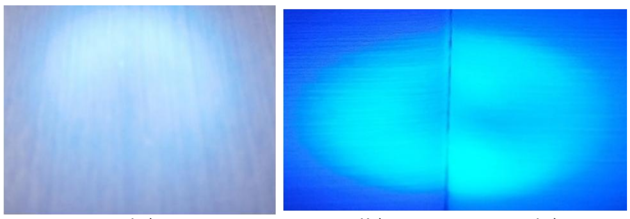
a) b)

Figure 2 Intensity of color expression of: a) PP fibres of without content (standard) and with content of 0.1 and 0.01 wt.% UVB and EOB3 photoluminescent pigments; b) PA fibres without content (standard) and with the content of 0.1 and 0.01 wt.% photoluminescent pigments UVB, EOB3 and H-KSN



3a) 3b) 3c)

Figure 3 Color intensity of PP fiber: a) standard PP fiber, b) PP fibres with a content of 0.01 wt.% PL pigment EOB3; c) PP fiber with a content of 0,1 wt.% PL pigment EOB3



4a) 4b) 4c)

Figure 4 Color intensity of PA fiber: a) standard PA fiber, b) PA fibres with a content of 0.01 wt.% photoluminescent pigment EOB3 and c) PA fibres with a content of 0.1 wt.% photoluminescent pigment EOB3

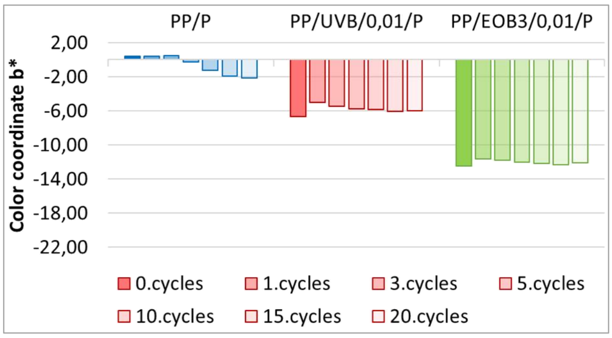
3.2 Verification of the permeability of the efficiency of photoluminescent pigments in PP and PA fibres

Verification of the permanence of the photoluminescent pigments UVB, EOB3 in PP and photoluminescent pigments UVB, EOB3 and HKS-N in PA fibres (concentration 0.01 and 0.1 wt.%) used in the construction of textiles (knitted fabrics) was performed after 1, 3, 5, 10, 15, 20 maintenance cycles by washing and drying, followed by evaluation of the color coordinate b* on the ULTRASCAN XE instrument and optical manifestation of photoexcitation under a UV lamp. The maintenance of textiles was performed in accordance with the standard STN EN ISO 6330: 2012 by the procedure 4N at the water temperature 40±2°C using the reference detergent 3 (ECE - phosphate-free powder detergent without optical brightener and without enzymes). Drying was performed according to procedure C: drying in a horizontal position in the spread state. The effect of washing on the change in the color coordinate b* of fabrics containing the above-mentioned PL pigments is shown in the graphs in Figure 5.

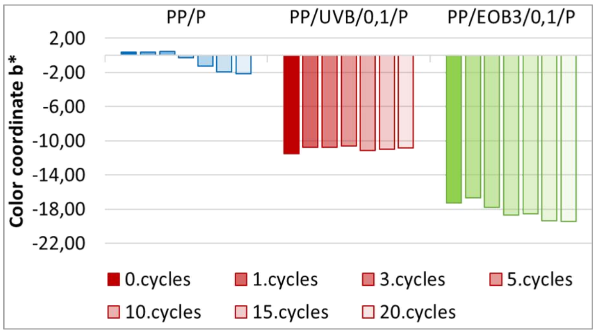
The trend of the decrease/increase in the intensity of the color expression of the photoluminescent pigment UVB in the PP fiber due to washing is comparable at both concentrations. The biggest decrease was always observed after the first washing cycle, when the photoluminescent pigment was apparently washed from the surface of the fiber. As the number of washing cycles increased, the intensity of the color expression changed continuously. After 20 cycles of washing, the decrease in the intensity of color expression was observed in the knitted PP fabrics containing PL pigment UVB at both concentration levels in the comparison with the knitted fabrics containing PL pigment EOB3. The difference in the intensity of radiation can be considered as statistically insignificant, as it could have arisen as a result of the same influences, including the influence of the fabric construction (knitted fabrics - change in density during handling).

<u>*Knitted fabrics prepared from PA fibres*</u> with a content of 0.1 wt.% of the UVB photoluminescent pigment, even after 20 washing cycles, had the same intensity of blue light emission as before washing. After 20 washing cycles of knitted fabrics prepared from PA fibres with a content of 0.1 wt.% of the photoluminescent pigment EOB-3 the color intensity increased +6% higher.

After 20 washing cycles of knitted fabrics prepared from PA fibres with a content of 0.1 wt.% of the photoluminescent pigment H-KSN the color intensity decreased -10%.



a)



b)

Figure 5 Influence of washing on the change of color coordinate b* of knitted fabrics: a) PP knitted fabrics with concentration 0.01 wt.% photoluminescent pigment UVB and EOB3 in the fiber; b) PP knitted fabrics with concentration 0.1 wt.% photoluminescent pigment UVB and EOB3 in the fiber

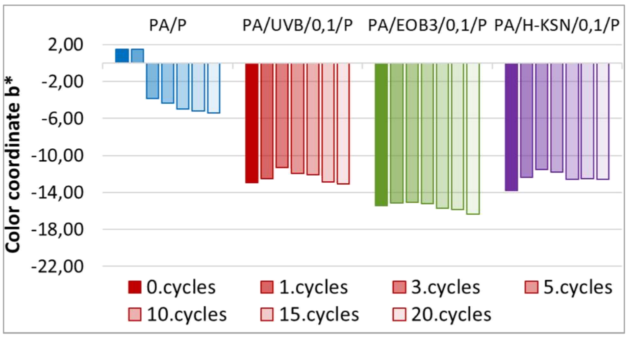


Figure 6 Influence of washing on the change of the color coordinate b* in PA knitted fabrics with a concentration of 0.1 wt.% pigment in the fiber

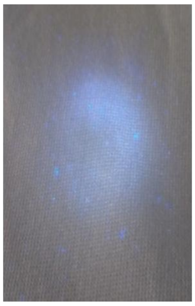
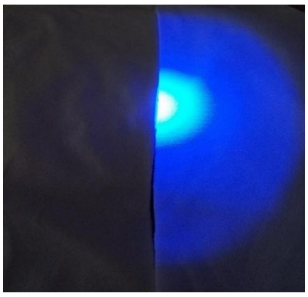
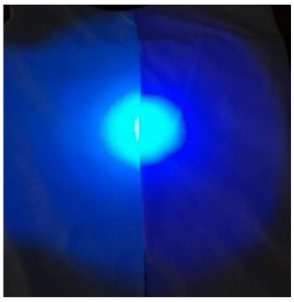

7a)

7b)

7c)

Figure 7 Intensity of color expression in PP knitted fabrics with photoluminescent pigment EOB3: a) knitted fabric of standard PP fiber; b) the standard knitted PP fabric on the left and the knitted fabric containing 0.1 wt.% pigment in the fiber on the right, c) the knitted fabric containing 0.1 wt.% pigment in the fiber on the left and on the right is a knitted fabric containing 0.01 wt.% pigment in the fiber

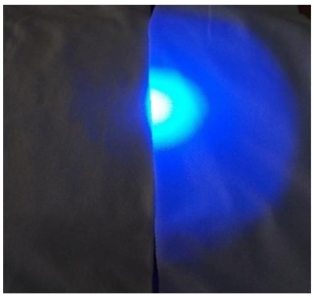


Figure 8 Intensity of color expression of PA knitted fabrics with photoluminescent pigment EOB3: on the left is a knitted fabric made of standard PA fiber, on the right is a knitted fabric containing 0.1 wt.% pigment in the fiber

The optical effect of photoexcitation in textiles (knitted fabrics) with the highest intensity of blue light emission under a UV lamp is shown in Figures 7 and 8.

3.3 The evaluation of human-ecological properties of PP and PA photoluminescent fibres

In order to demonstrate health safety, a set of analysis was performed on photoluminescent PP and PA fibres to verify the human-ecological properties and to confirm the health safety of developed PP and PA fibres with PL pigments according to the test methods of the international association OEKO-TEX® Standard 100. Analyzes were performed by 3 methods:

- by liquid chromatography (HPLC Agilent 1260 LC, 6120 MS) with diode and mass detector (LC/DAD/MS). *Alkylphenols* and *alkylphenol-ethoxylates* were determined according to OEKO-TEX® M-25 & ML-25. The analyzed samples of developed PP and PA fibres meet the required limits according to STANDARD 100 by OEKO-TEX®.
- Subsequently, the content of UV stabilizers was determined on samples of developed PP and PA fibres without and with a content of 0.1 wt.% photoluminescent pigment according to OEKO-TEX® M-28 & ML-28. The presence of forbidden UV stabilizers was not detected in any of the analyzed samples of developed PP and PA fibres and they meet the required limits according to STANDARD 100 by OEKO-TEX®.
- by atomic absorption spectrometry (SPECTRA DUO AA 240Z, AA 240 FS; AMA 254). The content of *extractable heavy metals* was determined in the samples of developed PP and PA fibres without and with a content of 0.1 wt.%. photoluminescent pigment UVB, EOB-3 (PP fibres) and UVB, EOB-3 and H-KSN (PA fibres) according to OEKO-TEX® M10 & ML-10. The performed analyzes confirmed that the laboratory samples of the developed photoluminescent PP and PA fibres do not contain harmful substances and meet the required limits according to STANDARD 100 by OEKO-TEX®.
- by gas chromatography with a mass detector (GC/MS). Determination of *polycyclic aromatic hydrocarbons (PAH)* in the samples of developed PA and PP fibres without/with content of 0.1 wt.% photoluminescent pigment UVB, EOB-3 (PP fibres) and UVB, EOB-3 and H-KSN (PA fibres) according to OEKO-TEX® M-23 & ML-23. The determined amount of PAH was below the detection limit (less than 0.3 mg/kg). According to the performed analyzes, it is clear that the analyzed textile samples do not contain harmful polycyclic aromatic hydrocarbons. Determination of *phenol, chlorinated phenols and*

orthophenylphenol (OPP) in the samples of developed PA and PP fibres without/with content of 0.1 wt.% PL pigment according to OEKO-TEX® M-7. The determined amount of chlorinated phenols was below the detection limit (for trichlorophenols, monochlorophenols and OPP less than 0.1 mg/kg and for tetrachlorophenols, dichlorophenols and PCP less than 0.05 mg/kg). The results of analyzes of the determination of OPP and chlorinated phenols indicate that these dangerous substances are not present in the tested samples.

4 CONCLUSION

The processability of the selected laboratory samples of photoluminescent PP and PA fibres into the construction of single jersey fabrics was confirmed in the laboratory. The textile processability of the developed photoluminescent PP and PA fibres into the assortment of knitted fibres was at a good level, without registration of any errors or without possible exclusion of the fiber sample. The degree of efficiency of photoluminescent pigments in developed PP and PA fibres and fabrics prepared from them was evaluated after the 20th cycle of washing by instrumental method determining color change defined by color coordinate b* and optical demonstration of photoexcitation initiated by photon absorption of electromagnetic radiation under UV lamp with LED lights. The most significant intensity of blue light emission was achieved with PP and PA fibres with a content of 0.1 wt.% photoluminescent pigments EOB3.

The measured color coordinates b* of knitted fabrics samples prepared from photoluminescent PP and PA fibres confirmed the results measured in PP and PA fiber coils in terms of selecting the most suitable type of photoluminescent pigment (EOB3) and its concentration (0.1 wt.%) in the fiber. PP and PA fibres and textiles with PL pigments as well as textiles without photoluminescent pigment are white in daylight and are not recognizable to the naked eye of the observer. When using a UV lamp, a physical phenomenon is observed. The textile material containing a photoluminescent pigment emits more light than a fabric without a photoluminescent pigment. In the prepared textile materials containing photoluminescent pigment, an optical excitation emitting a blue color was observed with the naked eye, which allows significant identification of the product containing the used photoluminescent additives. Based on the measurement of the results of human-ecological properties, the performed analyzes confirmed that the laboratory samples of the developed photoluminescent PA fibres do not contain harmful substances and meet the required limits according to STANDARD 100 by OEKO-TEX®.

ACKNOWLEDGEMENT: This work was supported by the Slovak Research and Development Agency under the Contract no. APVV-18-0187.

5 REFERENCES

1. Purvis C.: Challenges in the global man-made fibres market, Proceedings of 49th Dornbirn Man-Made Fibres Congress, 15-17 September 2010, Austria, p. 48
2. https://www.cas.sk/clanok/618514/colnici-zlikvidovali-napodobneniny-hraciek-a-textilu-v-ohni-skoncilo-21-tisic-fejkov/
3. Bamfield P.; Hutchings M.G.: Chromic Phenomena, Technological Applications of Color Chemistry, 2nd Ed., The Royal Society of Chemistry, Cambridge, 2010, ISSN 978-1-84755-868-8
4. Kitai A.: Luminescent Materials and Application, John Wiley & Sons, Ltd, 2008, ISBN: 978-0-470-058 18-3, Available from: http://kirchhoff.weebly.com/uploads/1/6/3/0/1630371/xandrea.pdf, Accessed: 2018-01-18
5. Krasovitskii B.M.; Bolotin B.M.: Organic Luminescent Materials, Weinheim NY, VCH, 2002
6. Bala R., Eschbach R., Zang Y.: Substrate Fluorescence: Bane or Boon, In Proc. 15th IS&T/SID Color Imaging Conference, Nov.2007, Albuquerque, NM, pp.12-17
7. Rossier R.; Hersch R.D.: Hiding patterns with daylight fluorescent inks, 19th Color and Imaging Conference, 2011, pp. 223-228
8. Berns R.S.: Billmeyer and Saltzman´s Principles of Color Technology, 3rd Ed., New York: John Wiley, 2000, 247 p., ISBN 04-711-9459-X

MAIN INDICATORS OF TEXTILE ENTERPRISES` FINANCIAL SECURITY ASSESSMENT

Aktam Usmanovich Burkhanov[1] and Bobir Ortikmirzaevich Tursunov[2]

[1]*Finance and Accounting Faculty, Tashkent State University of Economics, I. Karimov Street 49, 100003 Tashkent, Republic of Uzbekistan*
[2]*Economic Security Department, Tashkent State University of Economics, I. Karimov Street 49, 100003 Tashkent, Republic of Uzbekistan*
burkhanov.a.u@yandex.ru; tursunov-bobir@mail.ru

Abstract: *The relevance of the topic of developing indicators for ensuring financial security for textile enterprises increased especially during the Covid-19 pandemic. The world has developed a situation where supply and demand simultaneously stopped. The magnitude of the global economic loss due to the Covid-19 pandemic has not yet been determined. The financial security assessment takes into account external and internal threats of the enterprise. In this paper were examined the scientific, theoretical and practical aspects of financial security of enterprises and their maintenance. Due to the specific nature of textile enterprises, financial security indicators are listed. 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 methodic 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.*

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

1 INTRODUCTION

One of the most important conditions for ensuring sustainable growth and the formation of positive results of its financial activities is the existence of an effective financial security system for any enterprise, including a textile enterprise. The formation of the positive results of the enterprise financial activities is the existence of an effective system of financial security, which will protect the company from external and internal threats. But in order to form a system for ensuring financial security and evaluate the effectiveness of the entire system, it is necessary to have tools for assessing the financial security of an enterprise.

Textile industry is one of key fields of world economy, according to world statistics textile products account for 5.0% of world trade and 6.4% of industrial exports [1]. At the end of 2017, the use of production in this industry amounted to 88.0% in India, 81.2% in the Netherlands, 81.0% in China and 78.9% in Turkey. [2, 3]

In recent years, Uzbekistan has pursued a policy of accelerated modernization of the textile industry. However, the level of utilization of production capacities of textile enterprises in the republic remains low. Incomplete use of available production capacities at textile enterprises negatively affects the financial condition of the enterprise, which leads to a decrease in the return on investment. The Strategy for Action on Five Priority Directions of Development of the Republic of Uzbekistan in 2017-2021 defines priority tasks for “further modernization and diversification of the industry by moving it to a qualitatively new level, aimed at accelerating the development of high-tech manufacturing sectors, primarily for the production of finished products with high added cost based on deep processing of local raw materials” [4].

Based on the foregoing, the relevance of the topic is determined by the need to develop indicators to ensure the financial security of textile enterprises. In this study, the authors developed a methodology for assessing the financial security of textile enterprises.

2 LITERATURE REVIEW

Research related to the methodology of ensuring the financial stability of enterprises is carried out in the world's leading research centers and higher education institutions, including the American Institute for Economic Research [5], International Bank for Reconstruction and Development [6], World Bank [7], World Finance [8], World Acceptance Corporation [9], Mc Finance, World Acceptance Corporation, Columbia University (USA) [10], International Valuation Standards Council [1], LEK Consulting, Oxford University [11], UK, International Bank for Economic Cooperation, The European Group of Valuers' Associations, Strategic Management Society (Europe) [12], Russian Research Financial Institute (NIFI) [13], Moscow State University, Faculty of Finance [14], St. Petersburg University of Economics [15]. Research has been conducted in higher education schools.

A number of scientific results have been obtained as a result of research on the methodology of financial security and management of enterprises. In particular, the American Institute for Economic Research (USA) developed a methodology for valuing enterprise assets; developed a method for assessing the impact of the concept of enterprise value management on its growth (McKinsey & Co.[1], L.E.K. Consulting, HOLT Value Associates-USA); developed the principles of financial accounting of real estate (World Finance-USA); developed a conceptual framework for the presentation of fundamental values in the financial statements (Oxford University, UK, Higher School of Economics, Russia); developed profitable and cost-effective methods of valuation of the enterprise (International Valuation Standards Council-UK); The Economic Value Added method (University of Harvard-USA) was used to assess the share of investment and innovation projects in the value of enterprises.

Lawrence Haar, Laura N. Haar [16], Angela C. Lyons [17], Weimin Li [18] and others analyzed of population aging and financial security and problems of .financial option perspective on energy security and strategic storage. The theoretical foundations of financial security, as part of economic security, are dealt with by many economists. P.F. Drucker [19], R. Mayer [20], A. Blank [28], consider both the theoretical foundations and practical approaches to implementing financial security at the enterprise. R.S. Papekhin [29] analyzed methods and indicators for assessing the level of financial security of an economic entity. The problems of strategic planning of financial security at the enterprise are studied by A.V. Kirov and others [30]. The author's definition of the financial security of an enterprise expresses a certain financial condition of an enterprise, characterized by its ability to withstand existing and emerging threats, which is ensured by constant monitoring and diagnostics of its level, as well as the formation of a set of preventive and control measures.

The main objective of the financial security of the enterprise is to ensure its continued and maximum efficient functioning today and high potential for future development [21]. By economists J.F. Shao, Y. Li [22], T. Koltai, K. Stecke [23], B.O. Tursunov [24, 25] were researched some aspects of textile enterprises, as well as: production capacity, decision making in planning and others. In the other side, issues of financial security of investment funds and indicators to assess financial security of the banks were investigated by A.U. Burkhanov [26, 27].

In the process of analyzing of scientific literature, it was determined that in economic theory, financial security of an enterprise is considered, as a rule, in two aspects, or as one of the components of economic security. The main condition for ensuring a favorable and safe financial condition of the enterprise is its ability to withstand threats. The level of financial security of the enterprise will depend on how effectively its management and managers are able to identify possible threats in advance and avoid them, and neutralize the damage from their impact. But in all the above-mentioned researches, indicators of financial security assessment of textile enterprises was not considered, and we made an attempt to classificate indicators and criteria's of financial security assessment of textile enterprises, which was implemented on the textile industry.

3 ANALYSIS AND RESULTS

The financial security of enterprises largely depends on how much and how much money is at the disposal of the enterprise and in what direction they are invested. The funds of the enterprise are divided into own and borrowed funds, depending on the direction of capital used. An integral element of the study of financial security of the enterprise is its evaluation criteria. Therefore, it is necessary to form the criteria and normative levels of indicators used in the assessment and analysis of the financial security of the enterprise. There is more than one criterion for assessing a company's financial security. A system of indicators to assess the financial security of enterprises will be developed based on the characteristics of their activities.

In our opinion, the peculiarity of the textile industry is that, firstly, the production and demand are seasonal, secondly, the resources and resources in the textile industry are important, and thirdly, the external and external competition in this industry is not limited to external competition, appropriate to the purpose (Table 1).

Table 1 Indicators for assessing the financial security of enterprises

№	Name of the indicators	Calculation method	Normative degree
1	Absolute liquidity ratio	(Cash + Short-term financial investments) / Current liabilities	min 0.2
2	Rapid liquidity ratio	Liquid assets / Current liabilities	min 1.0
3	Current liquidity ratio	Current assets / Current liabilities	min 1.25
4	Financial leverage ratio	Equity / Debt liabilities	min 0.25
5	Financial margin ratio	Loans / (Assets - Debt liabilities)	max 1.0
6	Self-sufficiency ratio	Current assets / Sources of own funds	min 0.2
7	Asset utilization rate	Income from the sale of goods / Value of inventories	min 1.6
8	Return on equity	Net profit / Equity	min 0.15
9	Financial independence ratio	Sources of own funds / Balance asset	min 0.5 (optimal degree 0.65-0.75)
10	Asset return ratio	Net profit / Assets	min 0.0

Source: Compiled by the author on the basis of the sites [6-8].

Based on the above indicators, we assess and analyze the financial security of textile enterprises private enterprise "OSBORN TEXTILE" and Joint-Venture "UZTEX TASHKENT" operating in Uzbekistan.

Table 2 shows that in the analyzed years, the textile enterprise private enterprise "OSBORN TEXTILE" has met the regulatory requirements for financial leverage, capital adequacy, return on equity, financial independence (except 2014) and return on assets. This is a positive development in terms of ensuring the financial security of the Company. However, regulatory requirements for operational liquidity, absolute liquidity and asset utilization efficiency ratios have not been met. This is explained by the following reasons:

1. The non-fulfilment of the normative requirement on the liquidity ratio in the enterprise is explained by the absence of short-term investments in 2018, 2019 and a sharp decrease in the amount of cash, while short-term liabilities have a high growth rate.
   In 2019, the growth rate of short-term liabilities at the textile enterprise private enterprise "OSBORN TEXTILE" compared to 2018 amounted to 2.1 times, while cash decreased by 9.1 times.
2. Non-compliance with the normative requirement for absolute liquidity at the textile enterprise private enterprise "OSBORN TEXTILE" is explained by a sharp decrease in the amount of funds in 2019 compared to 2018 and the lack of short-term financial investments.
3. Non-compliance with the normative requirement on the coefficient of efficiency of use of assets at the textile enterprise private enterprise "OSBORN TEXTILE" is explained by the fact that the growth rate of income from the sale of goods is lower than the growth rate of inventories.
4. The financial margin ratio is one of the profit indicators that reflects the results of the main and additional activities. Margin, in contrast to profitability, is only necessary for the analysis of the internal situation of the enterprise and does not allow comparison with other enterprises.
   The fact that the coefficient of financial margin at the textile enterprise private enterprise "OSBORN TEXTILE" for the analyzed years is 0.0 and negative is explained by the imperfection of the company's practice of attracting loans and borrowings. In the analyzed years, the Company did not attract loans from commercial banks at all. Nor were his securities available.

Based on the results of the above analysis, in our opinion, the following measures should be taken to ensure that the financial security of the textile enterprise private enterprise "OSBORN TEXTILE" is met at the level of regulatory requirements:

1. In order to ensure a stable growth rate of the capital of enterprises, it is necessary to increase the volume of capital through the formation of the enterprise's issue income and retained earnings by ensuring the investment attractiveness of ordinary and preferred shares.
2. In order to ensure that the enterprise has fast and absolute liquidity ratios at the level of normative demand, first of all, it is necessary to increase the volume of short-term financial investments and cash; second, the amount of funds should not be allowed to decrease compared to the previous year; third, it is necessary to ensure that the growth rate of current assets does not lag behind the growth rate of current liabilities.
3. It is necessary to achieve a normative level of asset efficiency of enterprises by preventing the growth rate of inventories from exceeding the growth rate of gross profit from the sale of goods and increasing the turnover of inventories.

Now we will assess and analyze the financial security of another textile enterprise Joint-Venture “UZTEX TASHKENT” operating in Uzbekistan. Based on the coefficients given in Table 1, the financial security status of the textile enterprise Joint-Venture "UZTEX TASHKENT" was calculated in Table 3.

Table 2 Financial security of the textile enterprise private enterprise "OSBORN TEXTILE"

Name of the indicators	Years						
	2013	2014	2015	2016	2017	2018	2019
Absolute liquidity ratio	0.62	0.05	0.01	0.01	0.40	0.02	0.04
Rapid liquidity ratio	0.62	0.05	0.01	0.01	0.40	0.02	0.04
Current liquidity ratio	1.71	2.02	1.31	1.27	1.84	1.98	2.10
Financial leverage ratio	0.77	0.83	0.65	0.64	1.10	0.70	1.20
Financial margin ratio	-1.80	-0.10	-0.40	-0.90	0.00	0.00	0.00
Self-sufficiency ratio	0.41	0.51	0.23	0.42	0.46	0.49	0.52
Asset utilization rate	0.70	0.40	0.70	0.40	0.70	0.60	0.50
Return on equity	0.20	0.40	0.30	0.20	0.40	0.40	0.40
Financial independence ratio	0.51	0.39	0.55	0.72	0.70	0.65	0.71
Asset return ratio	0.10	0.04	0.08	0.09	0.10	0.09	0.10

Source: Calculations of authors on the basis of the annual report of textile enterprise private enterprise “OSBORN TEXTILE.

Table 3 Financial security of the textile enterprise Joint-Venture “UZTEX TASHKENT”

Name of the indicators	Years						
	2013	2014	2015	2016	2017	2018	2019
Absolute liquidity ratio	0.15	0.80	0.06	0.006	0.04	0.09	0.12
Rapid liquidity ratio	0.14	0.90	0.02	0.003	0.02	0.01	0.14
Current liquidity ratio	1.47	1.67	1.46	1.51	1.60	1.70	1.90
Financial leverage ratio	0.43	0.36	0.67	0.58	0.70	0.70	0.50
Financial margin ratio	0.39	0.47	0.24	0.23	0.21	0.10	0.10
Self-sufficiency ratio	0.32	0.40	0.32	0.67	0.80	1.10	1.30
Asset utilization rate	0.50	1.02	0.70	0.70	1.90	2.20	2.70
Return on equity	0.20	0.30	0.06	0.03	0.11	0.19	0.30
Financial independence ratio	0.31	0.37	0.45	0.42	0.41	0.35	0.49
Asset return ratio	0.01	0.00	0.00	0.00	0.02	0.01	0.02

Source: Calculations of authors on the basis of the annual report of textile enterprise Joint-Venture “UZTEX TASHKENT”.

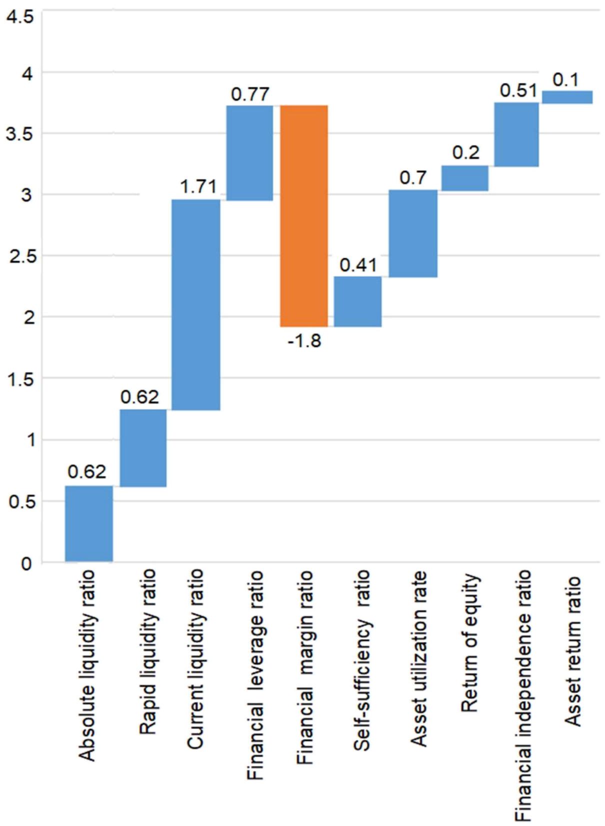


Figure 1 Diagram of financial security of the textile enterprise private enterprise "OSBORN TEXTILE"

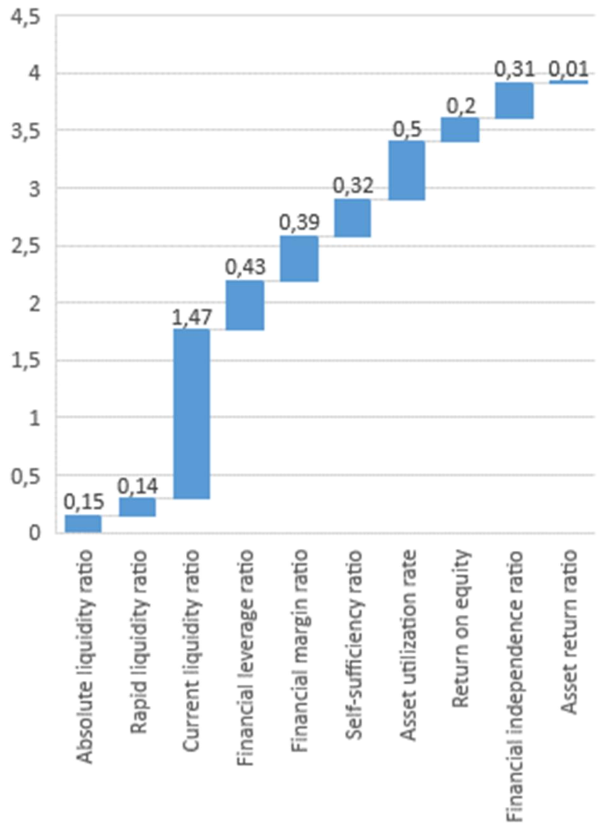


Figure 2 Diagram of financial security of the textile enterprise Joint-Venture “UZTEX TASHKENT”

In the Table 3 showed that in the analyzed years, the textile enterprise Joint-Venture "UZTEX TASHKENT" met the regulatory requirements for financial leverage, capital adequacy and return on assets. This is a positive development in terms o ensuring the financial security of the Company. However, the regulatory requirements for rapid liquidity, absolute liquidity, asset utilization efficiency and financial independence ratios have not been met.

This is explained by the following reasons:

1. Non-compliance with the normative requirements of liquidity and absolute liquidity ratios at the textile enterprise Joint-Venture "UZTEX TASHKENT" is explained by the small level of short-term investments and cash relative to current liabilities. For example, in 2019, the ratio of short-term investments and cash to current liabilities was only 10.4%.
2. Non-fulfilment of the normative requirement on the coefficient of financial independence of the enterprise is explained by the loss of capital in the enterprise.
3. Failure to comply with the regulatory requirements for the coefficient of efficiency of use of assets is explained by the fact that the growth rate of income from the sale of goods at the textile enterprise Joint-Venture "UZTEX TASHKENT" is lower than the growth rate of inventories.

4 CONCLUSIONS

Based on the results of the above analysis, in our opinion, the following measures should be taken to ensure the financial security of the textile enterprise Joint-Venture "UZTEX TASHKENT" at the level of regulatory requirements:

1. In order to ensure the normal level of liquidity ratio in the enterprise, in order to ensure that the growth rate of cash assets does not lag behind the growth rate of current liabilities, first, it is necessary to increase the rate of turnover of creditors; secondly, the company should focus on ensuring the growth of current assets by increasing the volume of short-term loans and investments of commercial banks; third, to increase profits by reducing the cost of the product or increasing the price of the product, it is necessary to take measures to drastically reduce the amount of all assets relative to revenue.
2. In order to increase the absolute liquidity ratio in the enterprise, firstly, it is necessary to increase the turnover of receivables, and secondly, to increase the volume of investments in short-term securities issued by highly solvent issuers.
3. In order to meet the normative requirement of the coefficient of financial independence of the enterprise and to ensure a stable growth rate of capital, it is necessary to prevent the erosion of capital by reducing operating costs.

Also, the current liquidity, equity and return on assets of textile enterprises of private enterprise "OSBORN TEXTILE" and Joint-Venture "UZTEX TASHKENT", which were assessed and analyzed above, have shown a steady growth trend in recent years. We analyze the factors influencing these coefficients.

The following main factors influenced the growth of the level of self-sufficiency in the textile enterprises of private enterprise "OSBORN TEXTILE" and Joint-Venture "UZTEX TASHKENT":

- increase in the amount of own funds, in particular, in the private enterprise "OSBORN TEXTILE" in 2019 the amount of own funds increased by 18.0% and, accordingly, in the Joint-Venture "UZTEX TASHKENT" by 42.5%;
- decrease in the amount of current accounts payable, in particular, in 2019 in the Joint-Venture "UZTEX TASHKENT" current accounts payable decreased by 22.3% compared to 2013;
- decrease in the share of receivables from current working capital, in particular, the share of receivables in Joint-Venture "UZTEX TASHKENT" in 2013 amounted to 38.2%, by 2019 this figure decreased to 11.1% and reached 27.1%;
- Increasing the number of solvent buyers.

The analyzed liquidity of private enterprise “OSBORN TEXTILE” and Joint-Venture ”UZTEX TASHKENT” in the textile enterprises is higher than the norm, which is positive on the one hand, and insufficient use of current assets by enterprises and obstacles to obtaining short-term loans. The following main factors influenced the growth of the current liquidity ratio in the textile enterprises of "OSBORN TEXTILE" and Joint-Venture "UZTEX TASHKENT":

- increase in the amount of own funds of enterprises, in particular, in the "OSBORN TEXTILE" in 2019 compared to 2013 the amount of own funds increased by 8.7%, respectively in the Joint-Venture "UZTEX TASHKENT" increased by 2 times;
- decrease in the amount of short-term liabilities, in particular, the amount of short-term liabilities in Joint-Venture "UZTEX TASHKENT" in 2019 compared to 2013 decreased by 34.5%;
- increase in income from sales of products, in particular, the amount of income from sales of products in “OSBORN TEXTILE” in 2019 compared to 2013 increased by 52.2%;

- collection of receivables, in particular, in Joint-Venture "UZTEX TASHKENT" in 2019 compared to 2013 the amount of receivables decreased by 47.9%.

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.

The growth rate of return on assets during the analyzed years in the textile enterprises of private enterprise "OSBORN TEXTILE" and Joint-Venture "UZTEX TASHKENT" is based on the high level of production, operating costs and exchange rate differences.

ACKNOWLEDGEMENTS: *We are thankful for rector of Tashkent State University of Economics professor Sharipov Kongratbay Avezimbetovich for his supporting this research. Also, we are hereby to vice-rector D.Sc. of Tashkent State University of Economics Eshov Mansur Pulaovich for his advices in preparing in methodology of this research.*

5 REFERENCES

1. www.mckinsey.com;
2. WTO. International Trade Statistics, 2017, URL: http://www.wto.org
3. http://www.ceicdata.com
4. www.lex.uz
5. www.aier.org;
6. www.imf.org (International Monetary Fund)
7. http://www.worldbank.org (World Bank Group)
8. http: // www.wisp.ru (catalog of Internet resources on security, Russia
9. www.ey.com;
10. www.bloomberg.com;
11. www.ox.ac.uk;
12. www.strategicmanagement.net;
13. www.nifi.ru;
14. www.mse.msu.ru;
15. www.isma-edu.eu
16. Haar L., Haar L.N.: A financial option perspective on energy security and strategic storage, Energy Strategy Reviews 25, 2019, pp. 65-74, https://doi.org/10.1016/j.esr.2019.100364
17. Lyons A.C., Grable J.E., Joo S.H.: A cross-country analysis of population aging and financial security, The Journal of the Economics of Ageing 12, 2018, pp. 96-117, https://doi.org/10.1016/j.jeoa.2018.03.001
18. Li W, Wang X.: The role of Beijing's securities services in Beijing–Tianjin–Hebei financial integration: A financial geography perspective, Cities 100, 2020, https://doi.org/10.1016/j.cities.2020.102673
19. Drucker P.F.: The practice of management, Oxford, UK, Elsevier Butterworth-Heinemann, 2007
20. Mayer R.: Production management, New York, McGraw-Hill, 1968
21. Konopleva I.A.: Management of business safety and security: textbook for universities, INFRA-M, 2008
22. Shao J.F., Li Y.: Multi-agent production monitoring and management system for textile materials and its applications, Journal of Industrial Textiles 40(4), 2010, pp. 380-399, https://doi.org/10.1177/1528083710380428
23. Koltai T., Stecke K.: Route-independent analysis of available capacity in flexible manufacturing systems, Production and Operations Management 17(2), 2008, pp. 211-223, https://doi.org/10.3401/poms.1080.0017
24. 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
25. 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
26. 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
27. Burkhanov A.U., Akhmedov F.H.: Indicators to assess financial security of the banks, International Journal of Innovative Technology and Exploring Engineering 9(1), 2019, pp. 5456-5460, https://doi.org/10.35940/ijitee.A3894.119119
28. Blank I.A.: Management of financial security of the enterprise, 2nd ed., Kiev: Elga, 2009, 776 p. (in Ukrainian)
29. Papekhin R.S.: Theoretical foundations of financial stability of enterprises, Volgograd: Volgograd Scientific Publishing House, 2008, 60 p. (in Russian)
30. Kirov A.V.: Financial security as a condition for financial stability, Financial Bulletin: Finance, Taxes, Insurance, Accounting No. 6, 2010, p. 23-32 (in Russian)

IMPROVEMENT OF STRUCTURE DETERMINING QUALITATIVE CHARACTERISTICS OF HYDROPHOBIZED VELOUR

Anatolii Danylkovych[1], Viktor Lishchuk[2] and Arcady Shakhnovsky[3]

[1]Kyiv National University of Technologies and Design, Nemirivicha-Danchenka Str. 2, Kyiv 01011, Ukraine
[2]JSC "Chinbar", Kurenivska Str. 21, Kyiv 04073, Ukraine
[3]Igor Sikorsky Kyiv Polytechnic Institute, Peremohy ave. 37, Kyiv 03056, Ukraine
ag101@ukr.net; chinbar@i.kiev.ua; AMShakhn@xtf.kpi.ua

***Abstract**: The paper studies optimization of formulation of the alkenmalein-acrylsyntane composition in manufacturing of hydrophobized nutria fur velour with high structural and defining characteristics. A modified McLean and Anderson method was used to synthesize the experimental design. Mathematical modeling approach as well as a hierarchical technique of multi-objective optimization led to the identification the optimal formulation of the filling and hydrophobicizing composition. Based on the experimental results, an adequate non-linear mathematical model "formulation of the alkenmalein-acrylsyntane composition vs properties of fur velour" was constructed. The hierarchical method of successive concessions (epsilon constrained method) allowed to optimize the composition formulation. The optimal composition comprises 37.7 % m/m of alkenmalein polymer, 34.0 % m/m of polyacrylic emulsion Melio Resin A-821, and 28.3 % m/m of BNS synthane tannin. Developed technology ensures high consumer properties of nutria fur velour. The studies of water resistance have shown a significant increase in resistance of fur velour to the action of water in dynamic conditions. The developed technology has the great benefit of increasing the yield of fur velour area by 6.7% in comparison with the intermediate product of chrom-aluminum retanning. Taking into account considerable porosity and heterogeneity of the fiber structure of the raw material, an increase in yield is significant. The optimized formulation of the filling and hydrophobicizing composition can be used effectively in the technologies of manufacturing limed hide and leather materials of high water resistance. With the combination of properties the obtained hydrophobized nutria velour is suitable for the production of pickled leather products, which will be operated in extreme conditions.*

***Keywords**: nutria velour, filling, velour properties, hydrophobization, McLean-Anderson method, multicriteria optimization, hierarchical method of successive concessions.*

1 INTRODUCTION

In order to improve the physico-chemical properties of fur during its operation in extreme conditions, new effective modification methods must be found. Particularly, an important task is the preparation of natural materials for goods used in conditions of high humidity. Various chemical reagents can be used for such preparation to hydrophobize materials containing protein. The effectiveness of hydrophobic substances depends essentially on the features of the porous structure of the collagen-keratin material and its pelage. It should be noted that the increased porosity of the fur semi-finished product significantly complicates the process of its hydrophobization, since it requires additional physico-chemical processes and mechanical operations to form the proper operational and technological properties.

In particular, greater attention should be given to the use of new hydrophobic mixtures, as well as suitable filling agents, to create high water-resisting materials for pickled leather products. The completion of that task is of both scientific and technical significance. In this regard, the possibility of using natural rawhide materials unsuitable for fur production [1] is of great relevance. Expanding the range of products from fur semi-finished products with high water-resisting properties is possible due to the use of coarse-pored raw material with coarse pelage. New filler-hydrophobic compositions and processing modes should be developed for the effective use of this rawhide. The use of mathematical modeling and optimization methods is the necessary condition for successful development of scientifically grounded processes of forming a semi-finished product in the high water-resistance velour manufacturing. It is especially important to take into account the physico-chemical and technological properties of both the structure of the semi-finished product and the ingredients of the developed compositions.

2 LITERATURE REVIEW

In elastic leather and fur velour production technology, the processes of filling and hydrophobization play a significant role in the formation of materials with high performance properties. This is particularly true in case of raw materials with a specific irregular and coarse-pored structure.

Various synthetic polymers can be used for levelling of uneven and porous surface of the topographic areas of the skins. Polyacrylic or polymethacrylic acid, polyvinyl alcohol, copolymer of styrene and maleic anhydride, epoxy resins, polyisocyanates and especially amino resins may be used to fill the collagen-containing semi-finished product. In particular, the authors of [2, 3] as a result of filling have received natural materials with uniform properties in thickness, density, water resistance, increased strength and resistance to friction due to the use of water-soluble polymers. The synthesized copolymer based on butadiene and styrene at a ratio of 3 to 1 provided an opportunity to obtain elastic skin of a sufficiently filled and mobile structure [4].

The influence of the particle size of acrylic acid copolymers aqueous dispersions on the physico-mechanical properties of a semi-finished product was studied in [5]. The increase of thermal stability, strength and elasticity due to the use of aqueous emulsions of copolymers of butyl acrylate and styrene was identified.

To fill the leather semi-finished product with an aqueous dispersion of the acrylic copolymer, copolymers of acrylamide of methacrylic acid, nitrile of acrylic acid, maleic anhydride, vinyl acetate and butyl acetate were used in [6]. Compositions with different ratios of components were investigated, within the limits of their consumption 3.0-6.9% by weight of the semi-finished product.

In [7], a significant influence of the aminopolymers on the semi-finished product properties was proved. The aminopolymers mixture was based on dimethylurea and its modified derivatives synthesized by condensation of aldehydes with urea, melanin and dicyandiamide.

The resulting semi-finished product is characterized by high physical and mechanical properties, high grinding ability with the formation of low uniform pile. To fill the semi-finished product, sulfo-aromatic polymers were synthesized on the basis of polycondensation of sulfonated resorcinol and urea-formaldehyde resin with a particle size of aqueous dispersion of 0.7-1.4 μm [8]. The high diffusion capacity of synthesized polymers in the structure of a chromium semi-finished product is also shown. This diffusive ability ensures an increased degree of filling of the semi-finished product and its high elastic-plastic characteristics. Compared with the modified aminofurazan-formaldehyde polymer, the use of a sulfitated melamine-formaldehyde oligomer for filling the semi-finished product makes it possible to increase its density and elasticity. However, the presence of up to 10 mg/kg of free environmentally harmful formaldehyde in the product might be considered as a disadvantage.

Increasing the water-resistance of natural collagen-containing materials is achieved by filling the semi-finished product with reagents of a certain chemical composition. For example, monomeric and polymeric reagents [9] are used for this purpose, in particular silanes, fluorocarbon resins, polydimethylsiloxane rubbers, complex compounds of aluminum with wax or paraffin. Derivatives of oxycarboxylic acids, esters of fatty acids, etc. are also used. The authors [10] have studied the influence of fat emulsions based on triglycerides of rapeseed oil and fish oil on the sorption-desorption process as well as on the mechanism of water diffusion into the structure of the processed skin.

In [11], an acrylic acid copolymer and hydrophobic acrylate monomers were used to hydrophobize a chromium semi-finished product. Using this composition led to the increase in the degree of filling, water resistance, ductility and mechanical strength of the material. Copolymers with normal carbon chains have been proved to be effective in improving these properties. The greatest hydrophobic effect is achieved when the side chain length of the modifier is not less than C_{16}.

An emulsion of a fluorine-containing copolymer based on maleic anhydride, rapeseed oil or fish liver oil with the addition of dodecafluoroheptanol and octadecyl alcohol is also used to obtain a natural material of high water resistance [12]. The obtained material is characterized by a wetting angle of 155°, by dynamic water penetration of 55 min and by a static water absorption coefficient of 9 wt.%. The maximum hydrophobic effect is achieved at 5% fluorine content in the copolymer molecules. The use of hybrid polyfunctional polyurethanes with hydrophilic-hydrophobic radicals to increase water resistance and dirt repellency of materials has also been proposed [13]. However, after such modification, the rigidity of the material increases and its appearance deteriorates.

In [14-16], the complex effect of organosilicon polymer A-187 and plasma processing on the physico-mechanical and hygienic properties of skin was studied. This led to increase in the water resistance of the skin, as well as an increase in the strength of the material by 23%. The efficiency of hydrophobization of the material, determined by the duration of suction of a drop of water, is evidenced by an 86% increase in the duration of absorption of a drop of water [16] while reducing its hygroscopicity by 87 and 76%, for sheepskins and cattlehides, respectively.

Thus, one can use a wide range of reagents and compositions for filling and hydrophobization of natural materials. However, the practical application of the above-mentioned reagents is mainly empirical. The reactivity of the structure and properties of collagen-keratin material requires proper scientific substantiation.

Due to the expansion of the range of raw materials with a specific structure for the production of quality natural materials, further study of the effective formulations of filler & hydrophobic compositions is necessary. Taking into account the specificities of collagen-keratin structure, topographic unevenness of skin tissue, features of its porosity and low strength in the formation of nutria skins velour, it is necessary to develop an optimized formulation of filler-hydrophobic composition and determine the conditions of its effective use.

3 OBJECTIVES AND PURPOSE OF THE STUDY

The aim of the work is to study the process of forming hydrophobized nutria skins velour with coarse hair using the alkenmalein-acrylsyntane (AM-AS) composition. For this purpose, the following specific objectives have been set:

- determination of structurally sensitive quality characteristics of hydrophobized velour depending on the formulation of the filler-hydrophobizing composition;
- mathematical synthesis of the optimal plan of experiments for the study of formulations of mixtures;
- processing the results of experiments and identification of the mathematical model "formulation of filling composition vs velour properties";
- determination of the optimal formulation of the filling-hydrophobizing composition for the production of hydrophobized velour using the "composition formulation vs velour properties" model.

4 RESEARCH METHODOLOGY

The object of the study was the ways optimize the formulation of the filling-hydrophobic composition AM-AS for skins of male nutria with an area of 24-25 dm^2 with coarse beard hair after epilation and tanning (temperature not lower than 90°C) by technology [1]. The composition studied included an alkenmalein (AM) polymer synthesized on the basis of α-alkenes C_{20-24} and maleic anhydride with an average molecular weight of 38.10^3, polyacrylic (PA) emulsion Melio Resin A-821, offered by “Clariant International Ltd” company and the product of the synthesis of 2-naphthylsulfonic acid with dioxydiphenylsulfon - BNS synthane tannin (in accordance with Ukrainian standard specifications TU 17-06-165-89).

During the tanned nutria skins processing, after water removal and epilating, the semi-finished product was subjected to chrom-aluminum retanning. The ratio of the weight of water and semi-finished product is equal to 7 with the following consumptions: chromium tanner in terms of chromium oxide (III) 4 g/dm^3, alumokalum branch 7 g/dm^3. The retanning should be carried out at 40-42°C for 6 hours in a 15 dm^3 laboratory paddle. The filling and hydrophobization of a nutria semi-finished product skin tissue should be done at 40-43°C by successive addition the AM-AS composition to the system of ingredients. First, the AM-polymer was dosed into the paddle, after 15-20 minutes, a filling mixture (Melio Resin A-821 polyacrylic emulsion and BNB tanner) was added to the processing medium. After another 1.0 hour, the remaining hydrophobic AM polymer was added. The total duration of the process did not exceed 2.5 hours. The semi-finished product was hydroextracted in a centrifuge to a humidity of 52-53% and then underwent the process of drying and humidification until the moisture content of 12-14% had been reached.

Experimental data were obtained by implementing the D-optimal experimental plan, synthesized by the modified McLean and Anderson method [17], which involves limiting the quantitative content of its ingredients due to their physico-chemical and technological features. For the experiment, samples of nutria skins were selected by the method of proportional squares [18].

The efficiency of technological processing of tanned semi-finished nutria skins was determined by the following parameters:

- the difference between the volume of the AM-AS composition, spent in the process and the remainder of the composition in the exhausted solution;
- water-resisting properties of hydrophobized fur velour;
- yield of hydrophobized fur velour by area.

The water resistance of velour was estimated under dynamic conditions by the duration of water wetting on the PVD-2 device (Russia) during the deformation of the samples at a rate of 70 min^{-1}. The hydrothermal stability of the velour was evaluated by the initial reduction of the sample length, the porosity was determined by the ratio of the pore and sample volumes. Physico-mechanical properties of velour were evaluated according to the methodology [18] on a tensile testing machine RT-250M (scale A, 0-0.50 kN) at a deformation rate of 80 mm/min. The yield of the velour area was estimated by the ratio of the areas of hydrophobized and chromium-aluminum tanned [1] semi-finished product under standard conditions. Based on the experimental results, nonlinear polynomial mathematical models “formulation of the filler-hydrophobizing composition vs properties of velour” were obtained. These models were subsequently used to find the optimal formulation of the AM-AS composition by the hierarchical method of successive concessions [19-21].

5 OBTAINING A MATHEMATICAL MODEL "FORMULATION OF THE FILLER-HYDROPHOBIZING COMPOSITION VS PROPERTIES OF NUTRIA VELOUR"

A nonlinear mathematical polynomial model (1) was used to optimize the formulation of the AM-AS composition:

$$\hat{y} = \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k-1} \sum_{j=i+1}^{k} b_{ij} x_i x_j + \sum_{l=1}^{k-2} \sum_{i=l}^{k-1} \sum_{j=i+1}^{k} b_{l\,ij} x_i x_j \,, \quad (1)$$

where $\hat{y}$ is predicted value of the output variables; b_i, b_{ij} are model coefficients; x_i are designation of ingredients of the composition (in coded dimensionless form), i = 1, 2, …, k; k is number of ingredients; l, i, j are enumerators of ingredients.

It is important to emphasize that model (1) should retain the condition of normalization of the composition of the mixture:

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

During the experiments, the limiting variation range of ingredients X_i (3) was observed. The limits of change of ingredients mass in the mixture (X_i [g/dm^3]) at a total consumption of the mixture of 28 g/dm^3, determined by the results of previous studies, are shown in Table 1.

$$0 \le X_i^{\min} \le X_i \le X_i^{\max} \le 1 \quad (i = 1, 2, ..., k) \quad (3)$$

where X_i are designations of ingredients of the composition (in natural form); $X_i^{\min}$ and $X_i^{\max}$ are variation range limits (lower and upper respectively).

Table 1 Limits of variation of ingredients of the filler-hydrophobic composition

i	Limits of ingredients variation			
	natural values X_i [g/dm^3]		encoded values x_i	
	min	*max*	*min*	*max*
1	0.84	10.36	0.03	0.37
2	3.92	13.44	0.14	0.48
3	3.08	12.32	0.11	0.44
4	5.88	11.20	0.21	0.40

According to the results of previous studies, the general mathematical model (1) was reduced to the form:

$$\hat{y}_i = b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + b_{23}x_2x_3 + b_{24}x_2x_4 + b_{34}x_3x_4 + b_{123}x_1x_2x_3 \quad (4)$$

where $\hat{y}_i$ are predicted values of the structural and determining indicators of the quality of fur velour, i = 1÷3; x_1, x_2, x_3, x_4 are encoded values of mixture ratio factors (respectively, the amount of AM polymer that acts as an activator of the filling process, the amount of PA emulsion, the amount of BNS synthane tannin and the amount of AM polymer as a hydrophobisator in the final stage of processing).

The effectiveness of the formulation of the AM-AS composition was evaluated by the following quality indicators:

- y_1 is the amount of composition that diffused to the semi-finished product [%];
- y_2 is duration of dynamic water penetration of fur velour [sec];
- y_3 is the yield of the area of fur velour [%].

According to the principles of mathematical statistics, the coefficients of the regression model (4) can be determined by approximating the experimental data. For data acquisition, experiments were performed according to the synthesized plan. The task of planning the experiment was to obtain the maximum theoretically possible amount of information for a given number of experiments, taking into account the condition of normalization of the composition of the mixture (2), as well as the important requirement (5) of availability of all ingredients in the mixture:

$$x_i > 0,\; i = 1,2,\ldots,k. \quad (5)$$

The experimental design was synthesized according to the previously developed algorithm [17]. This algorithm is summarized as follows:

1) According to the McLean and Anderson algorithm [22], N theoretical candidate points are selected (in this case, N=41). Selection is carried out in such a way as to ensure the maximum mutual distance of the experimental points, as well as the distance of the experimental points to the center of the plan;
2) The best experimental design in terms of D-optimality (6) is selected from n experimental points by exhaustive search of all possible combinations of candidate points:

$$\det|D| \to \min \quad (6)$$

where $D=(F^{T}\cdot F)^{-1}$ is the dispersion matrix of the combination of candidate points on the current iteration of the synthesis of the experimental plan; F is experimental design matrix, dimension of the matrix is $n \times t$; t is the number of coefficients of the model.

Selection of the n most desirable variants of the formulation composition among the N candidate points (n<N) requires n-combination search of a subset of n distinct elements of the candidate points set, which has N elements. The total number of required combinations (7) can be estimated by methods of probability theory:

$$c_N^n = \frac{N!}{n!\,(N-n)!} \quad (7)$$

To find the coefficients of model (4), the synthesized experimental design must contain at least 10 experimental points (n=10).

As follows from (7), the synthesis of such a plan requires more than 10^9 different combinations. Thus, the synthesis of the experimental design requires significant computational resources. Therefore, during the search of experimental plan points, an algorithm of parallel (multithreaded) calculations was implemented. In the present case, 23.86 hours were spent on the computer synthesis of the optimal experimental design (Table 2) in a limited area of factor space (Table 1).

Table 2 The experimental design

Experimental points		Mixture ratio			
No	***laboratory records code***	x_1	x_2	x_3	x_4
1	2	0.210	0.140	0.440	0.210
2	3	0.200	0.480	0.110	0.210
3	4	0.030	0.460	0.110	0.400
4	5	0.030	0.320	0.440	0.210
5	10	0.030	0.140	0.440	0.390
6	12	0.370	0.140	0.110	0.380
7	14	0.190	0.140	0.270	0.400
8	27	0.370	0.225	0.195	0.210
9	29	0.030	0.480	0.195	0.295
10	34	0.225	0.335	0.110	0.330

Table 3 Properties of hydrophobized fur velour

Experimental point		Quality measures		
No	***laboratory records code***	y_1	y_2	y_4
1	2	79.2	1390.0	106.2
2	3	88.5	1260.0	102.4
3	4	73.4	1630.0	103.8
4	5	78.6	1370.0	101.5
5	10	65.3	1840.0	102.3
6	12	87.1	1565.0	104.3
7	14	89.4	1780.0	105.3
8	27	88.3	1353.0	104.7
9	29	79.1	1410.0	104.5
10	34	93.0	1560.0	106.1

After the implementation of the synthesized plan, experimental data were obtained. They characterize the effect of the formulation of the AM-AS filling-hydrophobizing composition on the properties of nutria velour (Table 3).

The coefficients of the mathematical model (4) were determined by approximating the experimental data (Table 2 and Table 3) by the least square method. Mathematical models are built for the three above-mentioned quality indicators of nutria velour depending on the formulation of the AM-AS composition. After parametric identification, the models have the form (8):

$$\begin{aligned}
\hat{y}_1 &= -138.69x_1 - 13.34x_2 - 84.27x_3 + 398.29x_1x_2 + \\
&+ 429.70x_1x_3 + 535.01x_1x_4 + 468.02x_2x_3 + 225.52x_2x_4 + \\
&+ 305.51x_3x_4 + 625.12x_1x_2x_3; \\
\hat{y}_2 &= 765.90x_1 - 3599.70x_2 - 3315.80x_3 + 21850.00x_1x_2 + \\
&+ 24474.00x_1x_3 + 3662.30x_1x_4 + 15166.00x_2x_3 + 11914.00x_2x_4 + \\
&+ 12409.00x_3x_4 - 153640.00x_1x_2x_3; \\
\hat{y}_3 &= 78.871x_1 + 35.227x_2 + 30.294x_3 + 307.490x_1x_2 - \\
&+ 444.790x_1x_3 + 102.200x_1x_4 + 202.830x_2x_3 + 303.050x_2x_4 + \\
&+ 284.150x_3x_4 - 2418.500x_1x_2x_3.
\end{aligned} \tag{8}$$

The obtained mathematical models (8) should be used only after confirmation of their adequacy. To study the adequacy, two parallel experiments were additionally conducted at three experimental testpoints (Table 4). The testpoints were randomly selected from among the candidate points that were not included in the synthesized experimental design.

The validity check shows, that all three obtained models are adequate, though the model for the yield of the area of fur velour (y_3) most accurately describes the experimental data.

Thus, the obtained adequate mathematical models “composition formulation vs nutria velour properties” can be further used to optimize the alkenmalein-acrylsyntane composition in the manufacture of nutria fur velour. The validation of models for adequacy (Table 5) was performed according to Fisher's statistical test (F-test).

Table 4 Structural and defining measures of hydrophobized nutria velour at the testpoints

Testpoint No	Mixture ratio				Quality measures					
	x_1	x_2	x_3	x_4	y_1		y_2		y_3	
1	0.036	0.321	0.250	0.393	82.9	83.4	2011	1990	106.7	106.3
2	0.036	0.393	0.250	0.321	87.1	86.8	1690	1681	106.1	106.0
3	0.072	0.393	0.214	0.321	89.7	90.2	1559	1562	104.6	104.1

Table 5 The results of validation of models for adequacy

Quality measures	Values of the F-distribution for mathematical models		Adequateness (F_c>F_T)
	tabular value F_T*	***computed value*** F_c	
y_1	5.24	15.127	Yes
y_2	5.24	13.114	Yes
y_3	5.24	468.67	Yes

*For the level of significance q = 0.1 and the number of degrees of freedom f_1 = 9, f_2 = 3.

6 OPTIMIZATION OF THE FORMULATION OF THE COMPOSITION BY THE METHOD OF SUCCESSIVE CONCESSIONS

Mathematical programming methods were used to find the optimal formulation of the AM-AS composition for the processing of nutria fur velour skins. The optimization model (9) belongs to the class of multigoal nonlinear constrained programming problems:

$$\begin{aligned} &\{y_i(\overline{X})\} \to \max, \\ &\overline{X} \in Q. \end{aligned} \tag{9}$$

where $y_i(\overline{X})$ are optimality criteria based on models (8). *i*=1,2,…*m*; $\overline{X}$ is the set of optimization factors, $\overline{X} \Leftrightarrow x_i,\ i = 1,2,\ldots,k;$ $\overline{X} \in Q(\overline{X})$ is the system of constraints of the optimization problem based on conditions (2), (3), (5); m is the number of optimality criteria.

Simultaneous optimization approaches are most often used to solve models (9), an example of such approaches is desirability function based methods [17, 23].

However, in this study it was decided to use a hierarchical approach to multigoal optimization, as this approach enables to control the optimization process step by step. The applied procedure for finding the optimal solution of problem (9) is based on the hierarchical method of successive concessions (also called Constraint Method) [19-21].

Optimization of the formulation of the filling-hydrophobic AM-AS composition was performed according to the following procedure:

1) Carrying out a qualitative analysis of the relative importance of the criteria $y_i(\overline{X})$, *i*=1,2,…*m*. Construction of a hierarchical list of criteria (10) in descending order of importance:

$$\left\{y^{[1]}(\overline{X}), y^{[2]}(\overline{X}), \ldots, y^{[m]}(\overline{X})\right\} \tag{10}$$

where $y^{[i]}(\overline{X})$ is optimality criterion, which is in the *i-th* place in the hierarchical list (10).

2) Setting the criterion $y^{[1]}(\overline{X})$ as the "current" criterion.
3) Solving a single-criteria optimization problem taking into account the "current" criterion as an objective function:

$$y^{[1]}(\overline{X}) \to \max, \quad \overline{X} \in Q,$$

and determining the optimum $y^{[1]}_{\max}(\overline{X})$ by the current criterion.

4) Set assignment (i.e. allowable deviation) value $\delta^{[1]} \ge 0$ for the criterion $y^{[1]}(\overline{X})$.
5) Setting the criterion $y^{[2]}(\overline{X})$ as the "current" criterion.

Adding a criterion $y^{[1]}(\overline{X})$ to the system of constraints taking into account the values $y^{[1]}_{\max}(\overline{X})$ and $\delta^{[1]}$:

$$\begin{aligned} &y^{[2]}(\overline{X}) \to \max, \\ &y^{[1]}(\overline{X}) \le y^{[1]}_{\max}(\overline{X}) - \delta^{[1]} \\ &\overline{X} \in Q, \end{aligned}$$

6) Solving a single-criteria optimization problem for the "current" criterion.
7) Repeating steps 4, 5, 6 of this procedure until the hierarchical list is exhausted (11).

In the optimization procedure used by the authors, the successive concessions method is combined with the evolutionary method of nonlinear optimization - a genetic algorithm of the GENOCOP type [24]. The GENOCOP algorithm ensures the achievement of the global optimum by multiple solution of a single-criteria problem for the "current" criterion. According to the mentioned procedure, the optimization problem of the composition formulation was solved (Table 6).

As a result of optimization the optimal formulation of the composition was obtained (wt. parts): x_1=0.031, x_2=0.371, x_3=0.253, x_4=0.345 (see Table 6). The expected values of the output variables are y_1=84.0%, y_2=1838.0 sec, y_3=107.0%.

Therefore, the following procedure can be considered effective for filling and hydrophobizing the semi-finished product. Per 100 kg of retanned and epilated semi-finished nutria product after its centrifugation one should take 19.6 kg of alkenmalein-acrylsyntane composition, including: 6.664 kg of PA emulsion, 5.547 kg of BNS synthane tannin, 7.389 kg of AM polymer. It is necessary to spend 0.588 kg of alkenmalein polymer to activate the filling process.

Table 6 Optimization of composition formulation

Step No	Mixing proportion				"Current" criterion		
	x_1	x_2	x_3	x_4	*notation*	*optimum*	*assignment*
0	0.030	0.140	0.110	0.210	-	-	-
1	0.030	0.258	0.312	0.400	y2	2041.9	1837.7
2	0.030	0.340	0.283	0.347	y3	107.11	106.95
3	0.031	0.371	0.253	0.345	y1	84.4	-

7 TESTING THE TECHNOLOGY OF HYDROPHOBIZATION OF NUTRIA FUR VELOUR BY ALKENMALEIN-ACRYL-SYNTHANE COMPOSITION

The optimized formulation of the filling and hydrophobizing AM-AS composition was used to provide the technology of hydrophobized nutria fur velour production. Physico-chemical tests of hydrophobized nutria velour were conducted under standard conditions [18]. Reference method of nutria velour processing differed from the developed technology in the absence of the filling-hydrophobization process. In this case, the electrolyte-resistant emulsion Trupol DL (by Trumpler GmbH&Co., Germany) was used for the fat-liquoring of nutria velour. The process was carried out at 38-40°C with a fat consumption of 2.5 g/dm^3 for 1 hour.

The results of the study of the hydrophobized nutria fur velour physico-chemical properties are given in Table 7. Comparison of nutria fur velour obtained by the technology proposed by the authors with the product obtained by the reference technology (i.e., pre-existing technology) leads to the following conclusions. The hydrophobic effect is manifested in significant increase in the duration of dynamic water penetration compared to the material obtained by the reference technology. Considering the high cost of fur velour and a significant increase in area yield, it's possible to increase performance of a process and to reduce the cost of production.

Increasing the thickness of the skin tissue of hydrophobized nutria velour and, thus, increasing the uniformity of the material in topographic areas, promotes the more efficient use of semi-finished product in the manufacture of products. At the same time, the hydrophobized nutria fur velour obtained by the baseline technology is better in terms of deformation properties.

The laboratory studies show that the technology of hydrophobized velour formation allows to expand the range of water-resisting rawhide materials. The developed technology can be used without significant changes for the processing of other types of rawhides in the production of velour materials with high operational properties.

8 RESULTS

1. The optimization of the alkenmalein-acrylsynthane composition formulation in manufacturing of hydrophobized fur velour from epilated nutria rawhides with high structural and defining characteristics was investigated. A modified McLean and Anderson method was used to synthesize the design of experiments, taking into account "composition formulation vs properties of hydrophobized product" model. The hierarchical technique of multi-objective optimization was applied in order to find the optimal formulation of the filling and hydrophobicizing composition.
2. The optimal formulation of the filling and hydrophobising composition was developed. The optimal composition comprises 37.7 % m/m of alkenmalein polymer, 34.0 % m/m of polyacrylic emulsion Melio Resin A-821, and 28.3 % m/m of BNS synthane tannin. The consumption of composition ingredients are: alkenmalein polymer 7.3892%, polyacrylic emulsion Melio Resin A-821 6.664%, BNS synthane tannin 5.5468% (presented values are given as a percentage of the weight of the pressed semi-finished product). The ratio of semi-finished product to processing medium is 1:7.
3. The developed technology involves the combination of filling and hydrophobization processes. The advantage of such technology is the production of fur nutria velour with a significant increase in water resistance under dynamic conditions, as well as a larger area yield of 6.7% compared to intermediate product of chrom-aluminum retanning. This result is significant, considering the considerable porosity and heterogeneity of the fibrous structure of the skin.
4. The optimized formulation of the filling and hydrophobizing composition can be effectively used in the high water-resisting leather manufacturing technologies. The obtained hydrophobized nutria fur velour, on the totality of properties, is suitable for the production of pickled leather products of various purposes, which will be operated in extreme conditions.

Table 7 Physico-chemical properties of hydrophobized nutria fur velour

Indicator	Nutria velour obtained by developed here technology	Nutria velour obtained by reference technology
Dynamic water penetration [sec]	1800±17	25±5
Yield of area [%]	106.7±0.3	100.0±0.3
Skin thickness [mm]	1.18±0.4	1.06±0.7
Ultimate tensile strength [MPa]	1.17±0.20	1.09±0.25
Percent elongation at failure [%]	63.0±6.0	59.0±5.0
Total percent elongation of skin tissue at the load 4.9 MPa [%]	29.0±2.5	21.0±2.6
– elastic elongation [%]	18.5±1.6	12.0±1.2
– residual elongation [%]	10.5±0.9	9.0±0.8
Porousness of skin tissue [%]	63.0±3.0	67.0±4.5

9 REFERENCES

1. Danilkovich A., Lishchuk V., Strembulevich L.: Modern fur production, Kyiv: Phoenix, 2016, 320 p., (in Ukrainian)
2. Vinitsky V.D., Lebedev O.P., Makarov-Zemlyansky L.L., Ginzburg L.I., Gorbatov S.V.: Filling and retanning of chrome skins with new generation polymers, Kozhevenno-obuvnaya promyshlennost' (Leather and footwear industry) No. 6, 2002, pp. 32-34 (in Russian)
3. Lakshmiarayana Y., Jaisankar S.N., Ramalingam S., Radakrishnan G.: A novel water dispersible bentonite-acrylic graft copolymer as a filler cum retanning agent, Journal - American Leather Chemists Association 97(1), 2002, pp. 14-22
4. Chursin V.I.: Expansion of the raw material base in the production of new filling and retanning materials for the leather industry, Sat materials III All-Russian n. Conference "New Chemical Technologies: Production and Application", Penza: Volga House of Knowledge, 2000, pp. 61-64 (in Russian)
5. Ma J.Z., Lu H.: Elasticity studies on leather retanned with various types of acrylic polymers, Journal - American Leather Chemists Association 103(11), 2008, pp. 363-369
6. Vinitsky V.D., Lebedev O.P., Makarov-Zemlyansky L.L., Studenikin S.I.: Use of new generation copolymers for filling and retanning of leathers, Materials of the International Scientific and Technical Conference "Polymer Composite Materials and Coatings", December 2-5, 2002, Yaroslavl: publishing house of the Yaroslavl State Technical University, 2002, pp. 117–118 (in Russian)
7. Ostrovskaya A.V., Chernova A.V., Latulin I.I.: Fluorine-containing amino resins and their use in leather industry, Bulletin of Kazan Technological University No. 11, 2010, pp. 584-585 (in Russian)
8. Yurasova O.V.: Development and application of retanning composition in leather industry, Kozha I obuv' (Leather and shoes) No. 3, 2008, pp. 30-33 (in Russian)
9. Boynovich L.B., Emelianenko A.M.: Hydrophobic materials and coatings: principles of creation, properties and application, Uspekhi khimii (The success of chemistry) No. 7, 2008, pp. 619-637 (in Russian)
10. 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
11. Du J., Huang C., Pen B.: Influence of hydrophobic side chain structure on the performance of amphiphilic acrylate copolymers in leather-making, Journal of the Society of Leather Technologists and Chemists, 100(2), 2016, pp. 67-72
12. Zhaoyang L., Haojun F., Yan L., Bi S.: Fluorine-containing aqueous copolymer emulsion for waterproof leather, Journal of the Society of Leather Technologists and Chemists 92(3), 2008, pp. 107-113
13. Casas C., Bou J., Ollé L., Bacardit A.: Development of nanocomposites with self-cleaning properties for textile and leather, Journal of the Society of Leather Technologists and Chemists 102(1), 2018, pp. 33-41
14. Koizhaiganova M., Meyer M., Junghans F., Aslan A.: Surface activation and coating on leather by dielectric barrier discharge (DBD) plasma at atmospheric pressure, Journal of the Society of Leather Technologists and Chemists 101(2), 2017, pp. 86-93
15. Shataeva D.R., Kulevtsov G.N., Abdullin I.Sh.: Investigation of the effect of the interaction of nonequilibrium low-temperature plasma and organosilicon compounds on the physicomechanical properties of cattle hides, Bulletin of Kazan Technological University 17(11), 2014, pp. 73-75 (in Russian)
16. Shataeva D.R., Kulevtsov G.N., Abdullin I.Sh. Obtaining leather materials from the skins of sheepskin and cattle with improved hygienic properties by processing NNTP and organosilicon compounds, Bulletin of Kazan Technological University 17(11), 2014, pp. 86-88 (in Russian)
17. Danylkovych A.H., Korotych O.I.: Optimization of leather filling composition containing SiO_2 nanoparticles, Journal - American Leather Chemists Association 114(9), 2019, pp. 333-343
18. Danilkovich A.: Practical training on chemistry and technology of leather and fur: 2nd ed., Revised and ext.: Kyiv: Phoenix, 2006, 340 p. (in Ukrainian)
19. Haimes Y.Y., Lasdon L.S., Wismer D.A.: On a bicriterion formulation of the problems of integrated system identification and system optimization, IEEE Transactions on Systems, Man, and Cybernetics SMC-1(3), 1971. pp. 296-297, doi: 10.1109/tsmc.1971.4308298
20. Mavrotas G.: Effective implementation of the ε-constraint method in Multi-Objective Mathematical Programming problems, Applied Mathematics and Computation 213(2), 2009, pp. 455-465 https://doi.org/10.1016/j.amc.2009.03.037
21. Oliveira L., Saramago S.: Multiobjective optimization techniques applied to engineering problems, Journal of the Brazilian Society of Mechanical Sciences and Engineering 32(1), 2010, pp, 94-105, https://doi.org/10.1590/S1678-58782010000100012
22. Anderson V.L., McLean R.A.: Design of experiments: a realistic approach, Marcel Dekker, New York, Basel, Hong Kong, 1974, 418 p.
23. Kumar N., Das D.: Alkali treatment on nettle fibers part II: design of experiment and desirability function approach to study enhancement of tensile properties, The Journal of The Textile Institute 108(8), 2016, pp. 1468-1475, https://doi.org/10.1080/00405000.2016.1257347
24. Michalewicz Z.: Genetic Algorithms + Data Structures = Evolution Program, Springer-Verlag, Berlin-Heidelberg-New York, 1996, 388 p.

REVIEW OF MEN'S SHIRT PATTERN DEVELOPMENT FOR THE LAST 100 YEARS

Frederick Tungshing Fung, Lubos Hes and Vladimir Bajzik

*Technical University of Liberec, Faculty of Textile Engineering, Department of Evaluation
Studentska 1402/2, 46117 Liberec, Czech Republic
tassfashion@gmail.com, lubos.hes@gmail.com; vladimir.bajzik@tul.cz*

***Abstract:** From the 19th century until now, men's shirt pattern has been evolving and changing for the comfort and style that people need. No matter the fit of the shirt pattern is loose or tight, the style is fancy or practical; the pattern is always traced back to the original try and error draping techniques. This article is a look back on how the shirt pattern has been developed in the last hundred years and a discussion on how to predict the future development of shirt pattern will be in the conclusion.*

***Keywords:** clothing pattern, men's shirt, fit, pattern development, wearing comfort.*

1 INTRODUCTION

The very first shirt was found in Egypt around 3000 B.C. revealing the shirt was made up of three simple pattern pieces: lower front piece, lower back piece and upper front continued to upper back jointed at the shoulder and connected to the sleeve [1-4]. The whole piece of the front-back-shoulder-sleeve was pleated to create room for moving and to accommodate the shoulder, the chest and the arm, these 3 major body shapes (Figure1).

Figure 1 The oldest shirt found in Egypt revealing connected shoulder and arm piece by pleating

Since then, even the pattern shapes of the shirt have been developed and been changed, however; the basic shapes of the shirt pattern are remained very similar [5-6] that the major pattern pieces in a men's shirt are always with the front, the back and the sleeve. The development of men's shirt in those days was mainly by experience, practice, trial and error. Draping and a simple calculated drafting were/are the common practice [7-8]. This article is a review of the men's shirt pattern for the last hundred years analyzing the changing and evolvement of the pattern then looking forwards to the future development of it.

2 BASIC MEN'S SHIRT PATTERN

The fundamental shirt pattern set [9] is developed from three basic shirt blocks which are front, back and sleeve (Figure 2). A complete set of shirt pattern is made up of 7 pieces which are: front, back, back yoke, sleeve, cuff, collar and collar stand (Figure 3). This set of patterns can also be converted to fit a women's figure when bust darts and waist darts are added to take up the extra fabric under the bust and around the waist in the front and back to fit the women's figure better. A comparison in Figure 4 is showing the differences between a men's and a women's shirt pattern. Other details like buttonhole plackets, cuff plackets, pocket and facing are developed for functionality, wearing comfort and style.

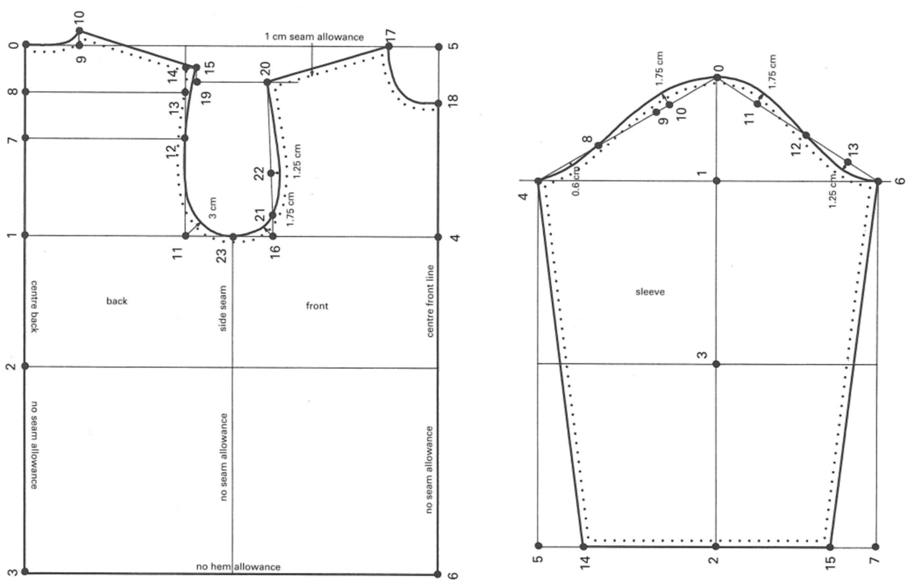


Figure 2 Basic bodice blocks: front, back and sleeve from which the complete shirt pattern set and other upper body garment patterns are developed

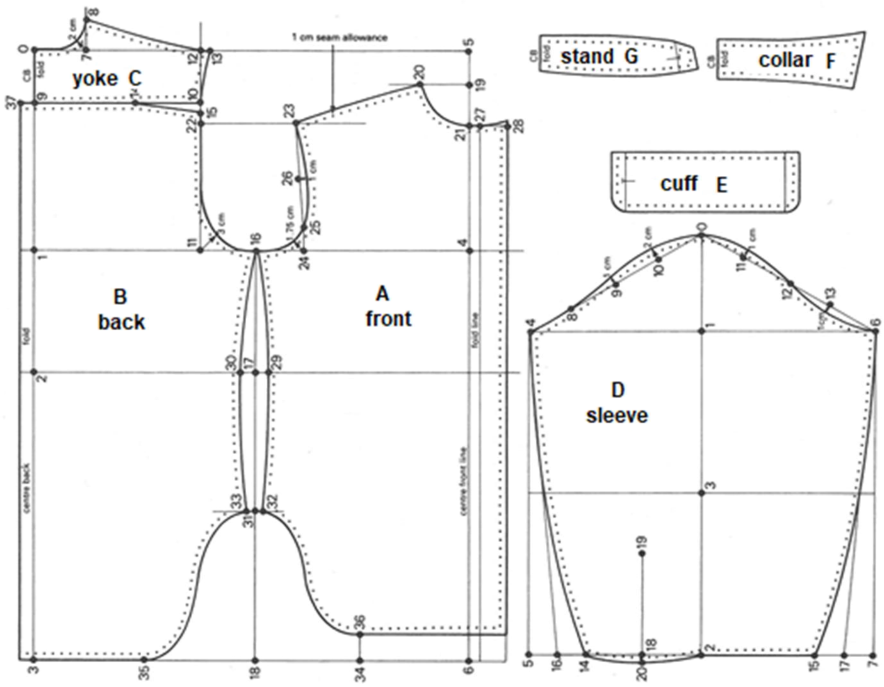


Figure 3 A complete set of shirt pattern A - front; B - back; C - back yoke; D - sleeve; E - cuff; F - collar; G - collar stand

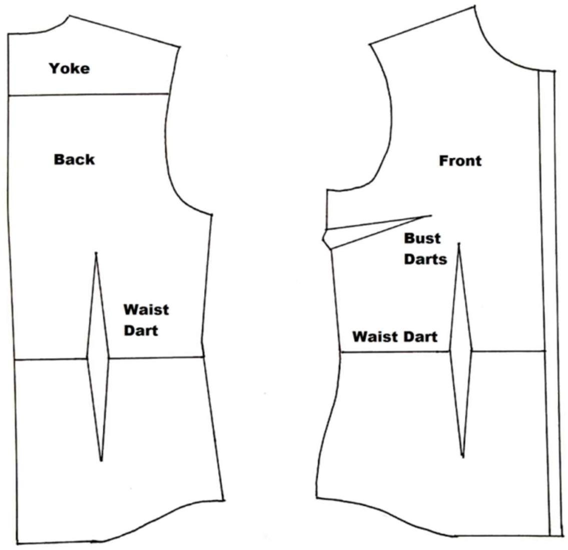


Figure 4 Women's front, back and yoke pattern pieces are similar to men's except the bust and waist darts are added in to better fit the female body

3 METHODS OF PATTERN MAKING

There are three major methods of pattern making: 1 - draping, 2 - drafting and 3 - CAD system. A brief introduction as follow:

3.1 By draping

Draping [10-11] is a technique mostly used by dressmakers or couture houses to create dresses or other garments for women. Muslin (plain-woven cotton fabric) in different weight and hands (softness) will be hung directly onto a customer's body or a dress form; then by using drawing tools, pins and scissors, the dressmaker will slowly sculpt the shape of her decided clothing. Then, the three-dimensional muslin will be transferred into two-dimensional pattern pieces on paper (Figures 5a-5b). Toward the completion of the garment, fittings and adjusting the pattern are a must. The finalized patterns can be made into a one of kind clothing or for mass production.

3.2 By drafting

This method is mostly used by tailors for men's clothing as well as small companies to produce pattern pieces directly on manila paper (a durable stiff paper specially made for pattern drafting). Measurements are taken from a mute (clothing company's model) or a customer, and then it will be translated to clothing patterns by manually calculating simple mathematical equations to create the fit and the style [12-13]. Since each pattern maker's experience is different so that the calculation for the fit, the wearing ease allowance may vary. It is also influenced by the company's needs. Figure 3 shows the calculated measurements and the drafted shirt pattern pieces and Figure 6 shows the pattern drafting in progress.

Figure 5a Dressmaker uses pencil, pins and muslin to sculpting the side pattern piece for the dress on the right. The black cotton tape underneath the muslin is used to define the design lines of the dress for the dressmaker to figure out the pattern shape

Figure 5b Showing part of the finished muslin shapes of the dress. These 3D muslin shapes will then be converted to 2D pattern pieces on paper for pattern cutting

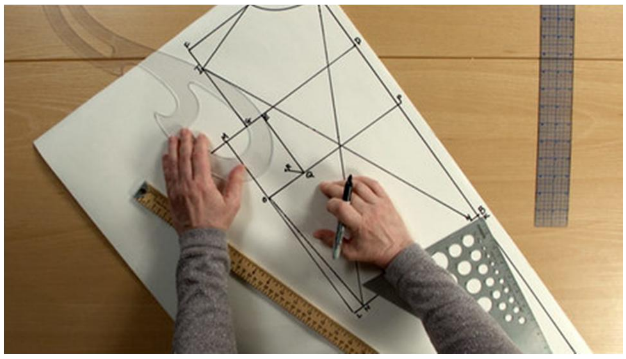


Figure 6 Showing the progress of a men's shirt drafting

3.3 By CAD system

Computer-Aided Drafting system is the fastest, easiest and more accurate pattern making tool though it is very expensive software and usually used by big clothing labels to prepare for their mass production. Most of the popular CAD system (Figure 7) in apparel/garments industry like Gerber, Tukatech, Optitex, Lectra and more; allow the user to adjust, to change, to cut, to grade and all other different functions to pattern making by inputting the measurements. It is highly efficient and time-saving [14-15].

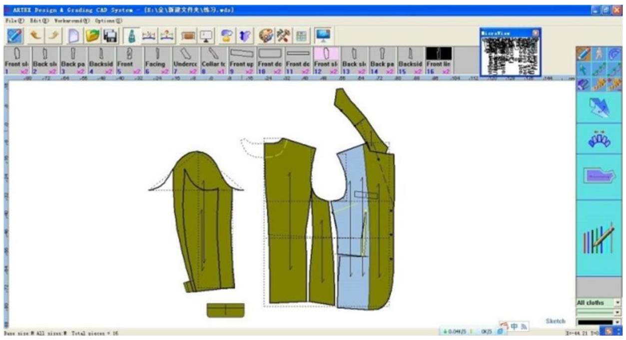


Figure 7 Showing one of the CAD software for pattern making

4 BRIEF HISTORY OF SHIRT DEVELOPMENT

In the 17th century, shirt was worn in Europe as an undergarment to protect the expensive waistcoat wearing on top and to prevent the jacket from sweat and soil [16-17]. Early in the 18th century, Beau Brummel [18-19] and another iconic figure in Regency England brought shirts into the spotlight and turned it into an essential garment for men.

During the 19th century, shirt was considered as luxurious attire due to heavy labor to keep it clean and white. Until later in the mid-19th century when the laundry techniques were improved, shirt market was expanding with affordable prices then the shirt was truly gaining its popularity.

For the last hundred years, shirt style and fit are constantly changing; from broad shoulder and wider chest circumference to allow more mobility but bulky, and to the slim fit which is narrower from the shoulder down to chest and waist and limiting movement yet provides the wearer a slender look. Moreover, the stylish cuffs, forever changing sleeve length, dozens of collar and collar stand styles combination plus decorative buttonhole plackets; shirt has been evolved into a big market in the garment industry [20]. Figures 8-11 are showing some details of shirt front, shirt back to cuffs and collar that will be discussed in the shirt pattern through the history of time Part 2, 3 and 4.

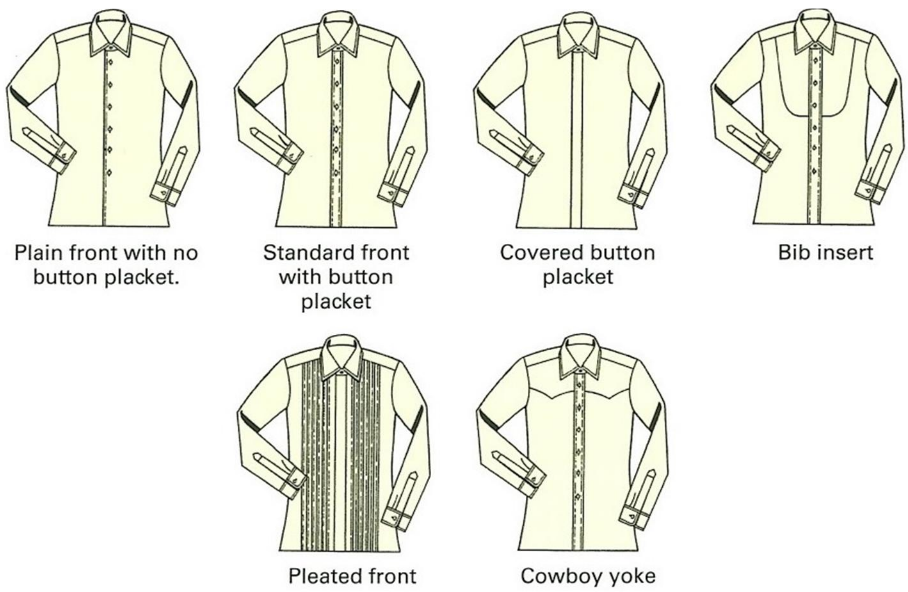


Figure 8 Details development of shirt front including button plackets, front yoke, inserted pieces and pleats

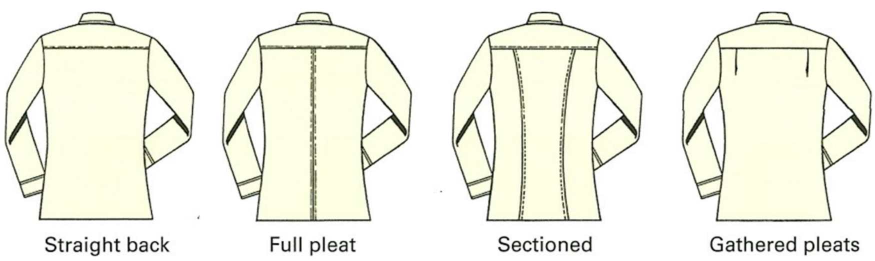


Figure 9 Shirt back development from single panel to 2, 3 panels and pleating

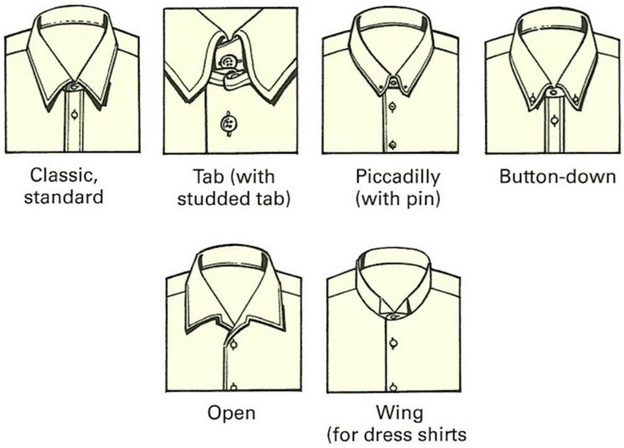


Figure 10 Shapes, height and opening angle of the collar has been changing throughout the history

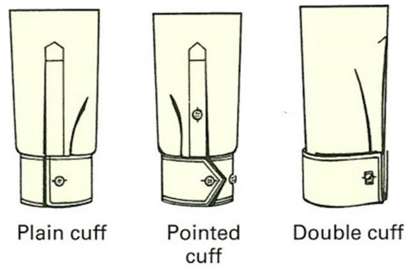


Figure 11 Subtle changes of cuffs are still based on the plain cuff pattern

5 SHIRT PATTERN THROUGH HISTORY OF TIME PART 1: THE BODICE

The 1900s

In the early 1900s, shirt was still tailor-made, roomy and worn as underwear for comfort. Shirt was the pull-over style (Figure 12) mostly made of linen, high maintenance and only privileged class could afford. After the mid-1900s when machines were invented to mass-produce and to clean shirts, shirt prices became affordable and popularized. Dress-shirt was always pull-over style until after coat shirt style [21, 22] (which is today's buttoned-front shirt) was developed around 1912 and then old-style slowly faded away in the early 40s. Since not many pieces were survived before the 1920s that shirt patterns can only be estimated from pictures and catalogue drawings.

Figure 12 Left, a replica of pullover style from the same era; right, showing the fit of the roomy shirt on people

Since shirts were mass-produced by machines. Dress shirt and work shirt were similar in patterns and sizes, only differences were the materials and details, for example like pearl buttons; number and details of pocket; single, double, triple-stitched or flat-fell seam finish. The dress shirt was almost always made of linen and work shirt was heavy twilled cotton [23]. The full-length shirt was 36 inches [24] from the 7th cervical vertebrae of the back neck down to the shirttail, 46 inches chest circumference and 19 inches biceps circumference (Figure 13) for a 15½ neck size man [25-27]. Shirt size was the neck circumference and sizes were divided into 14½, 15, 15½, 16, 16½, 17 inches, six sizes; considered men's figures were not athletic build as today that the shirt was very roomy [28].

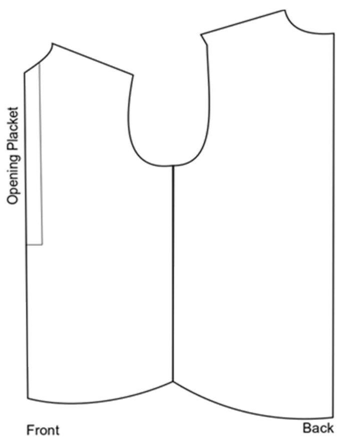


Figure 13 Estimated front and back patterns for visual reference only, not in true proportion

The 1910s-20s

During this era, dress shirt patterns remained unchanged but work shirt patterns had been developed into a few different elements (Figure 14). The back yoke from single to double, from thin to wide and across the shoulders; and later the yoke was extended to cover the lower chest and doubled to endure abrasion during work. Ventilation holes were punched and stitched onto the back yoke and along the armholes or the chest yoke extension to lower body heat during heavy workload (Figure 15). Chinstraps and scalloped yokes were developed for comfort. Patterns of work shirt were gradually slimmed down and shortened but still comfy and the fit of the shirt became the classic fit model for today’s shirt and this was quickly adopted by the dress shirt/business shirt [18, 29-30] during this era. Coat style shirt was developed in 1912 and slowly became popular while the pull-over style shirt remained until the early 60s’.

Figure 14 Package and the catalogue page from the 20s’ showing the fit of the shirt

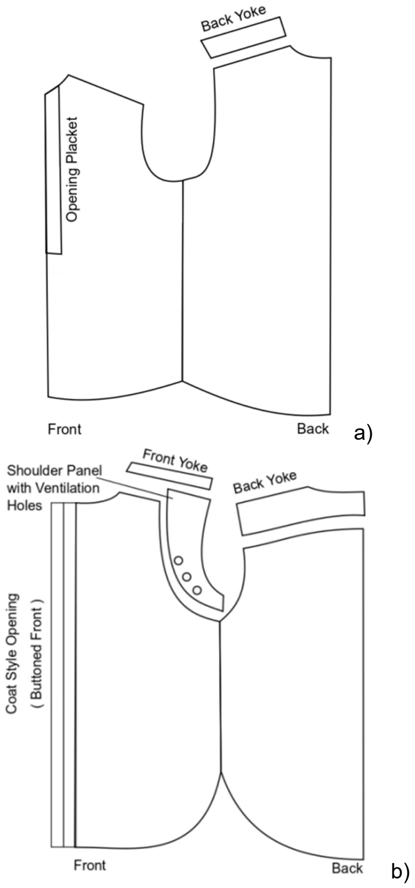


Figure 15 Dress shirt patterns: pullover style and high back yoke (a); work shirt patterns: coat style with front/back curved yoke and shoulder panel with ventilation holes (b)

The 1930s-40s

Buttoned-front shirt and classic fit dominated the market (Figure 16). Round shirttails were gone and replaced by squared hems. Shirt length was shortened to hip for the trendy untacked shirts liked Cuban collar (one-piece convertible collar) shirt, Hawaiian shirt, Camp shirt, etc., and also for easy tucked in when pairing with a pair of high-waisted pants. Sleeves were shortened; chinstraps and detachable collars were out of style. Flat yoke design became classic until today (Figure 17). Overall, shirts meant to fit only neck and shoulders but draped down loosely for comfy and style [31-34].

Figure 16 The easy-fitting style became a classic fit for today’s shirt

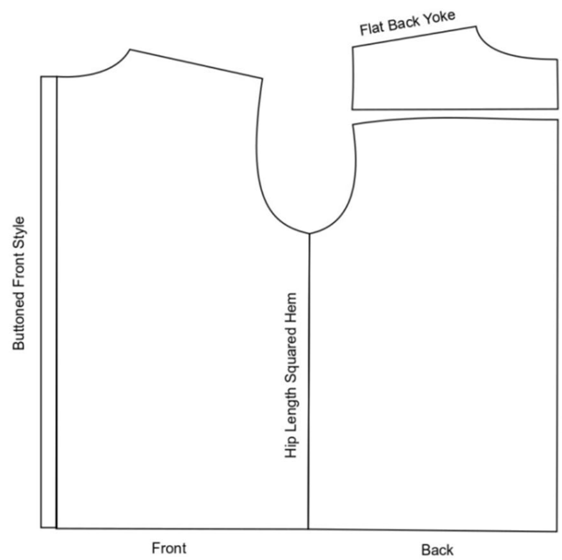


Figure 17 Loose, roomy, squared hem Camp shirt with flat back yoke and buttoned front style

The 1950s-60s

Post-war era, classic fit, buttoned-front shirt style and flat front/back yoke were standard elements in dress shirts, business shirts, workwear and casual wear. Changes were only in colors, patterns on shirt and materials (Figure 18).

Figure 18 Classic fit, the buttoned front became standard with more color and pattern choices

The 1970s

The ’70s was the era of synthetic materials and polyester was the highlight of all. Cotton/polyester blend or 100% polyester clothing were everywhere. These materials allowed designs of clothing to become narrower, tighter or even skin-tight that the whole suddenly slimmed down a lot (Figures 19 and 20).

Figure 19 Samples of slimmed and skin-tight fit shirt from the catalogue page

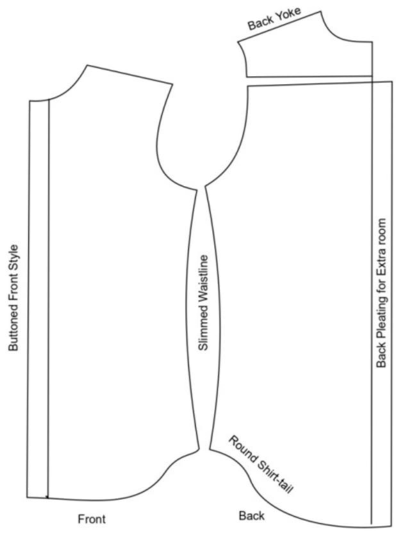


Figure 20 Slim shirt patterns: flat back yoke, take in waistline, back pleat and round shirt hem

<u>The 1980s-90s</u>

Since the 60s, the world economy had risen until the 80s’; everyone was celebrating and enjoying life. The entertainment business was flourishing and had a great influence on clothing, especially Hip-Hop style. Big, oversize, broad shoulder, loose and baggy shirt was popular casual wear in the young generation. However, the business shirt was still slim and snuggly fit that was inherited from the 70s’ trend [35] (Figures 21 and 22).

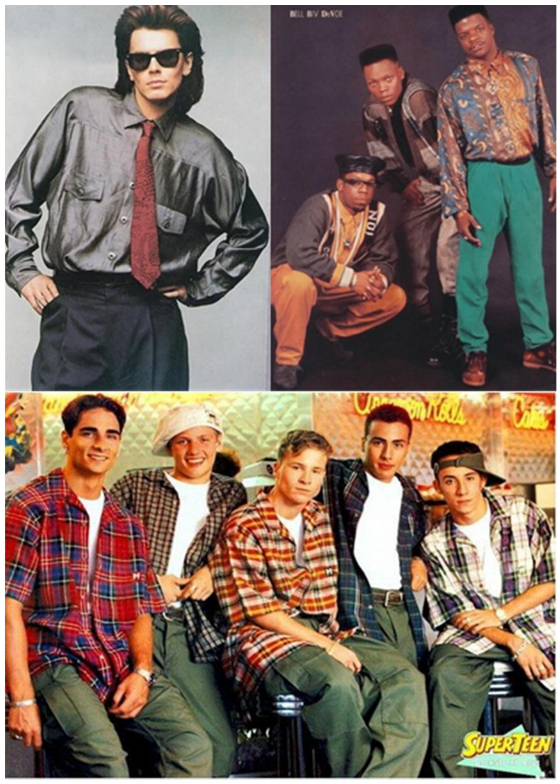


Figure 21 Samples of a loosely draped shirt with dropped shoulder and over-sized bodice

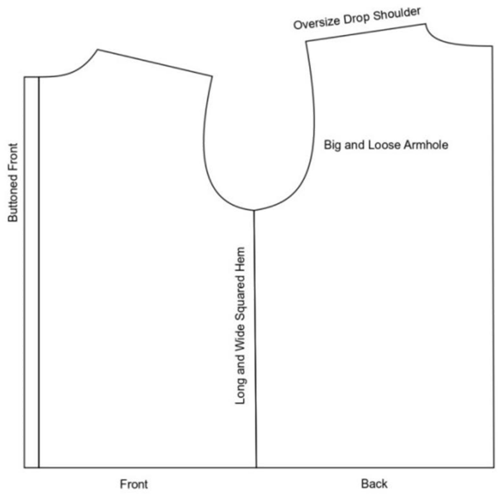


Figure 22 Big, loose, oversized and squared hem Hip-hop shirt patterns

The 2000s till now

Hip Hop baggy shirt continues till today among younger groups as their casual wear while older males are increasingly aware of tailoring, and making a garment fit right for their body shape, rather than going with the fashion trend [36].

For this reason, the adaptation to dress shirt and business shirt markets, the fit of the shirt was slowly divided into three major groups for mass production; they were classic fit, standard fit and slim fit. Until today, these three groups of fit are still used by every clothing company and become industry standard even though each company may define their fit slightly different or may have a different name for themselves, however; the core concept is the same which is to divide the majority of body types into manageable groups of fit for mass production (Table 1 [37], Figure 23).

From shirt was being worn as the undergarment to being part of the necessary elements of the classic attire for men, the shirt has been changing and developing through a different era. However, all these changes are still based on the basic pattern blocks as shown in Figures 2-3. Collar, collar stand, sleeve, cuffs, yoke, shirt front and back; no matter how these patterns turn from plain to fancy or even complicated pattern pieces, there are still strongly influenced by the original pattern blocks. Among all these changes, the fit is the most important parameter that will directly influence the comfort of the wearer. Shan mentioned, “Fit is defined as the relationship between the size and contour of the garment and those of the human body. It is a complex issue related to such as apparel construction, anthropometry, apparel comfort, apparel psychology, computer graphics, and so on” [38].

Figure 23 Samples of shirts with a classic, slim and regular fit

6 DISCUSSION AND CONCLUSION

Shirt is an important piece of garment, especially for men. Since the shirt slowly gaining its popularity in the 19th century until today, the market demand for the shirt is still growing globally [39, 40]. Especially nowadays, new technologies are involved and materials are invented; more and more innovative textiles and smart garments are developing. However, the clothing pattern still relies on the fundamental basic bodice and sleeve blocks which are originally derived from draping techniques hundreds years ago. With this hi-tech fabric slowly filling in the garment business, would the traditional basic blocks be compatible with the new materials; or should there be a new set of clothing patterns developed. Even clothing pattern is produced with the CAD system; it is still based on the basic blocks. When the materials / textiles are going forward but the basic clothing pattern set is still staying behind. Does it make sense?

Table 1 Comparison table of three common garment fits

	Classic fit	Regular fit	Slim fit
Pattern Cutting	Cut generously and hang loosely, very roomy	Hang loosely on the body but not baggy	Hang snugly but not too tight
Comfort	Less tight and more comfortable than a regular fit	Comfortable	Not as comfortable as regular fit
Sleeve	Big armhole and roomy sleeves	Full sleeves but not overly loose	Less full sleeve and smaller armhole
Shoulders	Broader shoulder yoke with a box pleat to allow more mobility	Less broad shoulder yoke may or may not have a box pleat	Slimmer shoulder yoke may have back darts
Measurement of a 15.5 neck size shirt	Chest 49” Waist 46”	Chest 47.5” Waist 44”	Chest 46” Waist 42”

A new pattern set should be researched and be invented. New pattern blocks should focus on build-in thermal insulation to keep the wearer warm, sweating efficiency and cooling effect by researching clothing air gaps and pattern sizes and shapes relationship. Of course, body movements and wearing comfort cannot be neglected. With new materials and new pattern set, this evidence creates the new world in the garment industry for our future.

7 REFERENCES

1. Rothstein N., Ginsburg M., Hart A, Mendes: Four Hundred Years of Fashion, Victoria and Albert Museum in association with Collins1984, ISBN 0-00-217190-2
2. Gant: History Of The Shirt-Shirt Guide, http://www.gant.com/shirtguide/shirt-history
3. "Timeline of Clothing and Textiles Technology", On Wikipedia, March 16, 2019. https://en.wikipedia.org/w/index.php?title=Timeline_of_clothing_and_textiles_technology&oldid=888053382
4. "History of Clothing and Textiles." In Wikipedia, March 17, 2019 https://en.wikipedia.org/w/index.php?title=History_of_clothing_and_textiles&oldid=888177262.
5. Brough D.: Neo-dandy: wearability, design innovation and the formal white dress shirt for men, Masters by Research thesis, Queensland University of Technology, 2008
6. Cunnington C.W., Cunnington P.: The History of Underclothes. Courier Corporation, 1992, 266 p., ISBN 9780486271248
7. Hulme W.H.: The Theory of Garment-Pattern Making: A Textbook for Clothing Designers, Teachers of Clothing Technology, and Senior Students, National Trade Press Limited, 1945, 136 p., ISBN 9780598617583
8. Aldrich W.: Metric Pattern Cutting for Menswear, 5th ed., Wiley-Blackwell, 2011, 200 p., ISBN 978-1405182935
9. Coffin D.P.: The Shirtmaking Workbook: Pattern, Design, and Construction Resources - More Than 100 Pattern Downloads for Collars, Cuffs & Plackets, Quarry Books, 2015, 176 p., ISBN 9781589238268
10. Sterlacci F.: "What Is Draping? An Overview and History", University of Fashion Blog, July 25, 2013, https://www.universityoffashion.com/blog/what-is-draping-an-overview-and-history/.
11. Aldrich W.: Fabric, Form and Flat Pattern, Wiley, 2007, 224 p., ISBN 9781405136204
12. Chan A.P., Fan J., Yu W.: Men's shirt pattern design part I: an experimental evaluation of shirt pattern drafting methods, Sen'i Gakkaishi 59(8), 2003, pp. 319-327, https://doi.org/10.2115/fiber.59.319
13. Chan A.P., Fan J., Yu W.: Men's shirt pattern design part II: prediction of pattern parameters from 3D body measurements, Sen'i Gakkaishi 59(8), 2003, pp. 328-333, https://doi.org/10.2115/fiber.59.328
14. Yuwei M., Mok P.Y., Jin X.: Computer aided clothing pattern design with 3D editing and pattern alteration, Computer-Aided Design 44(8), 2012, pp. 721-734. https://doi.org/10.1016/j.cad.2012.03.006
15. Han H.S., Kim J.Y., Kim S.M., Lim H.S., Park Ch.K.: The development of an automatic pattern-making system for made-to-measure clothing, Fibers and Polymers 15(2), 2014, pp. 422-425, http://dx.doi.org/10.1007/s12221-014-0422-6
16. "Shirt." On Wikipedia, June 24, 2018, https://en.wikipedia.org/w/index.php?title=Shirt&oldid=847293342
17. Norris H., Curtis O.: Nineteenth-Century Costume and Fashion, Courier Corporation, 1998, 264 p., ISBN 9780486402925
18. Boyer G.B.: True Style: The History and Principles of Classic Menswear, Basic Books, 2015, 272 p., ISBN 978-0465053995
19. "Beau Brummell", In Wikipedia, May 12, 2019, https://en.wikipedia.org/w/index.php?title=Beau_Brummell&oldid=896792895.
20. "100 Years of Fashion: Men ★ Glam.com", on YouTube, accessed May 16, 2019, https://www.youtube.com/watch?v=DaSkMWVlFUU&list=WL&index=23&t=0s.
21. http://www.marquise.de/en/1900/howto/men/index.shtml
22. http://menfashionworld.in/2020/02/11/men-fashion-world/
23. https://the-rite-stuff.com/blogs/news/the-evolution-of-the-work-shirt
24. https://vintagedancer.com/vintage/mens-vintage-inspired-clothing/
25. https://www.retrowaste.com/
26. https://menhealth.in/overview-1950s-mens-fashion/
27. https://nextluxury.com/mens-style-and-fashion/1920s-mens-fashion-style-guide/
28. https://ourworldindata.org/human-height
29. Peterson A.T., Hewitt V., Vaughan H., Kellogg A.T., Payne L.W.: The Greenwood Encyclopedia of Clothing Through American History, 1900 to the Present-Volume 1, 1900-1949; 1900 to the Present-Volume 2, Greenwood Press, 2008, ISBN 9780313333958
30. Laver J.: The Concise History of Costume and Fashion, Harry N. Abrams Inc.1979
31. https://streetxsprezza.wordpress.com/2017/08/03/the-vintage-sport-shirt/
32. https://www.pinterest.ca/pin/465489311483750332/
33. https://the-rite-stuff.com/blogs/news/the-evolution-of-the-work-shirt
34. https://vintagedancer.com/1940s/1940s-teenage-fashion-for-boys-and-young-men/
35. https://www.thetrendspotter.net/80s-fashion-men/
36. https://stylesequelblog.wordpress.com/2016/02/02/mens-fashion-trends/
37. "Difference Between Classic Fit and Regular Fit | Classic Fit vs Regular Fit", DifferenceBetween.com, January 18, 2017, https://www.differencebetween.com/difference-between-classic-fit-and-vs-regular-fit/
38. Shan Y., Huang G., Qian X.: Research overview of apparel fit, Soft Computing in Information

Communication Technology 161, 2012, pp. 39-44, https://doi.org/10.1007/978-3-642-29452-5_7

39. Lu S.: Statistics: Global Apparel Market 2016-2020, FASH455 Global Apparel & Textile Trade and Sourcing, blog, October 16, 2016, https://shenglufashion.com/2016/10/16/statistics-global-apparel-market-2016-2018/
40. http://www.textbooksfree.org/One-Page%20History%20of%20U.S.%20Economic%20Growth.htm

8 ILLUSTRATIONS

Figure 1: See the World's Oldest Dress, National Geographic News, February 18, 2016, https://news.nationalgeographic.com/2016/02/160218-oldest-dress-egypt-tarkhan-archaeology/

Figures 2, 3: Aldrich W.: Metric Pattern Cutting for Menswear, John Wiley & Sons, 2011

Figures 4, 13, 15, 17, 20, 22: owned figures

Figures 5a, 5b, 6, 7: from Pinterest, pinterest.ca

Figures 8-11: Hannelore E., Hermeling H., Hornberger M., Kilgus R., Menzer R., Ring W.: Clothing Technology, Beuth-Verlag GmbH, Berlin, 2004

Figures 12, 21: https://www.google.ca/search?q=hip+hop+80s+fashion+men&tbm=isch&hl=en&ved=2ahUKEwj16tzxuYHpAhVHyxQKHRsOBy0QrNwCKAJ6BQgBEM8B&biw=1349&bih=625#imgrc=qIOVlTtJHRAaTM

Figure 14: left [23], right [27]

Figure 16: left [32], right [23]

Figure 18: top [25], bottom [26]

Figure 19:

https://www.boredpanda.com/1970s-mens-fashion-ads/?utm_source=google&utm_medium=organic&utm_campaign=organic

Figure 23:

http://www.fashionindustrynetwork.com/m/blogpost?id=786233%3ABlogPost%3A168752937-
https://stylesequelblog.wordpress.com/2016/02/02/mens-fashion-trends/

EFFECT OF MULTIPLE USE ON THE DURABILITY OF COMPRESSION SOCKS

EmadEldin Sayed Gohar[1] and Adnan Mazari[2]

[1]*Faculty of Home Economics, King Abdul-Aziz University, Jeddah, Saudi Arabia*
[2]*Technical University of Liberec, Studentska 2, 46117, Liberec, Czech Republic*
mazariadnanahmed@gmail.com

Abstract: *Compression socks are widely used for medical purposes. The socks are classified as three pressure classes with different sizes according to circumference of leg. These socks are daily worn for complete and due to hygiene issues it's washed every day as well. The research work shows the effect of washing and multiple wearing on the durability of compression socks. There is significant decrease of pressure in terms multiple wearing and there was insignificant difference from the washing cycles. The results are beneficial for the patient who regularly uses the compression socks.*

Keywords: *socks, compression socks, pressure.*

1 INTRODUCTION

Compression socks are the widely used textile garment for pressure exertion on the lower part of the leg. It is used to reduce venous hyper pressure [1].

Working principle is lowering of pressure exertion from ankle to calf portion of the leg. The pressure exertion value should be highest at the ankle that must gradually decrease along the direction of the leg. This varying degree of compression pressure propagate and regulate blood flow, keep the muscles in-line at the right position to mitigate the injury risk, gives relief to many of chronic venous disease patients and used for therapeutic purposes [2, 3].

The intensity of compression pressure used for various diseases is categorized as moderate up to (20-30 mmHg) and firm compression (30-40 mmHg). This extent of pressure is decided and recommended to treat circulatory and vascular medical conditions as well for tired, sore, swollen, or aching legs [4-7].

Textile durability is the measure of textile ability to resist mechanical and chemical influences, that they are exposed during their manufacturing and subsequent using. It is determined by the length of time that a textile is able to maintain its innate characteristic, like strength, dimension and appearance, in use. This time may vary depending on the environment, the amount and degree of use and the user's judgment about the durability. Interpretation of textile durability has considerably changed over years. For example, hundred years ago, textiles were relatively expensive, so they were intensively used and repaired. Nowadays, textiles are much cheaper and customer more often prefers a buy of a new product than a repair of old one, which substantially influences the durability [8].

Performance and characteristics of textile materials are determined by their manufacture, i.e. the type of used fibers, yarn, fabric structure and finishing treatments. Generally, knitted textiles are less stable in use than woven textiles. This is caused by the fact they are produced from low twist yarns, and have a slack construction. So, knitted fabrics tend to deform easily under a fairly low degree of tension [12-16].

Devices used for measuring interface pressure

The most commonly used device for measuring compression pressure in industry is HATRA, which is required for measuring MCS (medical compression socks) by British standards, and HOSY device, required by German standard RAL GZ 387 [9-11].

HATRA device, with two metal bars, simulates a simplified leg shape onto the stockings are stretched. Moveable is just the top bar while the lower bar is fixed and has two curved attachments that are used to simulate calf or thigh. Holders for the top edge of stockings are also available in different sizes (i.e. thigh-high length, knee-high length, etc.). After the garment is placed on the leg form, a measurement is made by simultaneously stretching the stocking both length and width ways on the dimensions which simulate its wearing. The measurement head force element is brought into contact with the stocking at the place marked for measuring. When pressed against the material, the device counts pressure acting on the sensor [9-11].

The *HOSY* utilizes system of twenty tensile tester devices, where each is 5 cm wide. The measured stocking of any shape is clamped in these tester devices and measure without destroying. Upper gripping system is fixed, while the lower gripping system is moveable, and stretches clamped stocking at the specified length to the specified width, simulating its wearing. When it is stretched to the destined dimension, the force needed to stretch the stocking in the circumferential direction is measured. Based on these values an amount of applied pressure on the body is determined. In addition to interface pressure, it can measure elongation, tensile force, and residual pressure [9-11].

MST (medical stocking tester) consists of a flat, air-filled sleeve, connected to the pressure sensor. This sleeve is inserted between measured stocking and the leg or a leg form. Due to its low profile, there are no bulges on the stocking which would result in an inaccurate measurement, and the pressure can be registered at different height levels. The MST has been developed over the years, and while the earlier versions used a wooden leg form required to be changed to test different sized stockings, the current version can be used for quality control in production or laboratory environments, as well as on patients in the hospital environment [9-11].

Kikuhime device represents one of the easiest methods to measure compression pressure of MCS directly on the body. It is a portable monitoring device, consists of an oval polyurethane balloon sensor containing a 3 mm thick foam sheet, and this is connected to a syringe and a measuring unit. When is the sensor placed between the leg and the compression stockings, the transducer monitors the pressure experienced by the balloon and the pressure value is converted to mmHg and shown on the digital display [9-11].

Dimensional stability of textiles is the ability to keep its original dimensions during and after the manufacturing process and when it is in use by the customer. Knitted textiles can exhibit either reversible or irreversible shrinkage (i.e. dimensional decrease) or, growth (i.e. dimensional increase). Several factors affecting the change in dimensions of a knitted fabric exist: fiber characteristics, stitch length, machine gauge, yarn twist, yarn count, knitting tension, type of machine, type of needle, type of fabric, the method of relaxation procedure, the method of washing, finishing, drying, etc. Not all of those factors have such a major influence on fabric shrinkage, but the most responsible is the relaxation of internal stress imposed on the yarn during the knitting process [8].

Knitted fabrics have more than any other textiles tendency to dimensional instability and spontaneous changes. Already, in the knitting process is a fabric in unstable shape. When knitted textile is drawn-off, it shrinks in wales direction and the geometrical parameters are changed. After taking-off from the machine and removing strain, a fabric gets into a dry relaxation (relatively stable shape). After laundering, especially after multiple laundering is a fabric most approaching the state of complete relaxation (state with minimum of internal deformation energy and with the lowest tendency to change dimensions). Subsequent drying process must be without any mechanical stresses, it means lying, because when a knit is hanging, there is a tension leads again to the deformation and dimensional changes.

2 MATERIALS AND METHODS

The samples of socks are selected according to pressure classes, following is the detail of the standard pressure class of medical compression socks.

Table 1 Compression classes according RAL GZ 387

Compression class	Compression intensity	Compression in kPa[1)]	Compression in mmHg[2)]
I	Low	2.4 to 2.8	18 to 21
II	Moderate	3.1 to 4.3	23 to 32
III	High	4.5 to 6.1	34 to 46

1) 1 kPa = 7.5 mmHg; 2) 1 mmHg = 0.133 kPa

Three socks with similar composition and material are selected for Class 1, 2, and 3 for the standard leg circumference of 23-26 cm. the details are mentioned in Table 2.

The standard wooden leg with circumference of 24 cm from the Swiss company is selected for the experiment all the measurements of pressure are done on the ankle position.

Table 2 Specifications of MCS samples

Sample identification	Compression class	Structure	Composition	Manufacturer (Country)	Circumference [cm]
AI	CCLI/Light	Rib	60% polyamide, 40% elastane	Varitex (Netherlands)	23 - 26
BII	CCLII/Medium	Plain/Single Jersey		Varitex (Netherlands)	23 - 26
CIII	CCLIII/High		60% Tactel/polyamide, 40% Lycra/elastane	Aries (Czech Republic)	23 - 26

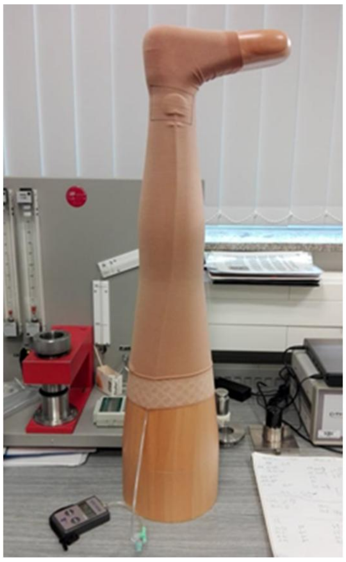


Figure 1 Placement of the pressure sensor on leg

Fabric thickness is measured as the perpendicular distance between the two fabric surfaces under a specified applied pressure. For fabric thickness determination SDL M034A device was used. The measuring was done according the standard ČSN EN ISO 5084 (80 0844). The standard specifies applied pressure 1 000 Pa, size of the pressure head 20 cm^2 and sample load 200 g. Measurement, the same as results, are recorded by computer. Ten measurements of material thickness were performed on each sock. Further properties of the socks are listed in Table 3.

Compression Pressure Measurement

Pressure measurement of socks was performed at the ankle level, the point where the Achilles tendon changes into the calf muscles. As literature shows, this is the area of socks that has to keep the biggest pressure and has to withstand largest differences in the circumference during its wearing. Pressure measurements were performed with using a standardized leg. For measuring the pressure exerted by stocking on the surface of wooden leg a Kikuhime device was used. To measure with Kikuhime, it needs to be calibrated after turning on, and then insert sensor between the surface of plastic leg and stocking.

Table 3 List of stitch density and thickness of socks

Sample identification	Wale density [Loops/cm]	Course density [Loops/cm]	Stitch density [Loops/cm^2]	Thickness [mm]
AI	28	22	616	0.94
BII	23.8	21.8	518.84	0.76
CIII	26.6	21	558.6	0.63

3 RESULTS AND DISCUSSION

All the samples were tested firstly for the compression after application, after 24; 28 and 48 hours respectively to observe the effect of the compression pressure on the wearing time.

Table 4 Mean compression pressure of socks

Pressure	AI	BII	CIII
	CCL I	*CCL II*	*CCL III*
mmHg	26.60	40.50	54.60
kPa	3.54	5.39	7.26

Figures 2-4 show that there is decrease of the compression pressure of medical socks after worn on the leg for 48 hours.

Table 5 Compression pressure of socks after long term usage

Sample identification	Pressure at cB [mmHg]					Total of pressure drop [mmHg]
	after application	*after 4 hours*	*after 24 hours*	*after 28 hours*	*after 48 hours*	
AI	26.67	23.00	18.00	17.00	13.67	13.00
BII	40.67	38.67	32.00	30.33	26.33	14.33
CIII	54.00	48.67	37.67	36.33	29.67	24.33

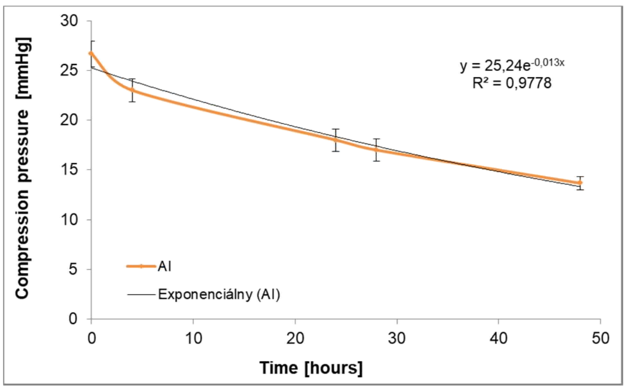


Figure 2 Decrease of compression pressure with time of wearing for Class 1

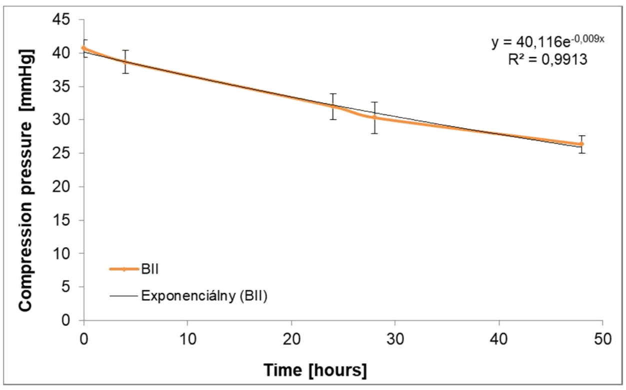


Figure 3 Decrease of compression pressure with time of wearing for Class 2

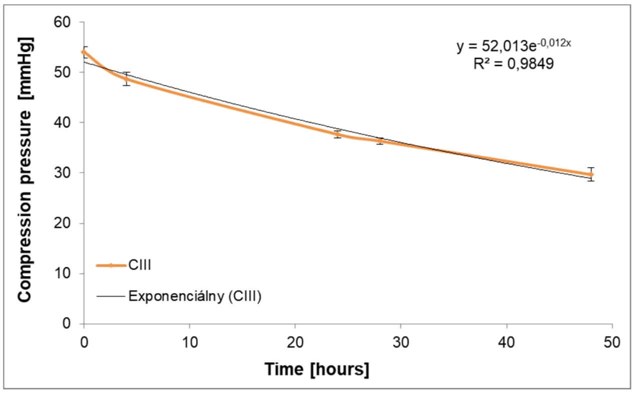


Figure 4 Decrease of compression pressure with time of wearing for Class 3

This shows that the pressure is lost by nearly 10-25% which is very crucial for the medical patients. This loss of pressure is majorly due to the relaxation of the knitted structure with time. Either the socks should be replaced after 6-8 hours or worn out and should be given some time to come back to its original structure.

Secondly the original all socks and the socks worn for 12 hours are tested for the load elongation, the curve shows that the each Class of compression socks are able to be extended even at lower force. The experiments are performed only on the course side as in compression socks the overall decrease of the socks radius causes the pressure and the role of the warps is very limited. Only a portion of the curve at identical force level is shown to compare the extension lines, which gives a realistic idea of socks on a real leg.

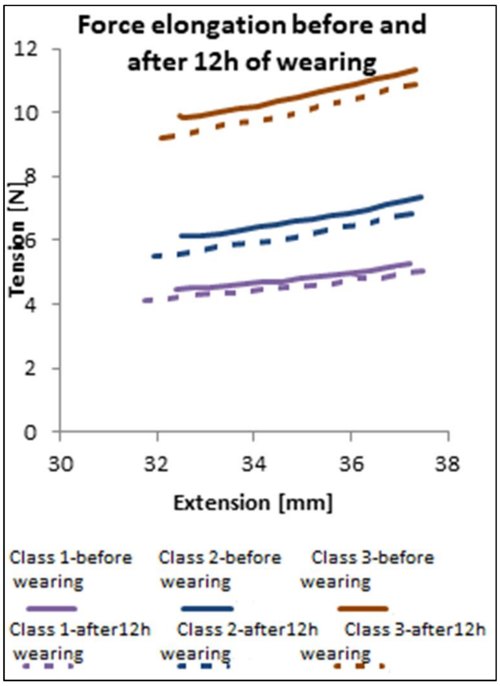


Figure 5 Force extension curve before and after 12 h of wearing

The percentage decrease of compression pressure after wearing is shown in Table 6.

Table 6 Percentage pressure degradation in 48 hours

Sample identification	Pressure decrease [%]			
	after 4 hours	*after 24 hours*	*after 28 hours*	*after 48 hours*
AI	13.75	32.50	36.25	48.75
BII	4.92	21.31	25.41	35.25
CIII	9.88	30.25	32.72	45.06

The socks were also hand washed to see the effect of washing on the compression pressure. The temperature of water was 35°C and the results in Table 7 shows a minor increase in compression pressure, which can be due to the contraction of knitted structure after washing. The effect is found to be insignificant.

Table 7 Pressure at ankle level after hand washing

Sample identification	AI	BII	CIII
Compression class	CCL I	CCL II	CCL III
Mean [mmHg] before washing	26.60	40.60	54.20
SD [mmHg]	0.97	1.84	1.23
Mean [mmHg] after washing	25.8	41.12	53.73
SD [mmHg]	0.87	1.5	1.7

The Table 7 is very essential to understand the insignificant different in compression pressure after hand washing, the compression socks are quite often washed to protect the patients form any bacterial infection. The producer recommends the hand wash but it is generally seen that most of the patient prefer to machine wash. In further research the effect of machine wash at different temperature will be analyzed.

3.1 Dimensional change

The exact original dimensions in a square form were indicated by textile marker pen on each sample of socks at the location of ankle level. The size of marked square was 50x50 mm. After the samples were washed and air-dried, the dimensions of the marked square were measured again to determine the change in dimensions. Table 8 shows the dimensions in course and wale directions before and after the M samples were washed, where D_{NW} are dimensions of marked square before washing, D_{HW} are dimensions after HW. Measurements were taken to the nearest 0.5 mm of the lines that were marked off.

Table 8 Dimensional change after different types of laundering

Sample identification	D_{NW} course x wale [mm]			D_{AHW} course x wale [mm]		
AI	50	x	50	50	x	48.5
BII	50	x	50	49	x	50
CIII	50	x	50	49	x	49.5

Dimensional changes expressed in [%], were calculated according the literature [6] as follows:

$$s = \frac{l_1 - l_2}{l_1} . 100 \quad (1)$$

where: s is shrinkage [%], l_1 is the initial dimension of the sample [mm] and l_2 is the dimension of the sample after washing [mm].

Change in dimensions is indicated (+) if shrinkage occurs or (-) when fabric is extended. The higher the dimensional change value, the more shrinkage or extension occurred. Table 9 shows the total dimensional change for course and wale in [%] for the marked square at ankle level of each MCS after being hand washed.

Table 9 Dimensional change in percent after hand washing

Sample identification	D_{AHW} course x wale [%]		
AI	0	x	3
BII	2	x	0
CIII	2	x	1

From the results of percentage dimensional changes is obvious that no fabric extension happened, but shrinkage occurs for all types of MCS. Wale direction can be labelled as a less stable direction due to the higher values for shrinkage.

The results demonstrate that shrinkage occurs during washing, but the amount of dimensional changes after washing does not occur with the same trend. Also, MCS samples with the same or similar stitch density or composition do not behave in laundering with the same trend, so influence of those factors on overall performance of MCS cannot be confirmed.

4 CONCLUSION

It is concluded from the research that the compression socks loses pressure insertion with respect to time. After just 4 hours of wearing there is minimum decrease of 10% whereas after 48 hours of wearing the compression pressure is decreased by 23%. For medical patients the precise pressure management is very important for health.

From the washing test it was concluded that the socks have insignificant change in the compression pressure after hand washing. The slight increase in the mean value was observed which is due to the shrinkage of the knitted structure.

It is recommended from the research to change the medical socks after 6 hours to have precise pressure rating.

Acknowledgement: *This Project was funded by the Deanship of Scientific Research (DSR) at King Abdul-Aziz University, Jeddah, under grant no. G: 1485-253-1440. The authors, therefore, acknowledge with thanks DSR for technical and financial support.*

5 REFERENCES

1. Siddique H.F., Mazari A.A., Havelka A., Mansoor T., Ali A., Azeem M.: Development of V-shaped compression socks on conventional socks knitting machine, Autex Research Journal 18(4), 2018, pp. 377-84, https://doi.org/10.1515/aut-2018-0014
2. Harpa R., Piroi C., Radu C.D.: A new approach for testing medical stockings, Textile Research Journal 80(8), 2010, pp. 683-695, https://doi.org/10.1177/0040517509343781
3. Smith M.W.L., Dalbey JC. Gradient compression hosiery knitted using core spun yarns, Patent application 7895863-B2 USA, 2011
4. Partsch H.: The use of pressure change on standing as a surrogate measure of the stiffness of a compression bandage, European Journal of Vascular Endovascular Surgery 30(4), 2005, pp. 415-421, https://doi.org/10.1016/j.ejvs.2005.06.002
5. Liu R., Kwok Y..L, Lao T.T.H., et al.: Objective evaluation of skin pressure distribution of graduated elastic compression stockings, Dermatologic Surgery 31(6), 2005, pp. 615-624, DOI: 10.1111/j.1524-4725.2005.31603
6. Partsch H., Partsch B., Braun W.: Interface pressure and stiffness of readymade compression stockings: Comparison of in vivo and in vitro measurements, Journal of Vascular Surgery 44(4), 2006, pp. 809-814, https://doi.org/10.1016/j.jvs.2006.06.024
7. Bera M., Chattopadhay R., Gupta D.: The effects of fibre blend on comfort characteristics of elastic knitted fabrics used for pressure garments, Journal of the Institution of Engineers (India): Series E 95, 2014, pp. 41-47, https://doi.org/10.1007/s40034-014-0029-x
8. Annis P.A.: Understanding and improving the durability of textiles, Philadelphia, Pa.: Woodhead Pub., 2012, 296 p., ISBN 978-0-85709-087-4
9. Liu R., Gou X., Lao T.T., Little T.: A critical review on compression textiles for compression therapy: Textile-based compression interventions for chronic venous insufficiency, Textile Research Journal 87(9), 2016, pp. 1121-1141, https://doi.org/10.1177/0040517516646041
10. Hegarty-Craver M., Kwon C., Oxenham W., Grant E., Reid L.: Towards characterizing the pressure profiles of medical compression hosiery: an investigation of current measurement devices and techniques, The Journal of The Textile Institute 106(7), 2015, pp. 757-767, https://doi.org/10.1080/00405000.2014.941535
11. Tyler D.: Application of Pressure Sensors in Monitoring Pressure, chapter 12 in: Materials and Technology for Sportswear and Performance Apparel, Hayes S.G., Venkatraman P. (Eds.), Boca Raton: CRC Press, 2016, pp. 289-310, https://doi.org/10.1201/b19359
12. Cotton Incorporated – 100% “Cotton, Moisture Management”, http://www.tx.ncsu.edu/, Accessed at 04.06.2020
13. by Emily: "Weft and Warp Knitting Differences," Machine Knitting Advice, 4 July 2012, https://machineknittingadvice.com/weft-and-warp-knitting-differences/

14. Allen F.: Knitting, Fibre2Fashion, 2013. Available: http://www.fibre2fashion.com
15. Petry D.: Moisture Management, Textile Auxiliaries Germany, 2008
16. Jintu Fan, Yu-Cheung Szeto, Manas Kumar Sarkar: “Fabric Simulating the Plant Structure for Moisture Management,’’ US Patent, July 16, 2013

NONWOVENS MADE OF RECYCLED CARBON FIBRES (rCF) USED FOR PRODUCTION OF SOPHISTICATED CARBON FIBRE-REINFORCED PLASTICS

Katharina Heilos[1], Holger Fischer[2], Marcel Hofmann[1] and Andrea Miene[2]

[1]Sächsisches Textilforschungsinstitut e.V. STFI, Chemnitz (DE)
[2]Faserinstitut Bremen e.V. FIBRE, Bremen (DE)
Katharina.Heilos@stfi.de; Fischer@faserinstitut.de

Abstract: *A qualified value-added chain for the re-use of recycled carbon fibres (rCF) as nonwovens in sophisticated fibre-reinforced plastics has been set up within the research project RecyCarb. The progress in processing technology was accompanied by setting up a reliable scheme of quality assurance. This article focuses (1) on the use of different web formation and bonding technologies to produce nonwovens (carding / airlay), ranging from highly-oriented to quasi-isotropic nonwoven structures, and (2) on the achievable mechanical properties of fibre-reinforced plastics produced using different processes from a range of typical rCF lots. Press-moulded composites reached tensile strength of approx. 530 MPa (CD) & 330 MPa (MD), and Young's moduli of 50 GPa (CD) and 31 GPa (MD). Similar values were obtained by resin-transfer moulding (RTM). Prepreg-based composites displayed tensile strength up to 330 MPa and Young's modulus up to 29 GPa. In addition, first experiments showed that repeated recycling of carbon fibres is possible with minor loss of stability.*

Keywords: *recycled carbon fibres (rCF); nonwoven; carbon fibre-reinforced plastics (CFRP); lightweight construction; mechanical properties.*

1 INTRODUCTION

The market predictions with an increase of 10% p.a. for carbon fibre-reinforced plastics (CFRP) are excellent 1. Consequently, there are increasing amounts of production scraps as well as materials reaching the 'end-of-life'. Actually, these materials can be recycled by milling or shredding and subsequent pyrolysis. The resulting products are entering the growing markets for recycled carbon fibres (rCF), although they are inhomogeneous in their morphology 2. These mixtures comprise randomly oriented roving residues & filaments in wide fibre length distribution. A few years ago, the only established industrial market was use of short fibres or milled material for injection moulding - a product more improving the antistatic properties than the mechanical properties of plastics. In addition, at that time there were no definitions for long rCF (>10 mm) and final products concerning necessary qualities (length distribution, minimum tenacity, homogeneity, etc.), sampling in process and quality of the final products compared to those made of virgin fibres 3.

Beside short fibre reinforcement in injection moulding 4, sophisticated applications of rCF in composites have been developed, like thermoplastic hybrid yarns 5, so-called 'secondary rovings' made of rCF plus binder 6 or nonwovens made either of pure rCF 7, or as hybrid nonwoven in combination with e.g. flax 8, 9.

Meanwhile basic principles for characterisation of rCF have been defined, enabling the quality classification for rCF off-line in the laboratory 10.

Another aspect is the environmental issue of using carbon fibres. From the energy demand of carbon fibre production and the high price of virgin fibres it is clear, that recycling and re-use of the fibres should be the favourable way. An actual review of LCA studies shows, that there are environmental advantages in the cradle-to-gate phase of rCF reinforced composites for specific cases, but as well the future demand for more intensive LCA studies 11.

Result of preliminary work was processing of long, but not endless recycled carbon fibres by means of the carding principle, using either 100% carbon fibres or blends with natural fibres and/or synthetic fibres first-time in pilot plant scale 12. The results depicted clearly, that web formation is possible not only from 100% primary carbon fibres, but as well from 100% recycled carbon fibres via mechanical carding 3, 12. The resulting average fibre length was approx. 85% of the pre-cut. These carbon fibre nonwovens were sufficient in strength, making them suitable as semi-finished products for CFRP-structures. Furthermore, a successful approach to produce composites from rCF preforms 13 has been reported.

Subsequently, within the frame of the research project RecyCarb 14 the research focus was set on:

- Process scale-up for nonwoven production into industrial and economical relevant scale with respect to the quality requirement,
- Set-up of a process-integrated monitoring of quality parameters,
- Evaluation of the effects of different nonwoven technologies, including first-time application of a combined nonwoven process for generating quasi-isotropic nonwoven structures.

Aim of the project work was to set-up a qualified value-added chain for recycled carbon fibres (rCF) by closing the technological gap between rCF und functional high-value re-use 14. The work comprised the definition of necessary initial quality & standards for consistent sampling in the process, process-attached monitoring in terms of Industry 4.0, reproducible intermediate quality by optimisation of the carding process and finally upcycling by re-use of rCF into high-value parts 15. The final report is available in German 14.

Consequently, meanwhile first rCF nonwovens are entering the commercial market, offered by several companies 16, 17.

This article highlights the achievable quality levels for rCFRP made of rCF nonwovens using different production methods suitable for industrial use.

2 MATERIALS & METHODS

2.1 Materials

Three types of rCF are used: off-cuts (mainly non-crimp fabrics) provided by partners of the consortium (Schmuhl Faserverbundtechnik GmbH, Liebschütz, DE and TENOWO GmbH, Hof, DE), hoover waste of the non-crimp fabric production (Saertex GmbH, Saerbeck, DE) or reclaimed fibres by pyrolysis, i.e. EoL-CFRP supplied by Eissmann Cotesa GmbH, Mittweida, DE and pyrolysed rCF by CarboNXT GmbH, Wischhafen, DE.

Offcuts and hoover waste were selected as suitable starting materials for nonwoven production due to their comparable virgin state concerning original sizing and resin free surface. Caused by the examined impregnation methods, the selected offcuts and hoover waste were appropriate for thermoset resins.

The pyrolysed rCF were supplied without sizing as a result of the pyrolysis, which has to be considered for the nonwoven production and the mechanical performance (fibre-matrix interface) of the resulting composites.

The fibre qualities have been analysed for each processed lot according to the scheme given below in section 2.4. Details of the results have already been published 18, with all production scraps in the range of 4,500 – 6,000 MPa tensile strength (exceptions not used in this work) and fibre diameter of 7 µm. Due to the demands of material input for the line, similar lots had to be mixed before processing. For this reason, the fibre strength in the produced nonwovens can be assumed to be 5,200±500 MPa; detailed values are not mentioned in the results. The pyrolysed fibres have been found to be approx. 10% lower in tensile strength and Young's modulus 10.

2.2 Nonwovens production

Nonwovens were produced on a dust-proof pilot plant with 1 m working width at the Center of Textile Lightweight Engineering at STFI, Chemnitz, DE, described in 15, 19. An additional exhaust system enables a dust-reduced production. First the rCF material is cut to an average length of 50-120 mm using a guillotine cutting machine. This is followed by fiber opening and separation in a modified tearing machine. For the subsequent web forming the line offers two options: either airlay- or carding process.

In the aerodynamic web forming process (Airlay Card K12-direct from Autefa Solutions Germany GmbH, Friedberg, DE) the carbon fibers are transported via air-stream and are deposited randomly on a filter belt. Thus, the resulting nonwoven structure is quasi-isotropic.

Carding is performed by using a MiniCard unit, combined with a cross-lapper type Topliner, both supplied by Autefa Solutions Germany GmbH, Friedberg. In the carding process the carbon fibers are separated via a tambour (main cylinder) and several stripper/worker pairs, and are finally deposited in a zigzag pattern by the cross-lapper according to the requested mass per unit area. As result, anisotropic nonwovens are obtained, displaying higher strength in cross-direction (CD) than in machine direction (MD).

Finally, mechanical bonding is performed by needling or stitch-bonding process in order to produce the desired nonwoven. In needle-punching process barbed needles punch vertically in and out of the material, while in the stitch-bonding process an additional warp knitting thread is introduced to bond the nonwoven 20.

In addition, nonwovens were produced at TENOWO GmbH by using a carding/cross-lapping process combined with stitch-bonding.

Nonwovens were preferably produced with mass per unit area 300 g/m² in airlay process as well as in carding process. In addition, the possibility of a second recycling by using own nonwoven production scraps and using them again for producing rCF nonwovens has been examined. This resulted in so-called re-recycled nonwovens (rrCF nonwovens) with mass per unit area ranging from 100 to 250 g/m².

2.3 Composite production

The manufactured rCF-nonwovens were processed into so-called rCFRP by three different types of composite manufacturing processes: (1) hand lay-up by impregnation with epoxy resin, followed by compression-moulding to a thickness of 2 mm using a hydraulic column downstroke press at STFI, (2) resin transfer moulding by vacuum impregnation a Schmuhl Faserverbundtechnik GmbH, Liebschütz, DE and (3) the wet lay-up method with autoclave at Eissmann Cotesa GmbH, Mittweida, DE.

2.4 Scheme of sampling & analysis

A scheme for sampling has been developed for incoming rCF lots as described in 15, derived from DIN EN 12751:1999 21.

Incoming fibre lots have been characterised using Dia-Stron single-element analysis (Dia-Stron Ltd., Andover, UK) to assess fibre tenacity and Young's modulus acc. to DIN EN ISO 5079:1996 22, clamping length 3.2 mm. Preceding the tensile tests the cross-section of each single specimen was measured via laser beam. Up to 45 specimens were measured to ensure statistically firm results as described in 23. A part of the lots has been examined by SEM (Cam Scan CS24, EO Elektronen-Optik-Service GmbH, Dortmund, DE with Software analySIS 3.2, SIS Soft Imaging System GmbH, Münster, DE) to identify contaminations, dust, and/or fibre damages. Fibre length distribution of rCF lots shorter than 100 mm was analysed by image analysis FibreShape V6.1.2f with addon FiVer (IST AG, Vilters, CH), based on 2,500 up to >6,000 fibres, depending on sample homogeneity. The adaption of the sample preparation and measurement parameters has been described in 14. This enables the reproducible analysis of filter dust as well as inhomogeneous cut fibers.

If the incoming lots consist of roving snippets, the snippet length distribution was analyzed using a flat-bed scanner at 100 dpi and software FibreShape V5 as described in 10.

For the process control each three positions have been defined for off-line sampling as well as for on-line control via camera. Off-line sampling is scheduled for incoming lots control (fibre quality analysis), for the carded- or airlay-web and finally the needle felt (analysis of grammage). On-line control is scheduled at the airlay- and card supply (identification of contaminations), directly after card or airlay (control of fiber orientation and web homogeneity) and finally after needle-punching (control of fiber orientation and nonwovens homogeneity). Using this scheme enabled analytical control of the entire process and successful outcome of the processing experiments 15.

The system for on-line analysis developed within the project is based on CCD-camera technology and image analysis software, which has been developed at FIBRE, Bremen; DE. The analysis of the MD/CD ratio is conducted by means of the filament orientation distribution and displayed as histogram (detailed description in 14).

The manufactured laminates were analyzed in terms of tenacity according to DIN EN ISO 527-4/1b/2 24 and flexural strength according to DIN EN ISO 14125 25. The fibre volume fraction (FVF) has either been analysed acc. to DIN EN ISO 1172 26 or been calculated from nonwoven grammage, dimensions and weight of composite specimen.

3 RESULTS & DISCUSSION

Composite boards have been produced from the different types of rCF nonwovens mentioned above to examine the potential of these materials for lightweight construction applications. The results are presented separately for different typical production processes in the following subsections.

3.1 Composites made of different types of rCF nonwovens using hand lay-up

Two types of rCF have been used: pyrolysed fibres as well as production scraps, cut from dry non-crimp fabrics, hoover waste or rovings in different nominal length grades ('cut size').

The nominal and real fibre parameters as well as the nonwoven production parameters are listed in Table 1. These nonwovens were stacked to reach a grammage of 1.800 g/m² (6 or 9 layers, resp.), impregnated (hand lay-up) with epoxy resin and finally press-moulded to a thickness of 2 mm as described in section 2.

Table 1 Fibre and processing parameters

Sample name	rCF properties		
	nominal length [mm]	*roving length [mm]*	*nonwoven production*
pyrolysed fibre	60	45.5 ±24.7 after opener	carding, needle-punching 200 g/m² at STFI
50% pyrolysed fibre/50% scraps	60/100	n/a	carding, needle-punching 300 g/m² at STFI
scraps	50	36.5 ±12.3 after opener	carding, stitch-bonding 200 g/m² at TENOWO
scraps	70	45.6 ±15.4 after opener	
scraps	100	61.4 ±26.0 after opener	

As a result of the needle-punching, the boards contain a remarkable share of fibres in z-orientation. Thus, the boards did not comply exactly with the thickness of 2 mm. Therefore, the fiber volume fraction (FVF) was calculated individually from nonwoven grammage, dimensions and weight of specimen. It is listed in Table 2. From these data the average FVF can be given as 36±2%. Consequently, variations of grammage and pores have to be considered regarding FVF and mechanical properties of the boards, summing up to ±6%.

Sample specimens were cut from the resulting composite boards in machine- and cross-direction (MD and CD) to analyse their mechanical stability.

Table 2 Fibre volume fraction of the composites made from different types of rCF nonwovens

Sample name	Fiber volume fraction [%]
Pyrolysed fibre	34.2
50% pyrol. fibre/50% scraps	35.6
Scraps “50 mm”	37.9
Scraps “70 mm”	37.6
Scraps “100 mm”	35.5

The tensile strength values are presented in Figure 1. The samples were produced on two different lines: pyrolysed fibre and blends of pyrolysed fibres/scrap at STFI and scraps at TENOWO (cf. Table 1). Nevertheless, all samples display a predominant tensile strength in CD caused by the process set-up: the carded web with fibres oriented predominantly in MD is fed into the cross-lapper, where the orientation changes for almost 90°, giving a predominant CD orientation in the resulting nonwoven. Due to the different production equipment this effect is a bit more distinct for the pyrolysed fibre samples. It is easy to observe, that all composites produced from rCF scraps display the same tensile strength: 225-241 MPa in MD and 280-290 MPa in CD.

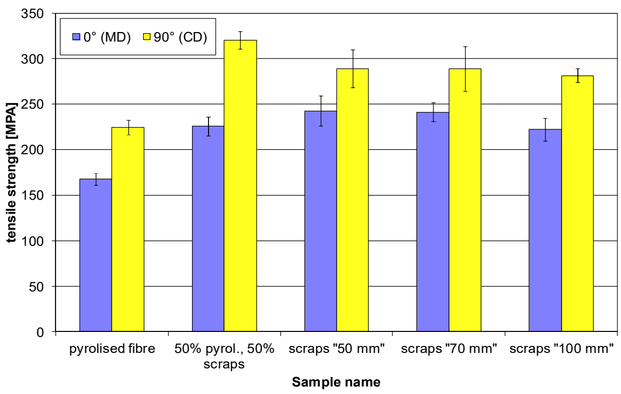


Figure 1 Tensile strength of the composites produced from different types of rCF nonwovens

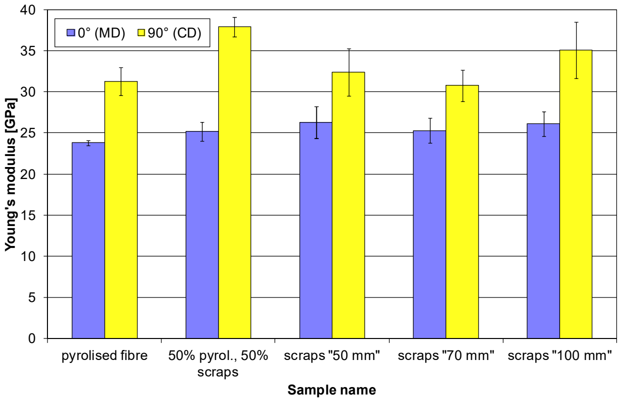


Figure 2 Young’s modulus of the composites produced from different types of rCF nonwovens

The differences between those three samples are within the limits of uncertainty. The sample made of 50% pyrolysed / 50% scrap fibres displays almost the same tensile strength in MD (225 MPa), and slightly larger tensile strength in CD: 320 MPa. This difference may be caused by the different number of web layers in the stack (6 instead of 9), which means as well a lower haul-off speed in the cross-lapper. This was found to cause a higher orientation in CD in previous research 19. The only sample with significantly lower tensile strength in MD (168 MPa) and CD (224 MPa) is the one made of 100% pyrolysed fibres. These fibres were more brittle than the scrap fibres. This caused not only higher losses in the nonwovens production (>45%, compared to 20-30% for scraps), but as well a shorter fibre length in the nonwoven. Consequently, all five samples are very similar in Young’s modulus, as displayed in Figure 2. The differences between the samples are within the limits of uncertainty (24-26 MPa in MD / 31-35 MPa in CD).

The flexural strength of the samples is shown in Figure 3. The same tendencies as for the tensile strength can be observed here.

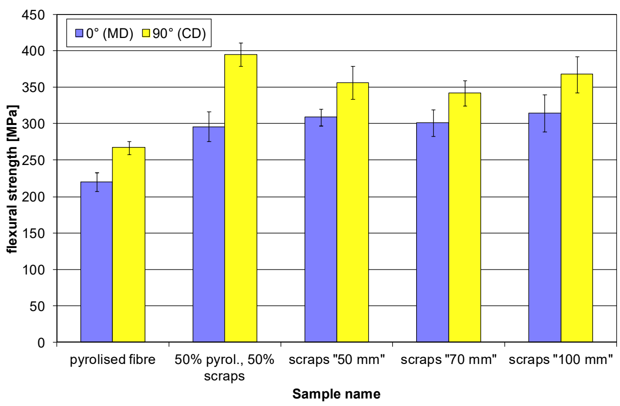


Figure 3 Flexural strength of the composites produced from different types of rCF nonwovens

Concerning the flexural modulus of the samples displayed in Figure 4 there is only one difference compared to Young's modulus: the samples containing pyrolysed fibres exhibit a higher level with 20 MPa (MD) / 25 MPa (CD) than the scrap samples with 15 MPa (MD) / 20-22 MPa (CD).

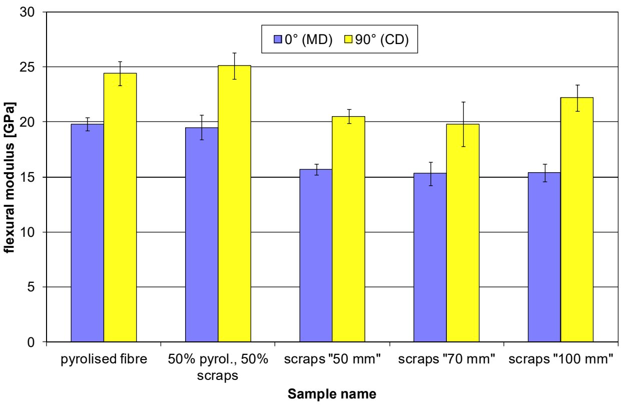


Figure 4 Flexural modulus of the composites produced from different types of rCF nonwovens

In general, the mechanical properties of the composites produced are substantially lower than those made of virgin carbon fibres in unidirectional arrangement. But, some differences compared to virgin fibre-reinforced plastics have to be considered:

- the nonwovens used here as reinforcement are NOT unidirectional (cf. data presented in section 3.4),
- the pyrolysed carbon fibres are without any sizing, which influences the fibre-matrix interaction, and
- rCF may be damaged by pyrolysis or mechanical processing, indicated e.g. by cracks.

Reference values are only available for virgin fibre composites. A hand lay-up and press-moulded composite based on woven fabric (i.e. bi-axial fibre arrangement, T300,Toray) with fibre volume fraction of approx. 60% exhibits tensile strength 800 MPa and Young's modulus 60 GPa 27. Almost 40% of the mechanical properties were achieved by the rCFRP reported in this work. Fibre volume fractions for nonwoven-reinforced composites are substantially lower than those 60%. From previous research it is known, that for needle-punched rCF mats the possible maximum fibre volume fraction for completely impregnated composites is not more than 50% 14. Considering the fibre volume fraction of approx. 36% for the composites reported here (i.e. 40% less than the Toray composites) the rCFRP reach a lower, but comparable level in terms of tensile strength and Young's modulus. As to be seen from the overview images in Figures 5(a), 5(c) & 5(f) for both samples containing pyrolysed fibres and exemplarily the 70 mm scraps sample, all display a good compactation with only small voids. This is also valid for the 50 mm and 100 mm scrap samples (thus not shown here).

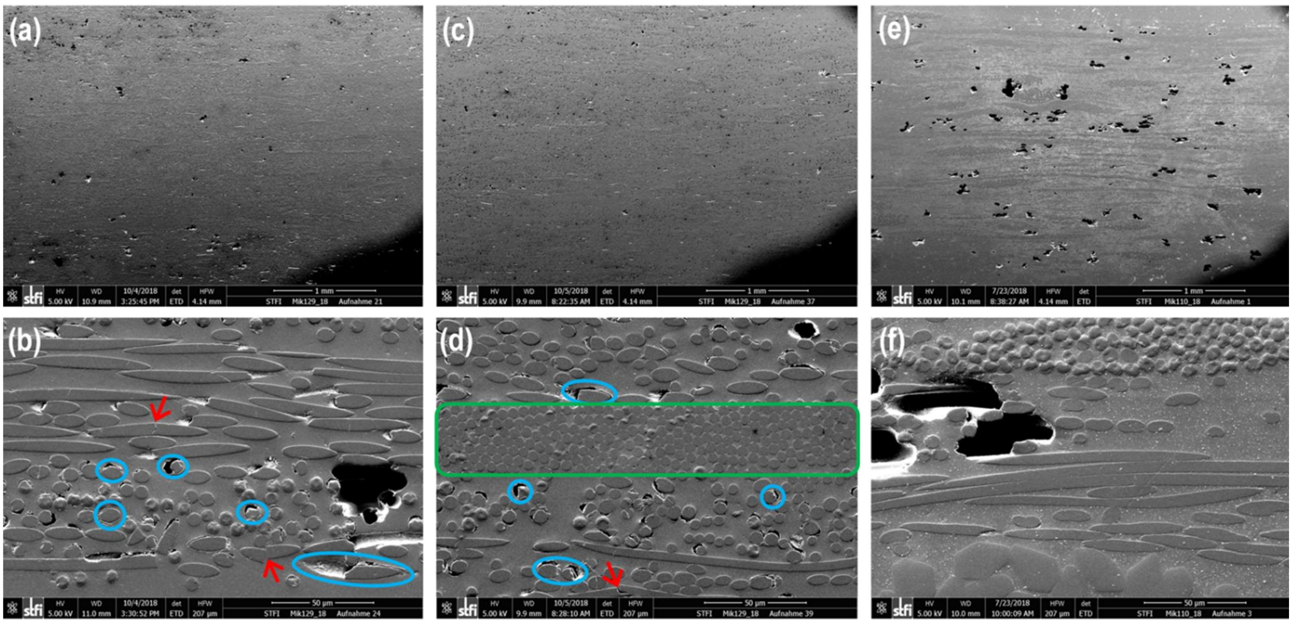


Figure 5 SEM images of the composites produced from pyrolysed rCF, (a) overview / (b) detail, 50% pyrolysed fibre/50% scraps, (c) overview / (d) detail, and scraps "70 mm", (e) overview / (f) detail. Exemplarily highlighted in (b) and (d): fibres without contact to the matrix by blue circles, cracks by red arrows, and remaining roving regions by green circles

The main difference between pyrolysed and scrap samples can be seen in the detail image Figure 5(b), highlighted exemplarily by blue circles: obviously most of the pyrolysed fibres are not impregnated well, although they are surrounded closely by the matrix. In addition, in some fibres cracks are visible, highlighted by red arrows. This coincides with the observed brittleness of the material during processing. As to expect, these effects are observed for much less fibres in the mix of 50% pyrolysed and 50% scrap fibres in Figure 5(d). Instead, this material contains larger regions of rovings not disintegrated during carding, highlighted exemplarily by green circles. These observation leads to the conclusion, that the missing sizing on the pyrolysed fibres causes a strong reduction of fibre-matrix interaction, leading to the lower mechanical strength observed for the 100% pyrolysed fibre sample.

The remaining difference of the scrap fibre samples compared to virgin fibre composites can be explained by the fibre fraction in z-direction and by the use of not endless fibres. In this context it has to be mentioned as well, that the composite production is not yet fully optimized. Thus, mechanical properties of approx. 80% of virgin fibre composites seem to be achievable for identical fibre volume fractions.

3.2 Composites with different fibre volume fractions using RTM

Composites with different fibre volume fractions have been produced on site of project partner SCHMUHL using the resin transfer moulding (RTM) process. Production scraps of SCHMUHL have been processed at STFI into nonwovens of 300 g/m², using the carding/cross-lapping process with subsequent needle-punching. Composite boards of 700 x 700 mm² with fibre volume fractions from 11% to 27% have been produced from this rCF-nonwoven using the RTM process. Epoxy resin was used as matrix.

Figure 6 displays the tensile strength of the composites. It can be clearly observed that again the tensile strength in CD is higher than in MD, due to the process variant with carding and subsequent cross-lapper. As to expect, the tensile strength increases with increasing fibre content in the material. As for the scrap samples described in the previous section, only a negligible number of small voids was detected in these composites by SEM, giving no hint for differences in impregnation.

The corresponding values for Young's modulus are presented in Figure 7, displaying the same tendency with Young's modulus dependent on increasing fibre fraction. Flexural strength and modulus of these samples follow the same scheme and are thus not shown here.

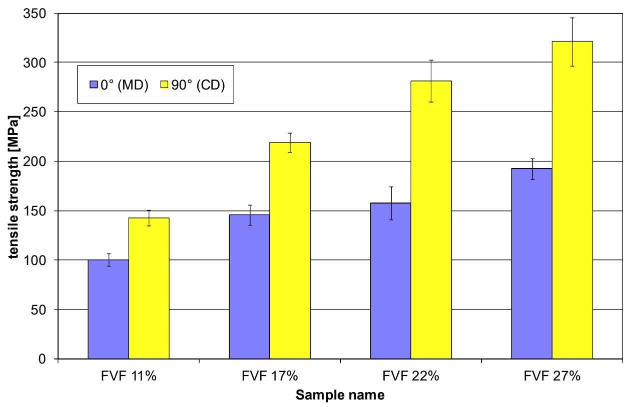


Figure 6 Tensile strength of the composites produced from rCF with different fibre volume fractions

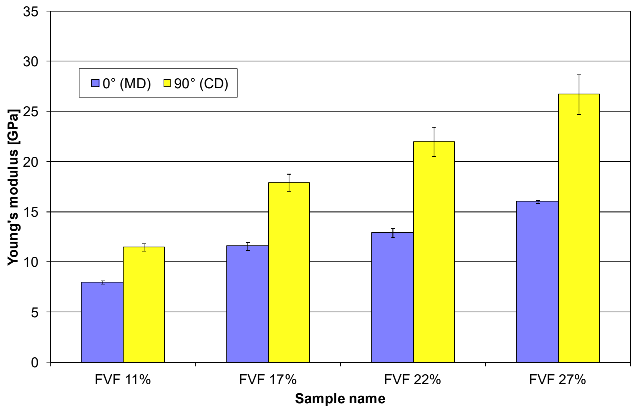


Figure 7 Young's modulus of the composites with different fibre volume fractions

3.3 Composites made of rCF-prepregs

Two rCF-prepregs have been produced at c-m-p GmbH, Heinsberg, DE from rCF-nonwovens (i) delivered by TENOWO (5731/3, Zetacomp CF, 266 g/m², based on scrap fibres) and (ii) STFI (K12, 300 g/m², based on scrap fibres). The nonwoven processed at TENOWO was carded and stitch-bonded, whereas the STFI-nonwoven was processed by airlay and needling. The applied matrix content was 67% epoxy resin 'CP041'. Both prepregs were consolidated in two variants: (i) press-moulding at STFI and (ii) autoclave method at EISSMANN COTESA. As reference, both nonwovens were laminated in hand lay-up at STFI and press-moulded. The samples and processing variants are listed in Table 3.

Table 3 Prepreg samples and processing variants

Sample name	Specifications	
	Process	FVF [%]
5731/3 HL	hand lay-up, press-moulding (reference sample)	38.2
5731/3 V1	prepreg, press-moulding	41.4
5731/3 V2	prepreg, autoclave method	17.0
K12 HL	hand lay-up, press-moulding (reference sample)	33.6
K12 V1	prepreg, press-moulding	37.0
K12 V2	prepreg, autoclave method	20.5

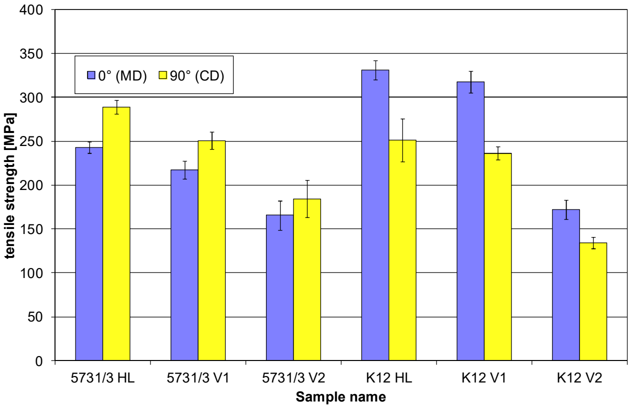


Figure 8 Tensile strength of the composites produced from rCF prepregs

The tensile strength determined for these composite boards is displayed in Figure 8.

Composites based on carded nonwovens show a significant CD orientation due to the carding and cross-lapping process, in contrast, the composites based on airlay nonwovens show a higher MD orientation. According to modelling of the airlay process 28 the higher MD orientation can be attributed to a higher conveyor belt speed.

For both composite variants (carded and airlay based) the tensile strength of the hand laminates is higher than for the prepreg samples. SEM analysis revealed that the hand laminates display the same amount of voids like the press-moulded V1-samples. Thus, the slightly lower tenacity of the press-moulded variants is caused more by the different resin used for V1 and V2.

The different lamination processes have also be condsidered: in hand lay-up each nonwoven layer in the stack is impregnated individually, while in prepreg production the resin is applied from one side. This may cause a worse impregnation of the nonwoven and, thus, a lower tensile strength of the composites. Presumably, the worse impregnation of the nonwoven can be compensated better by press-moulding, where mechanical pressure forces the resin to impregnate the nonwoven. Consequently, both V1-samples show a tensile strength similar to the reference, whereas the V2-samples made by autoclave process display a significantly lower tensile strength.

Especially the airlay based composites show a strong decrease (approx. 46%), while carding based composites show a loss of approx. 27%. This could be partly due to the technique of the airlay process with less fibre opening.

Not fully opened, unseparated fibres lead to higher restoring forces (due to the missing separation and orientation) and a larger number of air pockets that impede the impregnation process. While the impregnation using prepreg technology combined with a hydraulic column down-stroke press enables high pressure and slow heating up with constantly additional pressure, the prepreg technology combined with autoclave draws vacuum and cures the matrix material. This difference of the two technologies and the one sided impregnation causes probably more pipes and less impregnation during the autoclave process due to the resin flowing properties. The obtained SEM images are displayed in Figure 9 and provide this assumption.

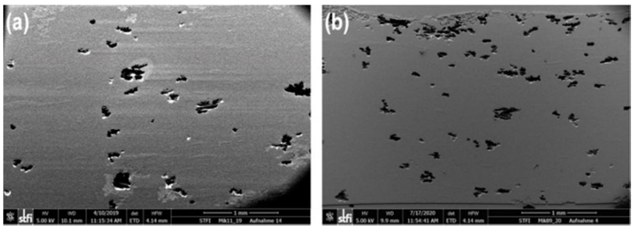


Figure 9 SEM images of composites based on airlay nonwovens produced using (a) press moulding and (b) autoclave technology

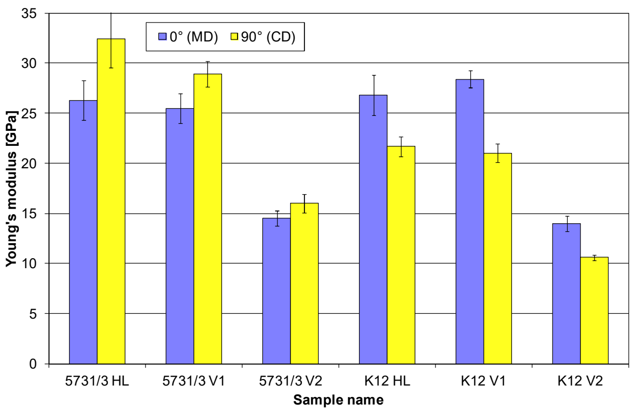


Figure 10 Young's modulus of the composites produced from rCF prepregs

In Figure 10 the corresponding Young's modulus values are shown. They display the same tendencies. This is also valid for the flexural strength and -modulus of these samples (not shown here). In general, these results display the feasibility of the prepreg process for rCF nonwovens.

Due to the achieved fibre volume fractions of approx. 10-38% (depending on the impregnation method, c.f. Tables 2 & 3) several demonstrators were developed (described in 29). At EISSMANN Cotesa, for example, a spoiler based on prepregs of stitch-bonded rCF-nonwovens combined with woven fabrics was developed. The spoiler is consolidated in autoclave method.

3.4 Composites from re-recycled carbon fibres

A lot of scraps (roving snippets, length 120 mm) has been used to test the ability of the process for repeated recycling. Nonwovens have been produced from this lot using both process variants (carding and airlay) with subsequent needle-punching.

Table 4 Composites produced from rCF and rrCF nonwovens

Sample name	Specifications			
	nonwoven grammage [g/m²]	MD/CD ratio by on-line monitoring	no. of layers in composite	FVF [%]
rCF-Airlay	300	0.92	6	37.0
rrCF-Airlay	250	n/a	7	26.3
rCF-carded	300	0.30	6	34.6
rrCF-carded	100	0.88	18	28.9

A part of this rCF nonwoven has been supplied again to tearing and nonwovens production as described above. The fibre length was reduced from initially 119 mm (incoming control) via 104 mm (first tearing) to finally 69 mm (second tearing). In the second process it was not possible to reach the intended grammage of 300 g/m². Due to the reduced fibre length, the resulting weight of the nonwovens was 250 g/m² in airlay and 100 g/m² in carding process. The resulting, so-called 'rrCF nonwovens', and the corresponding rCF nonwovens have been processed as usual by impregnation with epoxy resin and press-moulding. The samples and processing variants are listed in Table 4. An increasing number of layers in the composite lead to higher volume between the layers, which increases the thickness of the composite and decreases the FVF (Table 4).

Figure 11 shows the tensile strength of the different samples. For both airlay variants the results are as expected: tensile strength approx. 300 MPa and close to isotropic distribution. The MD/CD ratio calculated from the tensile strength is for both of them 0.8. The corresponding value from on-line monitoring at the line for rCF-Airlay is 0.9. Due to the reduced fibre length, the tensile strength of the re-recycled variant (rrCF-Airlay) is slightly lower.

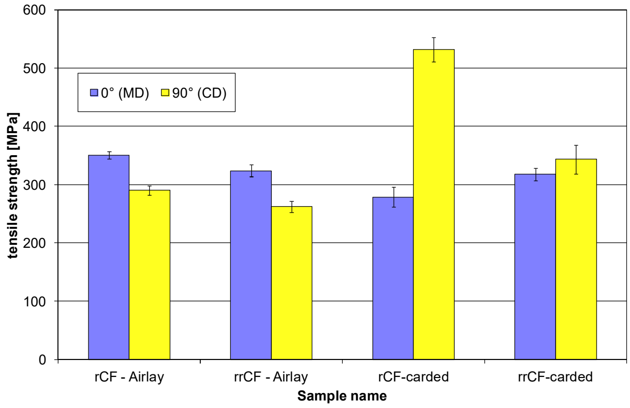


Figure 11 Tensile strength of the composites produced from rCF and rrCF nonwovens

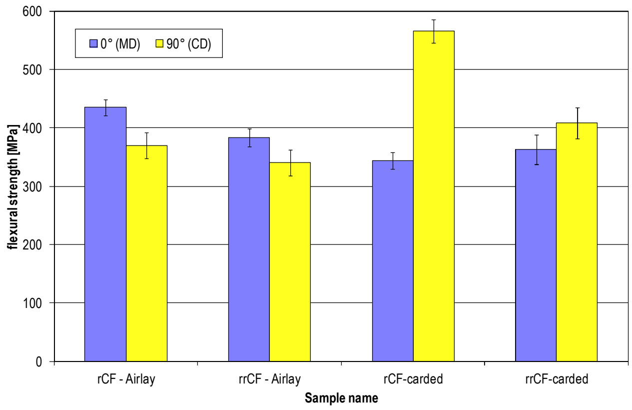


Figure 12 Flexural strength of the composites produced from rCF and rrCF nonwovens

For the carded samples the situation is different: the carded rCF sample displays the expected anisotropy with predominant tenacity in CD. The values of 279 MPa for MD and 532 MPa for CD conform to a MD/CD ratio of 0.5, whereas the value of on-line monitoring is 0.3. The re-recycled variant rrCF-carded displays unexpectedly a quasi-isotropic behaviour: the tensile strength is 318 MPa for MD and 343 MPa for CD, corresponding to a MD/CD ratio of 0.92. The value of on-line monitoring (0.88) supports this finding.

The flexural strength of these samples is presented in Figure 12, displaying exactly the same tendencies. This is also valid for Young's modulus and flexural modulus of these samples (not shown here).

In addition, the SEM image of the carded rrCF sample (Figure 13) does not exhibit unexpected findings. As for the other hand-lay-up samples, there are few voids to observe, while the impregnation is good. The only difference is that the rrCF display some cracks, as highlighted by red arrows. These cracks must be caused by the carding process prior to impregnation, because they are completely filled with matrix material.

The original data from on-line orientation analysis (previously published in 19) are presented in Figure 14 as histogram for the carded rCF and rrCF samples. It is easy to observe, that the carded rCF sample shows a clear CD-orientation with maximal fibre shares oriented around 90° and –90°. In opposite to that the rrCF sample is nearly homogeneously distributed, indicating a quasi-isotropic fibre orientation.

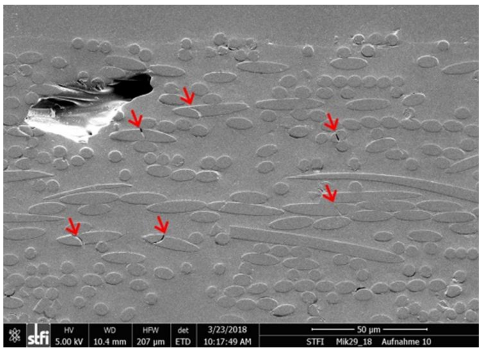


Figure 13 SEM image of the carded rrCF sample

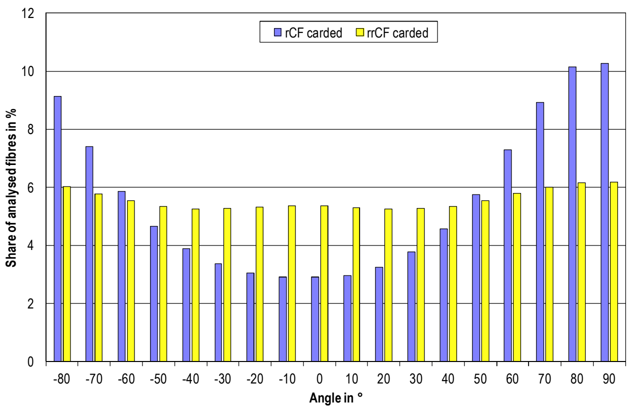


Figure 14 Distribution of fibre orientation from on-line analysis after carding process for rCF and rrCF. Data from 19, modified presentation

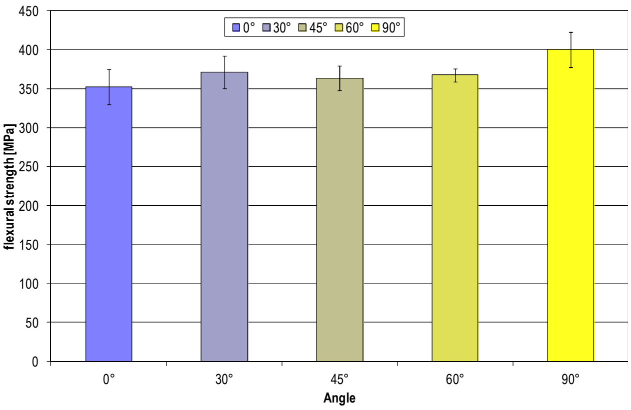


Figure 15 Flexural strength of sample rrCF-carded depending on the angle

In order to validate the nearly isotropic structure of this sample, additional specimens were prepared to analyse the tenacity in 45°. The result was 304 MPa, i.e. in the same range like the 0° and 90° samples (317 & 343 MPa). Due to the limited board size it was only possible to prepare smaller specimen for flexural strength analysis in 30°, 45° and 60° to analyse the properties more in detail. The results are shown in combination with the already known values for 0° and 90° in Figure 15. Visually there is a small but not significant increase from 0° to 90°, but in general the values are within the range of uncertainty. Thus, the material is really quasi-isotropic, as also seen from the on-line-control (cf. Table 3 & Figure 14).

This effect is caused by the higher haul-off speed in the cross-lapper, leading finally to a fibre orientation close to that from the airlay process 19.

In general, the results show the feasibility of at least one additional recycling cycle for carbon fibres with only minor loss of composite stability.

4 CONCLUSION

A process line has been set-up successfully, enabling the processing of 100% recycled carbon fibres into high-quality nonwovens by carding as well as by airlay. As reported elsewhere, in parallel a quality control system has been defined to ensure constant product qualities 19. In combination, this offers the possibility to produce taylor-made rCF qualities. Various lots of rCF, ranging from production scraps to pyrolysed fibres from ‘end-of-life’ parts, have been processed successfully to carded and airlay nonwovens. The possible range of fibre orientation after carding process reaches from highly-oriented in CD to nearly isotropic, depending on the material and processing parameters.

rCF-reinforced plastics have been produced, using different typical industrial processes to prove the processability. In press-moulding tensile strength values of approx. 530 MPa in CD and 330 MPa in MD have been achieved, combined with Young’s moduli of 50 GPa (CD) and 31 GPa (MD). Similar values were obtained by resin-transfer moulding (RTM).

Using stitch-bonded nonwovens, the production of prepregs opened successfully another process pathway. The prepreg-based composites displayed tensile strength up to 330 MPa and Young’s modulus up to 29 GPa.

In addition, first experiments showed that repeated recycling of carbon fibres is possible. The composites produced of so-called ‘rrCF’ displayed only a minor loss of stability compared to the corresponding rCFRP.

Compared to composites based on woven virgin-fibre fabric with fibre volume fraction of approx. 60% 27, almost 40% of the mechanical properties were achieved by the rCFRP reported in this work. Considering the lower fibre volume fraction of approx. 36% the rCFRP reach a lower, but comparable level in terms of tensile strength and Young's modulus. This difference can be explained not only by the fibre fraction in z-direction and by the use of not endless fibres. As well it has to be mentioned, that the rCF composite production is not yet fully optimized. Thus, mechanical properties of approx. 80 % of virgin fibre composites seem to be achievable.

Another topic for discussion is the price of rCF compared to virgin fibres: it is lower, ranging from 5 €/kg for scraps up to 12 €/kg for pyrolysed fibres in 2017. The future forecast for pyrolysed fibres was a decrease to 7 – 9 €/kg with increasing production capacities 14.

Summed up, the carbon fibre nonwovens generated on the line are very suitable as semi-finished products for CFRP-structures. Due to their high formability sufficient strength, and adjustable MD/CD ratio they are ideal candidates for sophisticated composites. Summed up, an industrial feasible process for recycling of carbon fibres has been proven to operate.

Acknowledgement*: Financial support by the German Ministry of Education and Research (BMBF) within the framework Entrepreneurial Regions, project futureTex, grant no. 03ZZ0608A–M is gratefully acknowledged.*

GEFÖRDERT VOM

zwanzig20 PARTNERSCHAFT FÜR INNOVATION

Bundesministerium für Bildung und Forschung

5 REFERENCES

1. Sauer M.: Composites-Marktbericht 2019 - der Globale CF- und CC-Markt 2019 - Marktentwicklungen, Trends, Ausblicke und Herausforderungen, Langfassung. Carbon Composite e.V. (CCeV), Augsburg, DE, September 2019. Short version available at https://www.carbon-composites.eu/media/3989/ger_ccev_marktbericht_2019_kurzversion.pdf, Accessed 2020-04-27
2. Heida L.: Boom time for carbon fibre recycling, Online article, TerraTechMedia, Amsterdam, NL 2019, http://terratechmedia.com/boomtime/, Accessed 2020-04-06
3. Hofmann M., Fischer H.: RecyCarb: Process Optimisation and On-Line Monitoring in the Recycling of Carbon Fibre Waste for the Re-Use in High-Grade Fibre-Reinforced Plastics, In Borgmann H. (Ed.): ITHEC 2016 - 3rd International Conference and Exhibition on Thermoplastic Composites, 11-12 October 2016, Congress Center Bremen, Germany. Conference Proceedings. WFB Wirtschaftsförderung Bremen GmbH, Bremen, DE, pp. 60-63, ISBN 978-3-933339-29-4
4. Szpieg M., Wysocki M., Asp L.E.: Mechanical performance and modelling of a fully recycled modified CF/PP composite, Journal of Composite Materials 46(12), 2012, pp. 1503-1517, https://doi.org/10.1177/0021998311423860
5. Abdkader A., Hengstermann M., Badrul Hasan MM, Hossain M, Cherif C.: Evaluation of spinning methods for production of hybrid yarns from rCF for CFRP components, Technische Textilien / Technical Textiles 60(4), 2017, pp. E 237-E 240, ISSN 0323-3243
6. Sigmund I.: Sekundär-Roving: Rezyklierte Carbonfasern in linearen textilen Strukturen für die Kunststoffverstärkung. Presentation in Sächsisches Textilforschungsinstitut e.V. (ed. & organis.): Tagungsband 12. STFI-Kolloquium „recycling for textiles“, 2. und 3. Dezember 2015 im Günnewig Hotel "Chemnitzer Hof". STFI, Chemnitz., DE 2015
7. Gulich B., Hofmann M.: From black gold to "golden fleece", AVR Allgemeiner Vliesstoff-Report 2013, No. 4, pp. 34-35, ISSN 0170-4060
8. Bachmann J., Wiedemann M., Wierach P.: Flexural mechanical properties of hybrid epoxy composites reinforced with nonwoven made of flax fibres and recycled carbon fibres, Aerospace 5(4), 2018, article no. 107, https://doi.org/10.3390/aerospace5040107
9. Longana M.L., Ondra V., Yu H., Potter K.D., Hamerton I.: Reclaimed Carbon and Flax Fibre Composites: Manufacturing and Mechanical Properties, Recycling 3(4), 2018, article no. 52, https://doi.org/10.3390/recycling3040052
10. Fischer H., Schmid H.: Quality control for recycled carbon fibres, Kunststoffe International 103(11), 2013, pp. 68-71
11. Bachmann J., Hidalgo C., Bricout S.: Environmental analysis of innovative sustainable composites with potential use in aviation sector - A life cycle assessment review, Science China Technological Sciences 60, 2017, pp. 1301-1317, https://doi.org/10.1007/s11431-016-9094-y
12. Hofmann M., Gulich B.: Nonwovens for composites - recycling carbon waste in the form of long fibres, JEC Composites Magazine No. 98, 2015, pp. 50-51
13. Hofmann M., Wenzel D., Gulich B., Illing-Günther H., Nestler D.: Development of nonwoven preforms made of pure recycled carbon fibres (rcf) for applications of composite materials, Key Engineering Materials 742, 2017, pp. 555-561, https://doi.org/10.4028/www.scientific.net/KEM.742.555
14. Fischer H., Heilos K., Hofmann M., et al.: RecyCarb - Ganzheitliche verfahrenstechnische Betrachtung und prozessbegleitendes Monitoring von Qualitätsparametern bei der Aufbereitung von Carbonfaserabfällen und deren hochwertigen Wiedereinsatz in textilen Flächengebilden als Basismaterial für Faserverbundwerkstoffe der Zukunft. In series: Forschungsberichte aus dem Faserinstitut Bremen no. 60, Books on Demand GmbH, Norderstedt, DE 2019, ISSN 1618-7016, ISBN 978-3-7494-3150-2
15. Fischer H., Heilos K., Hofmann M., Miene, A.: Second life for carbon fibers - re-use of recycled carbon fibers in sophisticated composite parts, Kunststoffe International 109(12), 2019, pp. 46-49, ISSN 1862-4243

16. Stevenson A.: Nonwoven textiles made with recycled carbon fibres for automotive applications, In International Newsletters Ltd, (ed.): International Conference on Nonwovens for High-performance Applications NHPA2017, Prague, 7-8 March 2017, International Newsletters Ltd, Droitwich, UK 2017
17. Anonymous: Tenowo: Vliesstoff auf Basis rezyklierter Carbonfasern, Technische Textilien 60(3), 2017, p. 201, ISSN 0323-3243
18. Fischer H., Hofmann M., Miene A., Yuan Q., Heilos K.: RecyCarb - Aufbau einer qualifizierten Wertschöpfungskette für rezyklierte Carbonfasern (rCF) zum Wiedereinsatz in anspruchsvollen Bauteilen. In Sächsisches Textilforschungsinstitut e.V. (ed. and organis.): Tagungsband 13. STFI-Kolloquium „recycling for textiles“, 6. und 7. Dezember 2017 im Hotel „Chemnitzer Hof“, Chemnitz. Sächsisches Textilforschungsinstitut, Chemnitz, 2017, pp. 26-27
19. Fischer H., Hofmann M., Miene A., Heilos, K.: Re-use of Pyrolysed Carbon Fibres in Sophisticated Composites as Industrial Viable Process With Integrated Quality Monitoring: RECYCARB, In Proceedings of 22nd International Conference STRUTEX, Technical University of Liberec, Liberec, CZ 2018, pp 233-239, ISBN 978-80-7494-430-7
20. Fuchs H., Albrecht W., Kittelmann W. (eds.): Nonwoven Fabrics: Raw Materials, Manufacture, Applications, Characteristics, Testing Processes, Wiley-VCH, Weinheim, DE 2002. ISBN 978-3-5273-0406-6
21. DIN EN 12751:1999. Textilien: Probenahme von Fasern, Garnen und textilen Flächengebilden für Prüfungen
22. DIN EN ISO 5079:1996. Textilien - Fasern - Bestimmung der Höchstzugkraft und Höchstzugkraftdehnung an Spinnfasern
23. Müssig J., Fischer H., Graupner N., Drieling A.: Testing Methods for Measuring Physical and Mechanical Fibre Properties (Plant and Animal Fibres), Chapter 13 in Müssig J. (Ed.): Industrial Applications of Natural Fibres - Structure, Properties and Technical Applications, Wiley-VCH, Weinheim, DE, pp. 269-309, ISBN 978-0-470-69508-1
24. DIN EN ISO 527-4:1997. Kunststoffe - Bestimmung der Zugeigenschaften - Teil 4: Prüfbedingungen für isotrop und anisotrop faserverstärkte Kunststoffverbundwerkstoffe (ISO 527-4:1997)
25. DIN EN ISO 14125:2011. Faserverstärkte Kunststoffe - Bestimmung der Biegeeigenschaften (ISO 14125:1998 + Cor.1:2001 + Amd.1:2011)
26. DIN EN ISO 1172:1998. Textilglasverstärkte Kunststoffe - Prepregs, Formmassen und Laminate - Bestimmung des Textilglas- und Mineralfüllstoffgehalts; Kalzinierungsverfahren (ISO 1172:1996)
27. Wielage B., Thielemann, G.: Leichtbau durch Hybridkonstruktionen am Beispiel einer Antriebswelle; Leichtbaukongress auf der euroLITE Salzburg 2009
28. Gramsch S., Klar A., Leugering G., Marheineke N., Nessler C., Strohmeyer C., Wegener R.: Aerodynamic web forming: process simulation and material properties, Journal of Mathematics in Industry 6(13), 2016, pp. 1-23, https://doi.org/10.1186/s13362-016-0034-4
29. Projekt futureTEX (ed.): TourAtlas RecyCarb. Booklet, 20 p., Sächsisches Textilforschungsinstitut e.V. (STFI), Chemnitz, DE 2019, Accessed 2020-04-27, http://www.stfi.de/fileadmin/futureTEX/forschungsvorhaben/RecyCarb/recycarb_touratlas-online_futuretex.pdf

STUDY OF STRUCTURE AND THERMAL CHARACTERISTICS OF STYRENE ACRYLIC POLYMER FILMS LACRYTEX 430 FILLED OF TITANIUM DIOXIDE

Ihor Horokhov, Irina Kulish, Tatyana Asaulyuk, Yulia Saribyekova, Sergey Myasnykov, Olga Semeshko and Natalia Skalozubova

Kherson National Technical University, Berislav highway 24, 73008 Kherson, Ukraine
kulish.in.411@gmail.com

Abstract: *The research is devoted to study the influence of nanosized titanium dioxide on the structure of polymer films formed from styrene acrylic polymer for the development of fire retardant finishing compositions for textile materials. An aqueous dispersion of styrene acrylic polymer Lacrytex 430 and nanosized titanium dioxide were used as the objects of study. Standardized methods have been applied to study the stability of suspensions of aqueous systems and the structure formation, surface morphology, degree of thermal destruction of filled and unfilled with titanium dioxide styrene acrylic polymer films. The degree of dispersion of the nanofiller in the styrene acrylic polymer matrix is determined. The morphology of the formed films is considered and the optimal concentration of titanium dioxide in the polymer film is determined. The degree of interaction between the components of the mixture was estimated and it is shown that titanium dioxide does not change the structural parameters of the filled and unfilled polymer at a concentration of 1-2 wt.%. Increased concentration of titanium dioxide negatively affects both on the density of crosslinking of the polymer units and on the molecular weight of the polymer chain segment due to the agglomeration of titanium dioxide nanoparticles in the polymer matrix, which can create stress concentration zones and suppress the effect of interfacial interaction of the components. Considering that the introduction of fillers into polymers can change the temperature characteristics of polymer composite materials, the process of thermooxidative decomposition of formed polymer films and the formation of coke residue have been studied. It is determined that the introduction of nanosized titanium dioxide promotes coke formation and increases the thermal stability of the filled polymer film.*

Keywords: *styrene acrylic polymer, polymer film, nanoparticles, titanium dioxide, thermal degradation, coke forming ability, fire retardant finishing compositions.*

1 INTRODUCTION

The problems of the environment and human health that arise when using flame retardants motivate scientists to search for new environmentally friendly substances. Traditional flame retardants for treatment of textile materials, such as halogen-containing substances or additives containing heavy metals, have a number of negative properties. It is forbidden to use formaldehyde-containing preparations for fabrics that are introduced into the fire retardant composition in order to increase its resistance to washing.

Among the directions for slowing down combustion processes, the introduction of nanoparticles into flame retardant finishing compositions as thermophysical additives can be noted [1].

For impregnation of nanoparticles, polymers or polymer blends are most often used. Due to the combination of various functional features, the formed nanocomposites are capable of providing excellent, often synergistic, material properties.

One of the main effects of the introduction of inorganic additives into the polymer is the dilution of the organic structure and its distribution to isolated domains, filling the pores and amorphous regions of the polymer. Therefore, during ignition, the destruction of such a structure becomes a more complex process due to the need to increase the amount of heat to achieve the pyrolysis temperature. This effect of "heat dissipation" is enhanced by higher heat capacity and lower thermal conductivity of the fillers or their endothermic decomposition. Aluminium oxide, mica, feldspar, clay, titanium dioxide, etc. can be used for this purpose.

It was shown in [2] that the addition of nanoparticles reduces the flammability of polymers due to a decrease in the rate of heat release, an increase in the time of ignition, and an ability to self-extinguish. The mechanisms of such protection include physical barrier effects and catalytic processes that can modify the degradation of polymers and form charred protective layers reinforced by nanoparticles. The inherent properties of nanoparticles are dependent on dispersion and chemical modifications to improve compatibility with polymers.

Nanoparticles of metal compounds showed good results in reducing flammability, since these substances are resistant to temperatures up to 1000°C (hydroxides, carbon nanotubes, etc.). Substances that decompose at temperatures below 400-500°C (hydroxides, salts) also give high flame retardant properties [3]. Metal oxides are also able to catalyze coke formation processes and form a protective layer on the surface of a burning polymer.

The most studied metal oxides include titanium dioxide, which in addition to thermal properties has a number of defining characteristics: non-toxicity, good electrical, chemical, thermal and photocatalytic properties.

The effect of the introduction of nanosized particles of titanium oxide (TiO_2) and iron oxide (Fe_2O_3) on thermal stability and reaction to the action of fire of polymethylmethacrylate (PMMA) was studied in [4]. It was shown that introduction of a small amount (5 wt.%) of nanosized Fe_2O_3 and TiO_2 increased the thermal stability of PMMA nanocomposites. The improvement in fire resistance of PMMA/TiO_2 and PMMA/Fe_2O_3 nanocomposites is explained by the limited mobility of polymer chains as a result of the reinforcing effect between the polymer and the surface of nanoparticles.

The inclusion of TiO_2 nanoparticles in PMMA leads to an improvement in fire resistance with a decrease in the peak heat release rate by ~40% [5].

Several works have focused on such approaches, as combining the flame retardant action of nanosized metal oxides (TiO_2, Al_2O_3) with coke formation induced by phosphorus flame retardant systems (ammonium polyphosphates, phosphinates) in PMMA [6]. Using the method of cone calorimetry with irradiation of 30 kW/m^2, it was established that in the presence of 20% nano-TiO_2 the heat release rate of the PMMA-based nanocomposite decreases by 50%. And when ignited, this index increases significantly (by more than 20 s). This phenomenon is explained by heat transfer between metal oxide nanoparticles and polymer chains due to an increase in the nanofiller/polymer contact surface. In addition, it was found that the introduction of TiO_2 into the PVC melt significantly inhibits the release of hydrogen chloride, flammable and toxic gases during the combustion process. Transition metal oxides such as MnO_2 and Fe_2O_3 do not have this advantage. Moreover, they contribute to the process of release and combustion of hydrogen chloride.

Given the above, it can be concluded that the development trends of the finishing industry are aimed at creating and expanding the introduction of organo-inorganic composite materials that can improve the quality of textile materials. The combination of the properties of inorganic nanoparticles, in particular heat resistance and reinforcing ability, with the technological characteristics of the polymer will contribute to the production of nanocomposite materials with desired properties for finishing industry.

2 THE GOAL OF THE STUDY

The goal of the work is to study the efficiency of filling a polymer film with nanosized titanium dioxide, and to establish the effect of this additive on the structure formation and thermophysical characteristics of the Lacrytex 430 styrene acrylic polymer.

3 MATERIALS AND METHODS

The zeta potential of the aqueous suspension of titanium dioxide with concentration of 0.02 wt.% depending on pH was measured by introducing a small amount of the suspension into the cells of Malvern Instruments Technical Note MRK 654-01 (Malvern, England) at room temperature and in the pH range from 2 to 10. Previously the suspension was stirred for 20 minutes on a magnetic stirrer. To improve the result, the suspension of titanium dioxide was subjected to 15 minutes of ultrasonic treatment.

An aqueous dispersion of styrene acrylic polymer Lacrytex 430 manufactured by OOO Polymer-Lak (Ukraine) was studied as a film former. Characteristics of the dispersion are given in Table 1.

Table 1 Characteristics of Lacrytex 430

Chemical composition	Dry residue [%]	pH	Particle size [µm]	Viscosity [MPa·s]
aqueous dispersion of copolymers of ester of acrylic acid and styrene	50	7.5-8.5	≈ 0.1	5000-15000

A polymer nanocomposite was created by introducing previously prepared suspensions of titanium dioxide in various concentrations into an aqueous dispersion of a styrene acrylic polymer.

The surface morphology of composite polymer films was studied using scanning electron microscopy.

Structural parameters of polymer films filled with titanium dioxide were determined by sol-gel analysis.

The chemical structure of polymer films filled with nanosized titanium dioxide was studied using IR spectroscopy. The spectra were obtained on a Nicolet-iS10 IR Fourier spectrometer (Thermo Fisher Scientific, USA) using a DTGS detector, a Smart Performer attachment equipped with a ZnSe crystal. The measurements were carried out with an expansion of 4 cm^{-1}, spectral region 4000-650 cm^{-1}. The spectra were processed using the OMNIC-7.0 program.

The method of thermogravimetric analysis was used to determine the efficiency of titanium dioxide as a thermophysical additive in a styrene acrylic polymer. The change in mass when exposed to elevated temperatures on the polymer was studied using TGA 7 (Perkin Elmer, USA). The samples of polymer films weighing 15 mg were heated at a temperature of 40 to 800°C at a constant heating rate of 10°C/min.

4 RESULTS AND DISCUSSION

In the textile industry, the studied nanomaterials are most often dispersed in multicomponent water systems. This can potentially lead to physicochemical changes in properties. For example, the state of agglomeration and surface charge are important characteristics of dispersions. During dispersion of nanoparticles in aqueous solutions, surface ionization and adsorption of cations or anions leads to the formation of a surface charge and the formation of an electric potential between the surface of particles and a volume of the dispersion medium.

To effectively control the properties of suspensions of amphoteric oxides, in particular titanium dioxide, the pH of the medium is changed, and additives of low molecular weight surfactants are introduced [7]. The aggregate stability of aqueous suspensions of titanium dioxide without surfactant additives is determined by the ion-electrostatic factor in accordance with the theory of Deryagin – Landau – Fairway – Overbek. The main factor affecting aggregative stability is the electrostatic barrier of interaction between particles.

Depending on the measurement technique, the surface charge can be represented by the surface charge density (potentiometric titration) or the zeta potential (electrokinetic method).

In the work, the stability of an aqueous suspension of titanium dioxide was evaluated based on measurements of the zeta potential using electrophoretic mobility. As a rule, in order to achieve a stable dispersion, the necessary value of the zeta potential should be below -30 mV or above 30 mV, i.e. in the range of -30 mV > ζ > 30 mV.

Agglomeration of nanoparticles in an aqueous system can be controlled by the hydrodynamic diameter of the dispersion. In the classical theory of stability of dispersed systems of Deryagin – Landau – Fairway – Overbek, the agglomeration of nanoparticles is determined by the sum of the electrostatic repulsive forces (the interaction of the double electric layer surrounding each particle) and the attractive force. An increase in the surface charge of particles (zeta potential) can increase the electrostatic repulsive force, prevent agglomeration and, therefore, reduce the hydrodynamic size of the dispersion.

A graph describing the effect of the pH of solution on the zeta potential of titanium dioxide nanoparticles is in Figure 1.

According to the results of measuring the electrokinetic properties, it was found that at the pH of 7 to 10, the suspension of titanium dioxide is stable because it has a significant negative zeta potential (from -30 mV to -45 mV). These results are consistent with published data [7-10].

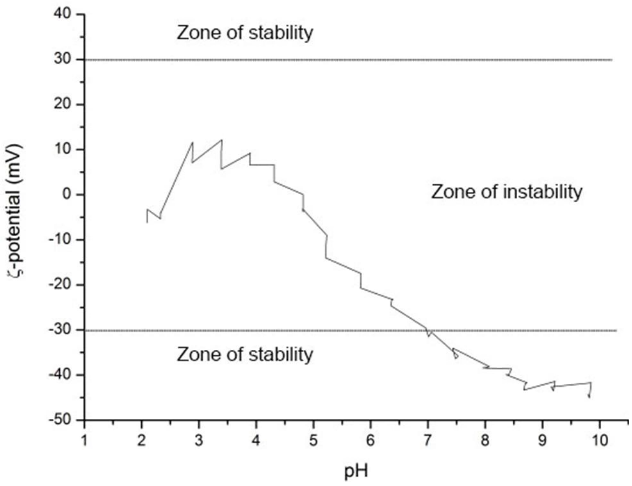


Figure 1 Dependence of the zeta potential of titanium dioxide nanoparticles on the pH of a medium

At the pH values from 2 to 7, the zeta potential is in the instability zone (from 10 mV to -30 mV). As a result, the attractive forces can prevail over the repulsive forces, that leading to the aggregation of titanium dioxide nanoparticles. The pH of the aqueous dispersion of styrene acrylic polymer Lacrytex 430 is in the range from 7.5 to 8.5, which is a favorable medium for nano-TiO_2 dispersion.

The dispersion of nanofiller in a polymer matrix affects the properties and purpose of nanocomposites. Considering that the use of nanoparticles with high uncompensated surface energy in a composition with a polymer can lead to the formation of aggregates, we studied the morphology of polymer films by the distribution of TiO_2 nanoparticles in the Lacrytex 430 polymer matrix. The research results are presented on micrographs of the surface of composite polymer films (Figure 2) obtained by scanning electron microscopy (SEM).

As can be seen from microphotographs in Figures 2a, 2b, the distribution of TiO_2 nanoparticles in styrene acrylic polymer with a filling of 1-3 wt.% is homogeneous with an insignificant amount of small agglomerates. With an increase in the TiO_2 content in the polymer matrix to 5 wt.%, the formation of large agglomerates (more than 1 mm) is observed (Figure 2c). Thus, the tendency to agglomeration of nanoparticles increases with a higher filling of the polymer with titanium dioxide (above 5 wt.%), which can negatively affect the initial properties of nanocomposites.

It is known that the introduction of fillers in polymers significantly changes the properties of polymer composite materials. In this regard, the study of the influence of fillers on the structural characteristics of the polymer films of styrene acrylic polymer Lacrytex 430 is of particular importance.

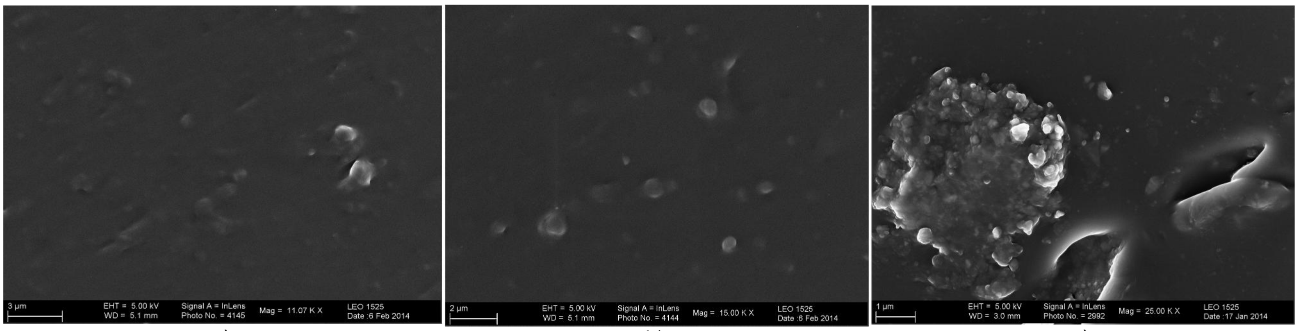
The degree of interaction between components of the mixture was estimated by sol-gel analysis through the equilibrium swelling of nanocomposites in solvents (Table 2).

According to the results of the study (Table 2), it was found that the introduction of titanium dioxide nanoparticles into the styrene acrylic polymer Lacrytex 430 does not lead to an improvement in the structural parameters of nanocomposites. At a concentration of nano-TiO_2 up to 2 wt.%, the average molecular chain length and the degree of crosslinking remain unchanged. Increasing the concentration of titanium dioxide reduces the studied parameters. As can be seen from the data of Table 2, the TiO_2 content above 3 wt.% increases the average molecular length, reduces the crosslinking density, which may be a consequence of the agglomeration of particles of titanium dioxide in the polymer.

The results of studying the chemical structure of polymer films using IR spectroscopy are presented in Figure 3.

The IR spectra of nano-TiO_2 are recorded in the frequency range 600-4000 cm^{-1}. Peaks at 1800-1630 cm^{-1} and wide peaks arising at 3100-3600 cm^{-1} correspond to stretching and deformation vibrations of hydroxyl groups on the surface of TiO_2 particles. A peak of about 2300 cm^{-1} is associated with CO_2 adsorbed on the surface of titanium dioxide. Strong absorption bands between 700 and 600 cm^{-1} relate to vibrations of Ti-O and Ti-O-Ti.

The IR spectra of the TiO_2/polymer nanocomposite are a combination of typical absorption spectra of the styrene acrylic polymer Lacrytex 430 and TiO_2. The characteristic absorption bands of the corresponding monomeric units of acrylate [11] are present at 1728 cm^{-1}, which is the result of asymmetric and symmetric stretching vibrations of the C=O carboxyl group. The S-O-C sites are observed at 1158 cm^{-1}, and deformation vibrations of C-CH_3 are observed at 1452 cm^{-1}. While the C-H out-of-plane peak is observed at 758 cm^{-1}, other prominent absorption peaks at 2955, 2923 and 2853 cm^{-1} are due to aliphatic (C-H) regions such as – CH_2 and -CH_3. The peak of average absorption at 698 cm^{-1} is associated with the externally in-plane bending of the phenolic ring. The spectrum of the TiO_2/polymer nanocomposite shows significant absorption at 668 cm^{-1}, which represents the Ti-O band.



a) b) c)

Figure 2 SEM image of the surface of Lacrytex 430/TiO_2 nanocomposites: a) Lacrytex 430/TiO_2 1 wt.%; b) Lacrytex 430/TiO_2 3 wt.%; c) Lacrytex 430/TiO_2 5 wt.%

Table 2 Structural parameters of Lacrytex 430 polymer films filled with TiO_2

TiO_2 content in polymer film [wt.%]	Structural indicators		
	Interaction index polymer/filler	Molecular weight of the chain segment Mc [g/mol]	Crosslinking density $v\times10^{-3}$ [mol/cm^3]
without additives	–	52	9.6
1	0.94	52	9.6
2	0.97	52	9.6
3	1.01	62	8.1
4	1.02	67	7.5
5	1.03	67	7.5
10	1.06	70	7.1
20	1.10	78	6.4
30	1.14	83	6.0

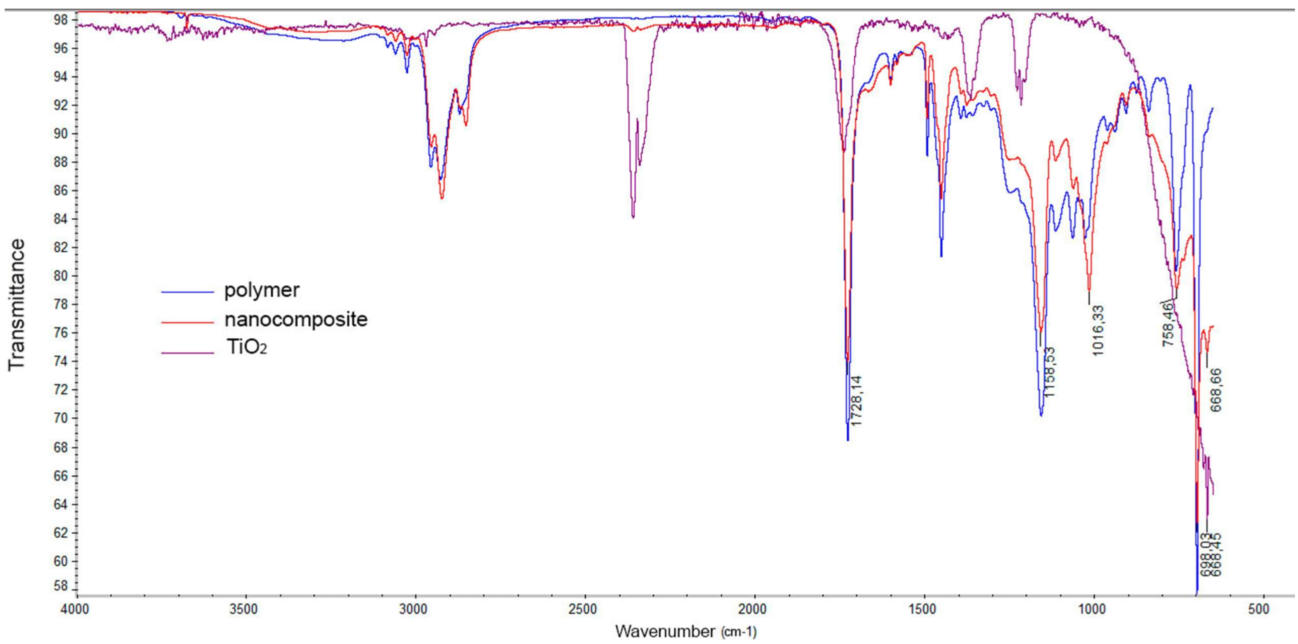


Figure 3 IR spectra of styrene acrylic polymer films

The effect of filling a polymer film with titanium dioxide on the process of thermooxidative decomposition of materials and the formation of a coke-like residue was evaluated by the method of thermogravimetric analysis. The thermograms of polymer composites are shown in Figure 4.

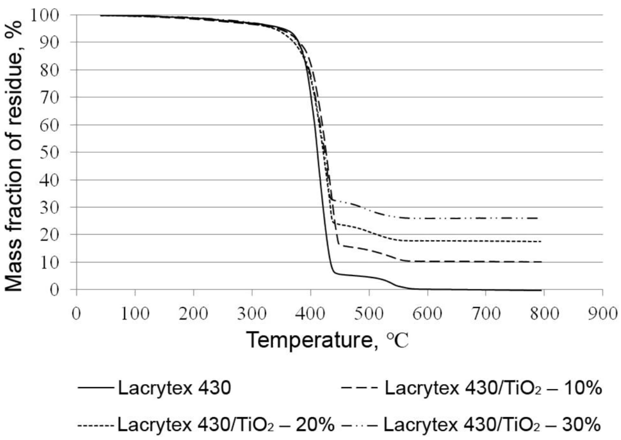


Figure 4 Thermogravimetric analysis of styrene acrylic film filled with titanium dioxide

The main stages of thermal destruction of the polymer composites are presented in Table 3.

According to the Table 3, styrene acrylic polymer has an initial decomposition temperature of 379°C. The initial temperature of destruction of $T_d^{0.1}$ for nanocomposites with TiO_2 of 30 wt.% corresponds to 372°C, and the half stage of destruction of $T_d^{0.5}$ rises to 425°C.

As can be seen from the obtained data (Table 3), an unfilled styrene acrylic polymer at a temperature of 600°C almost completely degrades, while the coke residue of nanocomposite films with different filling ranges from 10.39 to 25.95% and increases with increasing titanium dioxide content.

It can be concluded that the thermal degradation of nanocomposites is significantly affected by the interfacial interaction between the polymer and the nanoparticle, which allows nanoparticles to act as restriction zones (limitations). In turn, restricting the movement of the polymer chain makes its destruction more difficult at low temperatures and moves the temperature of the destruction of the polymer film filled with titanium dioxide to higher temperatures.

Table 3 Effect of temperature on the mass change of the styrene acrylic polymer Lacrytex 430 filled with titanium dioxide

Nanocomposite films [wt.%]	The main stage of destruction		Mass fraction of residue with increasing temperature [%]							
	$T_d^{0.1}$ [°C]	$T_d^{0.5}$ [°C]	100	200	300	400	500	600	700	800
Lacrytex 430	379	411	99.87	98.97	97.08	70.67	4.55	0.11	0	0
Lacrytex 430/TiO_2 10	377	421	99.68	98.62	96.71	82.11	14.38	10.39	10.29	10.14
Lacrytex 430/TiO_2 20	373	423	99.61	98.91	96.81	77.12	21.12	17.85	17.76	17.56
Lacrytex 430/TiO_2 30	372	425	99.71	99.12	97.26	78.02	28.89	26.95	26.05	25.95

5 CONCLUSIONS

As a result of the experiment, the effect of the addition of nanosized titanium dioxide on the structural characteristics and thermal properties of styrene acrylic polymer Lacrytex 430 was studied. The degree of interaction between the components of the mixture was estimated and it was shown that titanium dioxide does not change the structural parameters of the polymer at a concentration of 1-2 wt.%. The efficiency of titanium dioxide as a thermophysical additive in a styrene acrylic polymer was established due to a shift in the thermal degradation of the resulting composite to a region of higher temperatures.

6 REFERENCES

1. Weil E.D., Levchik S.V.: Flame Retardants I Commercial Use or Development for Textiles, chapter 11 in Flame Retardants for Plastics and Textiles: Practical Applications, Hanser Publisher, Munich, 2009, pp. 197-226, ISBN: 978-3-446-41652-9
2. Lopez-Cuesta J.M.: Flame-retardant polymer nanocomposites, chapter 16 in Advances in Polymer Nanocomposites: Types and Applications, Woodhead Publishing: Series in Composites Science and Engineering, 2012, pp. 540-566, https://doi.org/10.1533/9780857096241.3.540
3. Yurtov E.V., Sertsova A.A., Marakulin S.I.: Ispol'zovaniye nanochastichek soyedineniy metallov dlya sozdaniya trudnogoryuchikh polimernykh tekstil'nykh materialov [The use of nanoparticles of metal compounds to create flame-retardant polymer textile materials], Proceedings of XIX Intern. Science-practical Forum SMARTEX-2016, Ivanovo, IVGPU, May 2016, Part 1, pp. 36-39 (in Russian)
4. Laachachi A., Cochez M., Ferriol M., Lopez-Cuesta J.M., Leroy E.: Influence of TiO_2 and Fe_2O_3 fillers on the thermal properties of PMMA, Materials Letters 59(1), 2005, pp. 36-39, https://doi.org/10.1016/j.matlet.2004.09.014
5. Pasini S.M, Batistella M.A., Guelli Ulson de Souza S.M.A., Wang J., Hotza D., Ulson de Souza A.A.: Thermal degradation and flammability of TiO_2-polyetherimide nanocomposite fibers, Polymer Bulletin 9/2020, 2019, https://doi.org/10.1007/s00289-019-02970-1
6. Laachachi A., Cochez M., Leroy E., Gaudon P., Ferriol M., Lopez Cuesta J.M.: Effect of Al_2O_3 and TiO_2 nanoparticles and APP on thermal stability and flame retardance of PMMA, Polymers for Advanced Technologies 17(4), 2006, pp. 327-334, https://doi.org/10.1002/pat.690
7. Petrishin R.S., Yaremko Z.M., Soltis M.N. Vliyaniye pH sredy i poverkhnostno-aktivnykh veshchestv na dzeta-potentsial i agregativnuyu ustoychivost' suspenziy dioksida titana [The effect of pH of the medium and surfactants on the zeta potential and aggregative stability of titanium dioxide suspensions], Kolloidnyy zhurnal [Colloid journal] 72(4), 2010, pp. 512-517 (in Russian)
8. Tutigin A.S., Aizenshtadt A.M., Aizenshtadt M.A., Makhova T.A.: Vliyaniye prirody elektrolita na protsess koagulyatsii saponit-soderzhashchey suspenzii [The influence of the nature of the electrolyte on the coagulation process of a saponite-containing suspension], Geoekologiya, inzhenernaya geologiya, gidrogeologiya, geokriologiya [Geoecology. Engineering geology. Hydrogeology. Geocryology] 5, 2012, pp. 470-474 (in Russian)
9. Uphill S.J., Gosgrove T., Briscoe W.N.: Flow of nanofluids through porous media: Preserving timber with colloid science, Colloids Surfaces A: Physicochemical and Engineering Aspects 460, 2014, pp. 38-50, https://doi.org/10.1016/j.colsurfa.2014.05.008
10. Kuznetsova Yu.V., Kazantseva A.A., Rempel A.A.: Dzeta-potentsial, razmer i poluprovodnikovyye svoystva nanochastits sul'fida tsinka v stabil'nom vodnom kolloidnom rastvore [Zeta potential, size and semiconductor properties of zinc sulfide nanoparticles in a stable aqueous colloidal solution], Zhurnal fizicheskoy khimii [Russian Journal of Physical Chemistry A] 90(4), 2016, pp.625-630 (in Russian), DOI: 10.7868/S0044453716040154
11. Wang S.T., Poehlein G.V.: Characterization of water-soluble oligomer in acrylic acid-styrene emulsion copolymerization, Journal of Applied polymer Science 50(12), 1993, pp. 2173-2183, https://doi.org/10.1002/app.1993.070501217

DESIGNING FILTERING HALF-MASKS

S. Cheberyachko[1], L. Tretiakova[2], M. Kolosnichenko[3] and N. Ostapenko[3]

[1]State Higher Educational Institution, National Mining University, av. Dmytra Yavornytskoho 19, 49005 Dnipro, Ukraine
[2]National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Pr. Peremohy 37, 03056 Kyiv, Ukraine
[3]Kyiv National University of Technologies and Design, Nemirovicha-Danchenka str. 2, 01011 Kyiv, Ukraine
cesel@ukr.net

Abstract: *This work offers an approach to the design of the filter half-mask of a dust respirator with taking into account the anthropometric characteristics of faces of personnel. The ways of obtaining half-mask contours and construction of the obturation band are considered. Two designs of the front parts of the respirators are proposed, which are in comparison with each other by the size of the contact area of the obturator and the face and the calculated values of the coefficient of protection. Based on the data obtained, it is determined that half-masks constructed with consideration for the width and length of the face have better protective performance than with consideration for the length of the face and lips.*

Keywords: *filter half-mask, obturator circuit, protection factor, dimensional features of the face.*

1 INTRODUCTION

Anti-dust filter respirators are widespread in various industries due to their relatively low cost and simple design. However, there are some significant problems with their usage: the lack of a reliable fit of the obturator to the face along the obturation band, short duration of protective action, and others [1], which can significantly reduce the level of protection of personnel. Most of experts are of the opinion that the main disadvantage of filtering half-masks is the lack of reliable protection due to the low degree of conformity to the shape of the face, which is caused by the diversity of anthropometric characteristics of users' faces. It is established that the gaps most often occur in the area of the nasal bridge. It is experimentally determined that about 84% of the gaps are formed in the areas of the nose and cheeks [2]. The worst results when checking the half masks are recorded when talking and tilting the head (facial expressions). Therefore, improving the design of the half-mask and the obturator is an urgent scientific and technical task.

Analysis of publications: The design of personnel protection equipment (PPE) for respiratory organs consists of the development of a technical specification, a sketch and a technical project, design and working documentation. Respiratory PPE are classified into the third category of complexity for which conformity assessment is required [3]. Such procedure involves the internal control of production and checks of assets throughout the use and storage period. Experimental wearing and experimental testing of protective equipment takes extensive periods of time and expensive [4]. In addition, the implementation of such stages is time-consuming and requires high professional training of the developer [5]. Reducing the duration of such process without losing the quality of the filter half-mask can be achieved in various ways, in particular through the use of automated design systems. However, the design of PPEs of respiratory organs is not sufficiently formalized and is usually based on heuristic methods, which rely mainly on the specialist knowledge of the designer [5-8]. This can lead to errors and the loss of time to fix them. It is believed that the most time in the design of PPE of the respiratory system is spent of developing the shape and construction of the face mask [9]. The peculiarity of the design of respiratory organs is in changing a wide range of many parameters, including anthropometric characteristics of the human face; working conditions; changes in the physiological and psychological states of a person using PPE. There are a number of publications investigating the impact of a particular factor on quality, including the reliability of the respirator [10-13]. Therefore, the information database of anthropometric data was formed [10], the influence of the respirator on the physiological state of personnel was investigated [11], changes in the protective effectiveness during long-term use of PPE under different working conditions were evaluated [12], and a structural diagram of the reliability of PPE of respiratory organs was proposed [13]. This makes it possible to create the design of respirators from individual elements, highlighting certain stages of designing process. Leading manufacturers of respiratory protection equipment (Maskpol S.A., Scott Health & Safety) use information technologies to develop new types. The sequence of development of dustproof masks includes such stages [2]: research of anthropometric characteristics of workers' faces with the use of 3D scanning; construction of digital models of workers' heads of several sizes with the use of the main parameters of the face; construction of a 3D surface of a half-mask using NURBS-surfaces, B-splines or other digital models. An important stage is the unification of designs by similar anthropometric data and functional purpose. Depending on the structure of harmful substances (dust, aerosol, evaporation), the selection of an appropriate assemblies of filtering materials is performed. The main tasks are to increase the gapping of the mask to the face for different categories of consumers and increase the time of protective action. The analysis of modern tendencies of designing has shown that the important stage is search of new mathematical models and improvement of existing ways of processing of statistical data of anthropometrical parameters of faces. More precise 3D modeling of the mask surface will allow to take into account changes in facial parameters in the digital image. Such improvements make it possible to speed up and simplify the verification process during the design stages and make corrections during prototype production. Estimated protection times can be determined based on specific application conditions.

2 EXPERIMENTAL

All PPEs of the kit worker must be mutually consistent. Protective clothing takes into account the shape, size, design features and materials of the filter half-mask.

The purpose of the article is to substantiate the choice of design and technological solution of the model of protective filter face half-mask with improved protective and ergonomic parameters. To achieve the results, the following tasks must be solved: to determine the influence of the size characteristics of a person's face on the performance of half-mask protection; to develop a contour of a half-mask taking into account anthropometric sizes of faces; to select the appropriate filter materials for the production of half-masks and obturators; to develop a way to evaluate the protective characteristics of half-masks at the design stage.

3 RESULTS AND DISCUSSION

In order to solve the priority task, the researches of different authors on the effect of face size on the level of protection of workers when using PPE of respiratory organs are analyzed. It is established that for the production and further testing of respirators, special tables with the distribution of characteristics of testers on such anthropometric characteristics of the face, such as the length and width of the face or the length of the lips are widely used [2]. The studies carried out showed a high and long-lasting degree of protection for workers using half-masks created from the data of such tables.

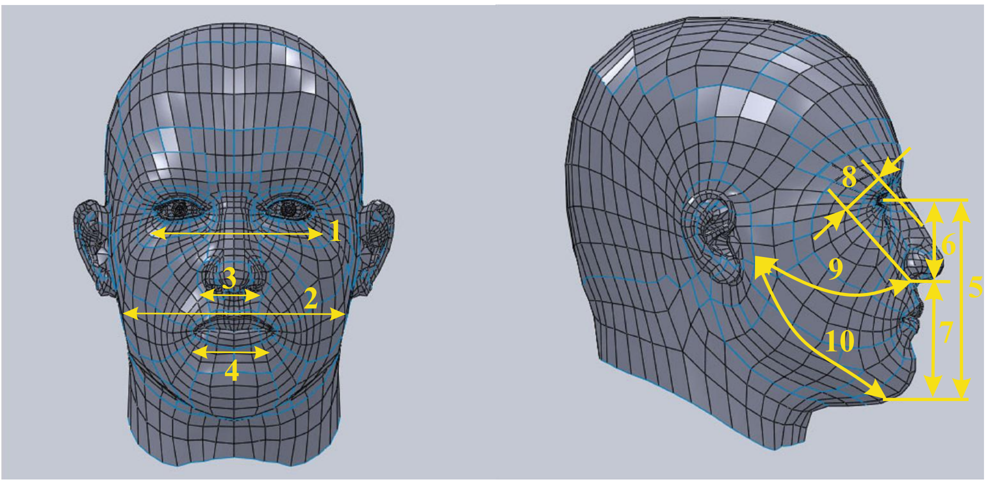
The next step identifies the facial features that are specific to our region. Using the recommendations given in [14], the dimensional features of the face are determined in accordance with Table 1. In order to solve the priority task, the researches of different authors on the effect of face size on the level of protection of workers when using PPE of respiratory organs are analyzed. It is established that for the production and further testing of respirators, special tables with the distribution of characteristics of testers on such anthropometric characteristics of the face, such as the length and width of the face or the length of the lips are widely used [2]. The studies carried out showed a high and long-lasting degree of protection for workers using half-masks created from the data of such tables.

The next step identifies the facial features that are specific to our region. Using the recommendations given in [14], the dimensional features of the face are determined in accordance with Table 1.

The measurement was performed using a caliper and centimeter tape on 400 people, of whom 320 were men and 80 were women. The range of values of the face length of the study subjects ranged from 98.5 mm to 143.2 mm, width ranged from 131.3 mm to 164.9 mm (Table 2).

Table 1 List of dimensional features of the face

Feature number (Figure 1)	Dimensioning symbol	Name of dimensioning	Feature name of dimensioning measurement technique
1	GONI	Width of face beyond eye line	Maximum horizontal width of face between end points in eyes hollows
2	ZYGO	Face width at lower jaw angles	Maximum horizontal face width between jaw arches
3	NOSEBRTH	Nose width	The distance between the right and left points of the wings of the nose
4	LIPLGTH	Lip length	The distance between the right and left points at the corners of the mouth
5	MENSELL	Face length	Distance between lower chin point and upper nose recess
6	NOSEPRH	Nose length	The distance between the lower nose point and the upper nose recess point
7	MSNL	Lower part of face	The distance between the lower chin point and the lower nose point
8	NOSP	Nose protrusion	The distance between the lower nose point and the average nose recess point
9	TRNA	Cheek width	The distance from the lower edge of the ear to the wing of the nose
10	TRMA	Cheek width	The distance from the lower edge of the ear to the chin



a) b)

Figure 1 Indication of the dimensional features of the face at front (a) and side (b)

Table 2 The results of measurements of dimensional facial features

Dimension feature codes	Mathematical expectation and confidence interval of face dimension [mm]		
	men	women	total
1. GONI	144.3 ± 8.9	135.3 ± 6.0	144.5 ± 8.9
2. ZYGO	130.2 ± 9.1	121.1 ± 9.1	128.4 ± 10.1
3. NOSEBRTH	32.7 ± 1.9	29.6 ± 3.3	32.0 ± 3.6
4. LIPLGTH	51.4 ± 3.7	45.0 ± 3.7	48.7 ± 4.8
5. MENSELLH	121.1 ± 8.4	115.2 ± 5.8	119.8 ± 7.8
6. MSNL	49.3 ± 4.5	43.2 ± 3.0	47.7 ± 5.0
7. NOSP	24.1 ± 2.7	22.4 ± 2.2	23.9 ± 2.6

The importance of the result of the work done is due to the need to check the respirators in the laboratory on volunteers who do not need to select according to the results of the size distribution and to remove from the inspection those who failed to find a suitable half-mask. This approach helps to protect the maximum number of employees, not just those whose facial parameters match the theoretical.

The next step is to look for the relationship between the obturator area and the safety metrics. The coefficient of protection K_3 of the respirator is determined by the formula:

$$K_3 = Q_0 / Q_l \tag{1}$$

where: Q_0 is total air flow during respiration [m/s]; Q_l is suction of air through the lines of obturation [m/s].

It is established that air leakage due to spaces between the filter half-mask seal and the face with uniform distribution of contact voltage can be calculated by the following formulas [15]:

$$Q_l = C_g C_u \tag{2}$$

$$C_g = \frac{k^3_{max} \cdot \Delta p}{l\mu} \tag{3}$$

where: k_{max} is the maximum height of the irregularities at the perimeter seal [m]; Δp is pressure drop [Pa]; l is the width of the seal [m]; μ is dynamic air viscosity [Pa.s]; C_u is the leakage permeability coefficient determined by the following formula [16]:

$$C_u = \frac{k_g \cdot \zeta}{8(1 - k_g)} \tag{4}$$

where: k_g is the coefficient of efficiency of use of the surface of the half-mask; ζ is the local loss factor.

In [17] it is recommended to determine the local loss coefficient for cracks by the formula:

$$\zeta = 2{,}5 + 5{,}5 \cdot 10^{-4} \left(\frac{l}{k_{max}} \right) \tag{5}$$

The coefficient of efficiency of use of the surface of the half-mask obturator is determined by the formula:

$$k_g = \frac{F_e}{F_o} \tag{6}$$

where: F_e is the effective surface of the obturator, which is close to the face [m^2]; F_0 is the total area of the half-mask obturator [m^2].

The effective surface of a half-mask mask can be determined in several ways, including the imprint on the soft layer, which is applied to the head of the dummy and by thermography (Figure 2).

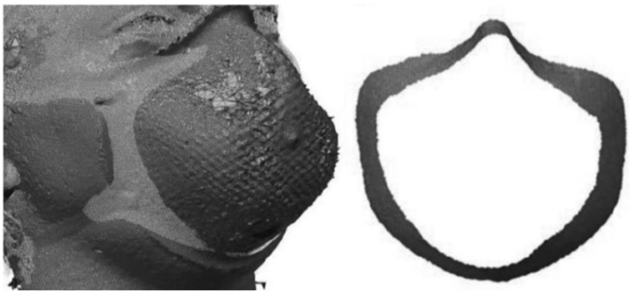


Figure 2 Determination of effective half-mask obturator area

The thermogram allows to determine the locations of the tight fit and, accordingly, the penetration of the aerosol along the obturation band by the intensity of the thermal radiation of the surface of the obturator in the infrared range. The reflection of the thermal field on the thermal imaging display is given in color, where the places of aerosol penetration into the sub-mask space through the slits between the obturator and the face are of particular color. The location of the local temperature anomaly on the surface of the obturation band is determined by the change in thermogram color.

In the second stage, two variants of the shape/line contour of the half-masking strip of the obturator are considered. The first takes into account the width of the face, the width of the nose and the distance from the nose to the chin. In the second embodiment, besides the points indicated, the width of the face behind the jaw is taken into account. On the basis of the obtained results of the measurements given in Table 2, the placement of critical points for the construction of an obturation strip on the face is proposed (Figure 3).

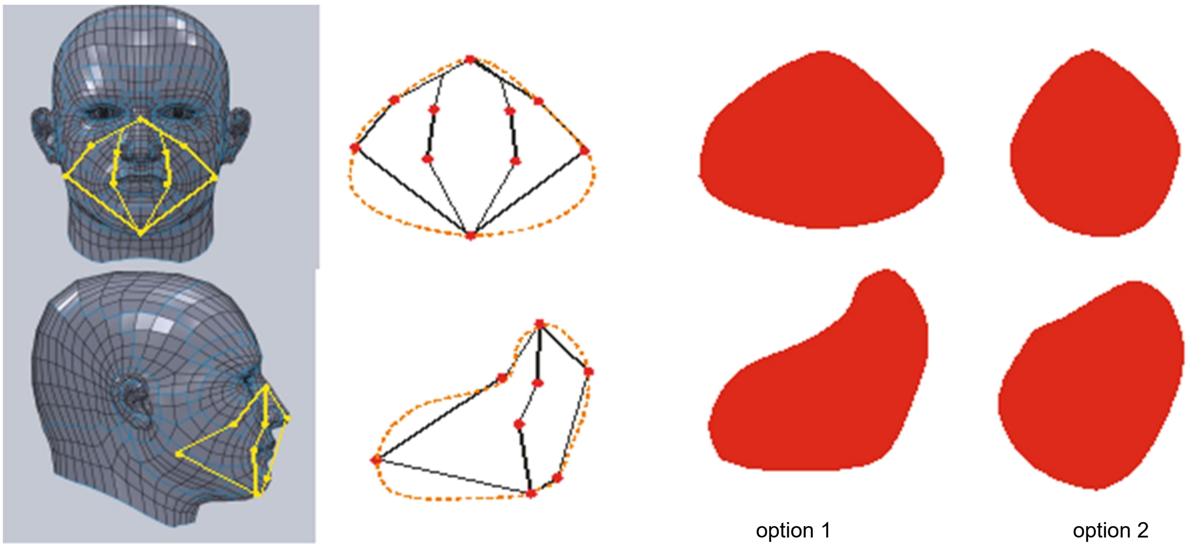


Figure 3 Schemes of the contour stripes

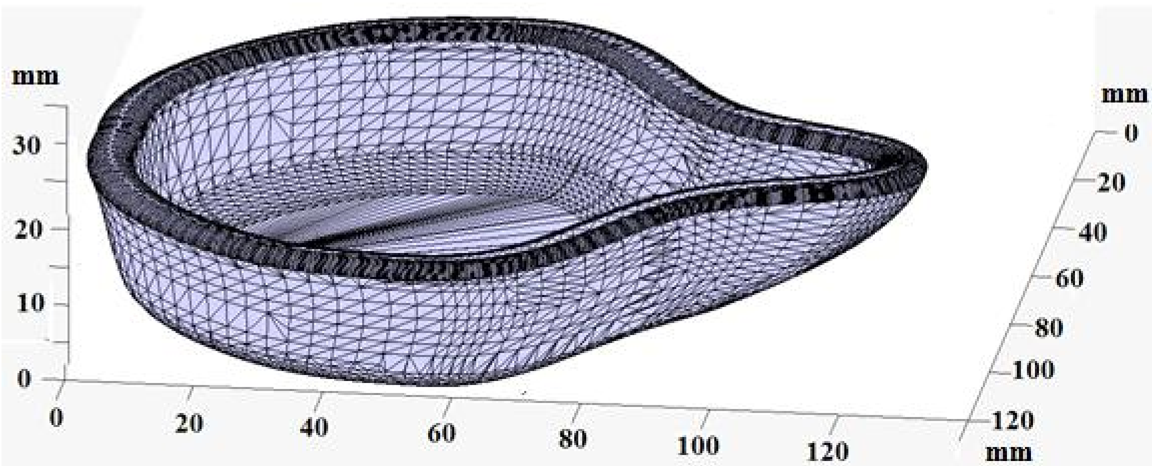


Figure 4 Surface view of the filter half-mask in the second option

The same is true for both options, such as the width of the nose and the distance from the nose to the chin. The difference is the choice between the width of the face and the length of the lips. Thus, the defined contour of the obturator is narrow at the top of the face and extended to the bottom to cover the cheek. It is experimentally proved that in the first option the influence of facial expressions during conversation and head turns is reduced, while in the second the contour is centered around the nose and mouth, and, as a consequence, there will be less material consumption of the filter and protective layers. The mask shape was obtained according to the coordinates of anthropometric points obtained during digitization of the scanned face shapes. The rough edges are smoothed using the appropriate Corel software. A sample of the constructed surface of the filter half-mask is shown in Figure 4.

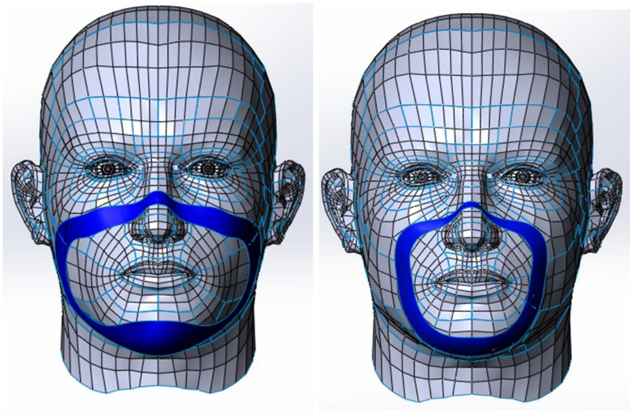
Further studies consisted of combining a half-mask with a head model to determine the contact area along the obturation band. The contact area between the head and the half-mask is provided as a non-uniform ring, which is bounded by the inner and outer boundary curves. We consider the surface of the contact area symmetrical and the possible asymmetry of the head in the first approximation is not taken into account. Some of the contact areas are manually adjusted because there are some inconsistencies with the computerized implementation in the 3D image of the half-mask. The most problematic area is the convex and in the half-mask image this area does not partially coincide with the size of the bridge. In real half-mask models, there is a plate that can improve the degree of fit by clamping down on the force in the bridge. Therefore, we assume that such actions do not make a significant error in determining the contact area. The simulation result is given in Table 3 and Figure 5.

Table 3 The results of calculating the area of the obturation band

Option number	Calculated contact area between half-mask and face areas [cm^2]				Total contact area [cm^2]
	bridge	right cheek	left cheek	chin	
1	2.2	3.1	3.1	4.0	12.4
2	1.2	2.2	2.2	2.6	8.2

The next step is to make a reasonable choice of materials for the manufacture of half-masks and obturator. It is advisable to make dust masks multilayered (Figure 6).

The structure of the package consists of materials different in purpose and other characteristics of layers. The first layer is the outer frame. Its purpose is to remove the largest particles of dust from the air stream, to protect the filter material from mechanical damage and deformation. The second and third are filter layers designed to refine the air of harmful impurities. Such layers determine the degree of protective effectiveness of the respirator. The fourth is the inner layer, which supports the filter material and directly contacts the face of the user. The material of the fourth is the layer is smooth, does not contain substances that cause irritation or allergy, improve the conditions of use (absorb moisture during breathing).



a) b)

Figure 5 Layout of half-mask obturation band on head model: a) option 1; b) option 2

Figure 6 Package of materials for the manufacture of half-masks: 1) inner layer; 2) fine refinement filter; 3) coarse refinement filter; 4) outer frame layer

The obturator is made of identical materials, and special materials (polyurethane foam, silicone, rubber) are used to increase the insulating characteristics. The developed half-mask samples are made of three layers of polypropylene filter material of different density (Table 4) and the inner layer is made of cotton fabric (Figure 7).

Table 4 Basic parameters of the filter layers from which the samples are made

	Filter layer indicators		
	first	second	third
Fiber radius α [μm]	10.0	3.0	7.0
The fiber packing density β	0.03	0.05	0.03
Thickness [mm]	4.0	3.0	3.0

a) b)

Figure 7 Appearance of filter half-masks: a) option 1; b) option 2

To ensure the necessary duration of the protective effect of half masks, their filters are made of several layers of materials of different density and thickness. The number of layers depends on air dustiness and operating mode.

$$K = \frac{C \cdot Q \cdot t_k}{\rho_d \cdot V_{\max}}, \tag{7}$$

where: K – number of filter layers; C – dust concentration in the air of the working area [kg/m^3]; Q – air volume discharge [m^3/s]; t_k – time in use [s]; ρ_d – dust deposit density [kg/m^3]; V_{max} – maximum dust volume [m^3].

One of the main steps in the manufacture of half-masks is to determine the attachment points of the headband to ensure a uniform distribution of the clamping forces along the obturation band. This is a prerequisite for providing protective performance. To solve this problem, you can use a calculation method based on the construction of models of external forces acting on the half-mask (Figure 8), or use a special measuring system, for example, Tactile free form sensor system (Sensor Products Inc., Madison, N.J.).

The solution to the latter problem is due to the process of thermographing the manufactured half-masks on several testers. Such tests give the opportunity to check the protective properties of the respirator at the stage of the test sample, and then make appropriate adjustments to the design of the obturator. Air flow through the half-mask was taken at 95 dm^3/min (according to [18]), the average resistance of the half-mask to the air flow was 75 Pa. The obtained thermal images are shown in Figure 9.

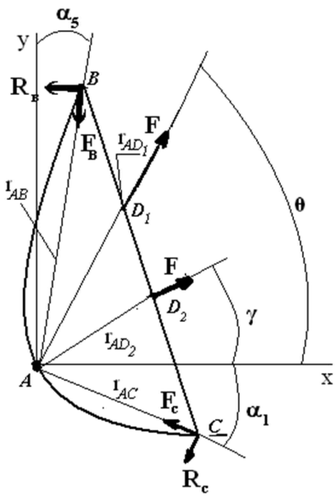
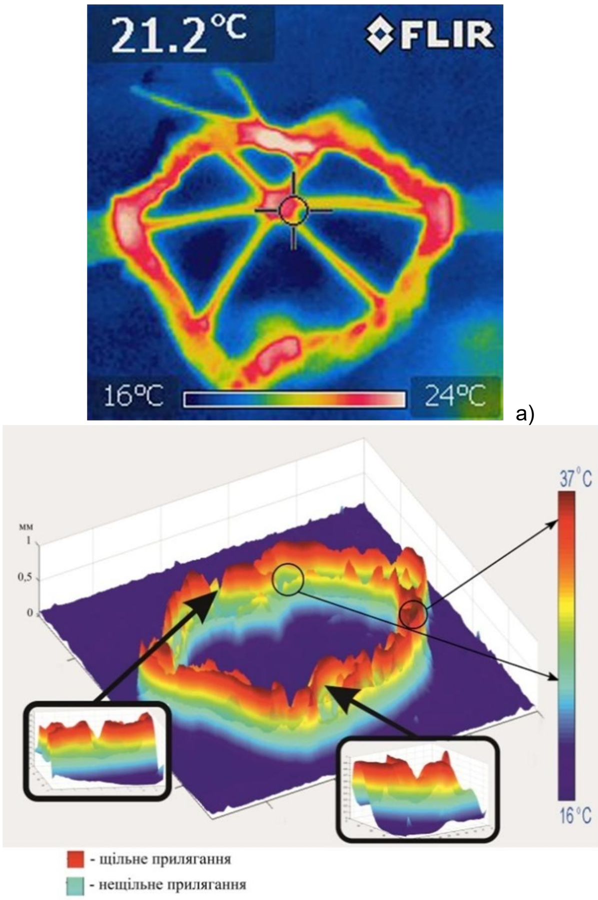


Figure 8 Calculation model for determining the placement of a headband



a) b)

Figure 9 Infrared image of a respirator according to variants: a) thermal imaging test; b) after processing in the Matlab package

Table 5 The results of the calculations of the protective effectiveness of half-masks

Number of variants	Pressure drop [Pa]	Total air flow rate Q_0 [m/s]	Maximum height of irregularities k_{max} [m]	Efficiency factor k_g	Indicator C_g [m^3/s]	Permeability factor C_u	Protection factor K_3
1	75	0.0015	0.04	0.8	$5.2 \cdot 10^{-5}$	1.25	28.7
2			0.06	0.7	$8.4 \cdot 10^{-5}$	0.74	17.9

The results of experimental studies and mathematical modeling were processed according to formulas (1 - 6) and maximum heights of irregularities and protective indices were determined (Table 5)

3.1 Discussion of the results

The tests made it possible to formulate an improved sequence of work on the design of filter half-masks. The characteristic dimensional features of the faces of potential consumers are identified. We use the obtained average dimensions as the initial information for mathematical 3D model of the head. According to the results of the simulation, the contour of the half-mask mask was constructed the area of contact with the face and the strip of the obturation were calculated, which makes it possible to choose the shape of the half-mask. It is known that the larger the contact area and the obturation band, the less gaps are formed during various movements of the head. Respiratory elements are selected: material type, number of material layers, exhalation valve, headrest, nose clip. The structure of the respirator depends on a number of factors: concentrations of harmful dust, particle size; type of filter material. Note that the available filter materials make it possible to provide the desired degree of air purification for all types of dust. In the third stage, we check the protective properties of the prototype by the magnitude of the air suction due to the tightness of the obturation band. Based on the mathematical model, the magnitude of the protection coefficient, we estimate the design taking into account the structure of the package of materials of half-mask, as well as the impact of each layer. The proposed algorithm differs from the known presence of a preliminary check of protective properties using a mathematical 3D model at the design stage.

4 CONCLUSIONS

As a result of the performed researches the main stages of designing half-masks were determined. The following sequence is proposed: determination of anthropometric face sizes; development of contours of the obturator and calculation of the area of contact with the face; selection of appropriate filter material; preliminary evaluation of the protective properties under the simplified procedure - thermography.

The basic statistical anthropometric sizes of faces of people for regions of Ukraine are defined. Two variants of designing the surface of facial half masks are considered. In the first variant as initial parameters are used: width of a face at the level of a nose; width of a nose and distance from nose bridge to a chin. In the second variant are used: the width of the face under the lower jaw, the width of the nose and the distance from the nose bridge to the chin.

The results of mathematical modeling showed that in half masks, which are built on the size of the width of the face and nose and the distance from the bridge to the chin, the area of the skirt is 1.5 times larger than in half masks, which were built on the second version. Laboratory tests have shown that the protection coefficient of the half-mask in the first variant is 40% higher than in the second variant.

A filter media assembly has been selected for the selected half-mask design. A three-layer assembly has been used in which the first layer is a frame layer, the second and third layers are designed to capture large and fine aerosols.

A technique has been developed to check the quality of the respirators based on the determination of the area of contact of the half-mask and the pressing force of the half-mask to the face. It has given the chance: to calculate factor of protection of a respirator at designing; to reduce errors at formation of a structure skeleton and a face seal design.

5 REFERENCES

1. Kirillov V.F., Bunchev A.A., Chirkin A.V.: On means of individual protection of respiratory organs of the workers (literature review), FGBU “Scientific and research Institute of Labour Medicine” of Russian Academy of Medical Sciences Labour Medicine and Industrial Ecology, No. 4, 2013, pp. 25-31 (in Russian)
2. Oestenstad R.K., Kenneth H., Perkins D.L., Perkins L.L.: Distribution of faceseal leak sites on a half–mask respirator and their association with facial dimensions, American Industrial Hygiene Association Journal 51(5), 1990, pp. 285-290, https://doi.org/10.1080/15298669091369664
3. Regulation (EU) No 2016/425 of the European Parliament and of the Council of 9 March on Personal Protective Equipment and Repealing Council Directive 89/686/EEC, 2016
4. Gudkov S.V., Dvoretsky S.I., Putin S.B., Tarev V.P.: Isolating Breathing Equipment and Fundamentals of its Design: A Textbook, M.: Mechanical Engineering, 2008, 188 p. (in Russian)

5. Ostapenko N.V., Kolosnichenko M.V., Lutsker T.V., Kolosnichenko O.V., Rubanka A.I.: Designing of special-purpose products: Textbook, K.: KNUTD, 2016, 320 p. (in Ukrainian)
6. Basmanov P.Y., Kamynskyi S.L., Korobeinykova A.V., Trubytsyna M.E.: Personal protective equipment: reference manual, St. Petersburg.: Russian Art Institute, 2002, 400 p. (in Russian)
7. Hrachev V.A., Sobiur S.V.: Respiratory protective devices (PPE), Benefit, M.: PozhKnyha, 2006, 288 p. (in Russian)
8. Struminska T.V., Prasol S.I., Kolosnichenko E.V., Chuprina N.V., Ostapenko N.V.: Designing of special clothing based on experimental researches of material properties, Vlakna a textil (Fibres and Textiles) 26(4), 2019, pp. 84-95
9. Gutierrez A.M.J.A., Galang M.D., Seva R.R., Lu M.C., Ty D.R.S.: Designing an improved respirator for automotive painters, International Journal of Industrial Ergonomics 44(1), 2014, pp. 131-139, https://doi.org/10.1016/j.ergon.2013.11.004
10. Zhuang Z., Bradtmiller B., Shaffer R.E.: New respirator fit test panels representing the current U.S. civilian work force, Journal of Occupational and Environmental Hygiene4(9), 2007, pp. 647-659, https://doi.org/10.1080/15459620701497538
11. Groce D., Guffey S., Viscusi D.J., et al.: Three-dimensional facial parameters and principal component scores: association with respirator fit, Journal of the International Society for Respiratory Protection 27(1), 2010, pp. 1-15
12. Plebani C., Listrani S., Di Luigi M.: Filtering facepieces: effect of oily aerosol load on penetration through the filtering material, La Medicina del lavoro 101(4), 2010, pp. 293-302
13. Tretiakova L.D.: A method for assessing the reliability of complex remedies, Occupational safety newsletter 3(57), 2010, pp. 29-31 (in Ukrainian)
14. Cheberiachko S.I. Radchuk R.D.: Methods of selection of testers at research of filtering respirators, Metrology and devices 3, 2015, pp. 28-35 (in Ukrainian)
15. Janssen L., Weber R.: The effect of pressure drop on respirator faceseal leakage, Journal of Occupational and Environmental Hygiene 2(7), 2005, pp. 335-340, https://doi.org/10.1080/15459620590965068
16. Oestenstad R.K., Elliot L.J., Beasley T.M.: The effect of gender and respirator brand on the association of respirator fit with facial dimensions, Journal of Occupational and Environmental Hygiene 4(12), 2007, pp. 923-930, https://doi.org/10.1080/15459620701709619
17. Coffey C.C., Lawrence R.B., Zhuang Z., Campbell D.L., Jensen P.A., Meyers W.R.: Comparison of five methods for fit-testing N95 filtering facepiece respirators, Applied Occupational and Environmental Hygiene 17(10), 2002, pp. 723-730, https://doi.org/10.1080/10473220290107002

DSTU 140:2004. Personal protective equipment for the child. Half masks and quarter masks. Requirements, tests, manufacturing,(Valid from 2004-06-01), State Standard of Ukraine, 2004(in Ukrainian)

STUDY OF DOMINANT QUALITY INDICATORS OF MATERIALS AND DESIGNS OF RAILROAD CONDUCTORS' UNIFORMS

Olena Kolosnichenko[1], Mykola Yakovlev[2], Iryna Prykhodko-Kononenko[1], Larysa Tretyakova[3], Natalia Ostapenko[1], Kalina Pashkevich[1] and Galyna Ripka[4]

[1]Kyiv National University of Technologies and Design, Nemirovich-Danchenko Street 2, 01011 Kyiv, Ukraine
[2] National Academy of Arts of Ukraine, Bulvarno-Kudrjavska Street 20, 01011 Kyiv, Ukraine
[3]National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Prosp. Peremohy 37, 03056 Kyiv, Ukraine
[4]Volodymyr Dahl East Ukrainian National University, prospect Central 59 A, 93400 Severodonetsk, Ukraine
3212793@gmail.com; gychamu@gmail.com; lt79@ukr.net; galina_anatolievna@ukr.net

Abstract: *The article is devoted to the study on determining the basic requirements for the design of conductors' uniforms of passenger rail transport. To solve the problems associated with highlighting the most significant indices for the materials and design features of individual products, the use of expert evaluation method has been proposed. A group of experts has been identified, consisting of clothing design experts, managers and representatives of Ukrzaliznytsia. The most essential indicators for materials, constructions and manufacturing technologies, using the method of ranking with normalized coefficients, have been determined on the example of men's and women's uniform suits. To verify the results, the degree of concordance of experts' opinions on the coefficient of concordance has been determined. The calculated values of the coefficients of concordance for all the considered problems are in the range $W=0.69 \div 0.78$, that indicates a high level of experts' agreement. Ranking identifies the sixteen most significant requirements for materials, structures, technologies and cost. Advanced models of women's and men's uniform suits with improved ergonomic and aesthetic performance have been proposed.*

Keywords: *uniform, expert estimation method, material quality indicators, design uniforms, rank correlation of indicators, coefficient of concordance.*

1 INTRODUCTION

Ukrzaliznytsia employs more than 308,000 people, some categories use uniforms. In 2017, the company spent 1.4 million UAH on the purchase of uniforms. All train drivers of locomotives and conductors of rolling stock of passenger trains were provided with uniforms. Their work is related to the influence of a number of harmful production factors: working at night shifts, dusty air, poor microclimate due to the presence of draughts, fluctuations in temperature and humidity, low-frequency vibrations, infrasound and noise. The high risk of injuries is due to a busy schedule, which is three-shifted with most conductors or there may happen extended working hours up to 12 hours. Accordingly, conductors' uniform is a complex multifunctional item that must meet the requirements for protective clothing and provide indicators of ergonomics, reliability, aesthetics and economy [1]. When developing the nomenclature of quality indicators of uniforms and materials for its manufacture, it is necessary to take into account the changing parameters of the environment, harmful production factors and topographies of their impact, the nature of work activity and materials characteristics [2]. The efficiency and duration of the uniform depend on the correct and reasonable choice of materials, design and technological solutions [3-5].

The main task of designing uniforms is the development of structural and harmonious solutions according to the strict classical style. The solution to this problem is related to a comprehensive approach that covers information on the properties and characteristics of textile materials, terms of use and available structural and technological solutions of the uniforms for Ukrzaliznytsia conductors [4, 6].

The preliminary analysis of the working conditions and the available uniforms of the conductors made it possible to establish that its assortment is quite large and consists of coats, cloaks, overcoats, jackets, camisoles, vests, blouses, shirts, trousers, skirts. Depending on the terms of usage, the use of products is possible separately and in kits. Such an analysis has become a prerequisite for the development of a nomenclature of mandatory and recommended indicators of uniforms. The conductors' uniforms should be seasonal, complete and consist of a sufficient and necessary number of items, each of which has an ergonomic, aesthetic and constructive technological solution.

There is a whole range of design requirements for railway workers' uniforms. A number of standardized (mandatory) indicators is related to materials that can be used for the production of certain uniforms. Another category of requirements is directly related to the design and technological development of products, which, along with the standardized list, should take into account the recommended (additional) indicators of reliability, ergonomics, aesthetics and economical ones [1, 7, 8].

The seasonal uniform kit consists of five to seven products. Considering it as a complex system has allowed us to determine that there is a sufficient number of external and internal factors that influence the course of its operation. Such factors are of different origin and are usually incommensurate, that is, it is difficult to distinguish a common benchmark of comparison. At the initial stage of designing, the designer does not have information about the importance of each factor, so it is difficult to assess the degree of their impact on the response function, which for this statement of the task is a ready-made uniform with a guaranteed term of usage [3, 6, 9].

Separate characteristics (physico-mechanical, hygienic, protective) of the materials have different units of measurement and their values are characterized by interval estimates. That is why the establishment of functional links between them and regulated indicators of uniforms is a very difficult task. Experts' opinions can overcome such complexity, and it also can be done by taking into account the designer's ability to make sound decisions in the event of impossibility of their complete formalization. In this regard, at the initial stage of the study, a task arises which is connected to the choice of the most important and the exception of the least significant factors, which allows to further reduce the number of experimental tests in laboratory and industrial conditions. The generally accepted procedure for screening factors [8, 10] because of a large number of indicators is quite cumbersome, time-consuming and requires considerable time to take the necessary measures.

According to the experience, in a number of cases, the results obtained at intermediate stages may have ambiguous, and sometimes contradictory, meanings. Such difficulties can be overcome by using the specialists' opinions, as well as taking into account the designer's ability to make rational decisions in the event that their full formalization is impossible. Therefore, it has been suggested to use the method of expert estimation to solve the problems related to the identification of the most relevant indicators for the materials and designs of individual products.

The purpose of the article is to determine the dominant indicators for materials, construction and manufacturing technologies of conductors' uniforms of passenger rail transport.

The following tasks have been solved in the article:

1. Requirements for women's and men's uniform suits concerning material, construction, manufacturing technologies and economic indicators have been analyzed and systematized;
2. It has been proposed to use the method of expert estimation in determining the dominant indicators, which allows to formalize the initial information into separate components of the process of uniform creation;
3. The qualification of the expert group has been determined and the level of consistency of their opinions has been checked;
4. The results obtained during refinement of models of uniform suits have been implemented.

2 RESEARCH MATTER AND RESULTS

Designing products you have to take into account a large number of requirements put forward by designers, customers and users of uniforms. Uniforms are purchased at the enterprise expense at annual tenders. Uniforms should meet the indicators of reliability, ergonomics, aesthetics, and to improve the competitiveness of products it is advisable to evaluate the economic indicators.

While designing uniforms, problems may arise due to a great number of requirements [1-4, 11, 12]. The main requirements include:

- the item dynamic conformity, which does not restrict movement, working position or sensory perception; does not cause movements that could be dangerous for the conductor or passengers;
- the item static conformity, which ensures the correct product fit on the body and does not change its correct position throughout the term of usage regardless of the environment, movements and working position of the conductor;
- ease of products usage that does not create complications in the performance of the conductors' duties, allow them to dress quickly and properly, provide the highest possible comfort level, provide information about the position and have elements of corporate identity;
- the comfortable microclimate under clothing. It does not allow the person to cool in the cold season and overheat in conditions of high temperatures, prevents wetting and perspiration;
- maintenance, cleaning and replacement of individual parts.

2.1 Input data

The uniforms effectiveness depends on the properties of the set of materials, which determine its ability to meet the requirements for protective, physical, mechanical and hygienic characteristics, and acceptable structural and technological solutions.

Let us consider the basic requirements with the example of designing uniforms for women and men, which are the most used and all-season clothing conductors. On the basis of the conducted analysis, the list of requirements for indicators of men's and women's uniform clothing of conductors for shoulder (jacket and ladies' jacket) and waist (skirt and trousers) products has been singled out. The basic requirements for materials and ready-made products are given in Table 1.

2.2 Model description

There are a lot of requirements and constraints while designing uniforms. The information availability, its reliability and correct usage largely determine the rationality of the chosen solution. However, in the design of garments, in addition to numerical and statistical data, information covers indicators that are not mathematical. In addition, the decision-making process involves focusing not only on quantitative values, but on aesthetic acceptance and convenience, taking into account the professional characteristics and fashion trends.

Most creative project tasks cannot be solved without human involvement. Choosing a rational solution involves human participation at the stages of formation of initial parameters in order that the final product meets the basic requirements. The peculiarity of designing clothes is the impossibility of formalizing the computing procedures. It is difficult to create formal models and methods that fully reflect the qualitative and quantitative relationships between materials, structures, manufacturing technologies and cost. These difficulties can be overcome by using the method of expert estimation. This method makes it possible to use the knowledge and opinions of experts to determine the dominant indicators in case of impossible complete formalization of the source information [7-10].

An expert estimation to determine the dominant quality indicators of the uniforms involves forming a group of experts, their interviewing, processing expert estimation and analysing the results. The reliability of the group expert estimation depends on the level of coherence of experts` opinion that participates in the survey.

At the first stage, twelve respondents were selected, including specialists from enterprises manufacturing uniforms, conductors, management of the railway, and specialists of research centers and laboratories of the textile industry. They were asked to rank the quality indicators of individual products according to their impact on the forecasted properties of the uniforms.

The method of direct estimating the ranking of initial requirements is difficult to use because of a large number of factors and their indicators (Table 1).

The indicators analyzed are diverse in both quantitative and qualitative characteristics. Therefore, the use of standard methods of expert estimation is not effective and requires adaptation to the specific tasks. A method of determining the rank of a group of indicators on the basis of normalized weight coefficients has been proposed [8].

Table 1 Requirements for material and products (men's and women's suit)

Requirements for material	**Requirements for products**		
	Construction	***Manufacturing technology***	***Economic indicators***
The content of natural fibers in the raw composition [%]	Dynamic conformity [grade]	Tensile loading of seams [H]	The cost of the product [UAH]
Color fastness to chemical influences, wet treatments, ultraviolet radiation, sweat [grade]	Static conformity [grade]	Air permeability of seams [$dm^3/(m^2.s)$]	Guaranteed lifetime [hours]
Crease-resistance [grade]	Ease of usage [grade]	Water permeability coefficient of the seam [$dm^3/(m^2.s)$]	Repair costs [UAH]
Breaking loading [N]	Lining availability	Technological processing of fasteners, vents, pockets, straps, collar	Cleaning costs [UAH]
Elongation at break [%]	Constructive form articulation	Technological processing of the lining	
Resistance to abrasion [cycles]	Direction and location of membership lines	Elasticity of the middle back seam, elbow seam of the jacket/ladies' jacket	
Thickness ratio [%]	Form stability	Individual items duplicate	
Air permeability [$dm^3/(m^2.s)$]	Internal pockets availability	Maintainability	
Water resistance [grade]	Availability of elements for clear belt fixation	The level of technical performance of the product, all available structural elements to the external perception	
Coefficient of thermal diffusivity [m^2/s]	Availability of distinction signs (corporate logo and position)	Level of finishing and ready-making of the product	
Coefficient of thermal conductivity [W/(m.°C)]	Artistic and color design		
Hygroscopicity [%]	Number of cleaning cycles		
Changing linear dimensions after wet treatments [%]			
Number of piles			

2.3 Ranking of task-demand for material and ready-made garment

The first stage identifies four groups of factors that determine the requirements for the material, construction, manufacturing technology and economic performance of the product. For each group, the normalized indicators are defined in the following order:

1. During ranking, *m* experts have been asked to place *n* requirements in the sequence that they consider to be the most reasonable and to assign to each requirement *X* ranks from 1 to *N*. For this rank 1 receives the most preferred indicator and rank *N* – the least important;
2. The normalized coefficient *K* for each of the *q* group of requirements is defined by the formula:

$$K_q = \frac{\sum_{j=1}^{m} X_q^j}{\sum_{q=1}^{n}\sum_{j=1}^{m} X_q^j}, \qquad (1)$$

where X_q^j is the rank of the q^{th} group of the requirement provided by the j^{th} expert; q = 1…n; j = 1…m;

3. After the normalization the results have been obtained, which are given in Table 2.

In the second stage, the experts are asked to rank the indicators in each group of requirements. According to the algorithm, normalized coefficients of K_q up to 12 material indices and 24 product indices have been determined. The total normalized ranking coefficient *K* of alternative solutions has been calculated by the formula:

$$K=K_q.K_i \qquad (2)$$

where K_i is the normalized coefficient for each i^{th} group of indices.

The ranking results highlight the eight most significant material requirements (Table 3) and the eight product indicators (Table 4).

2.4 Concordance testing of expert judgments

The coherence of expert opinions with a large number of indicators is determined by the level of consistency of opinions of a heterogeneous group of experts. The obtained ranking estimates can be taken as random variables, so generalized statistical characteristics are used to estimate consistency [7-9].

Table 2 Ranking of requirements for material and product

Factor	Requirements for material	Requirements for constructions	Requirements for manufacturing technology	Economic requirements
Normalized coefficient K_q	0.12	0.20	0.31	0.37
Rank	1	2	3	4

Table 3 Ranking of material indicators

№	Indicator	Normalized coefficients			Rank
		Ki	*Kq*	*K*	
1	Crease-resistance	0.04	0.12	0.004	1
2	Breaking loading	0.08	0.12	0.0093	2
3	Air permeability	0.09	0.12	0.0105	3
4	Water resistance	0.12	0.12	0.0140	4
5	The content of natural fibers in the raw material composition	0.13	0.12	0.0152	5
6	Resistance to abrasion, cycles	0.15	0.12	0.0176	6
7	Color fastness to chemical influences, wet treatments, ultraviolet radiation, sweat	0.16	0.12	0.0187	7
8	Elongation at break	0.23	0.12	0.0269	8

Table 4 Ranking of product indicators

№	Indicator	Normalized coefficients			Rank
		Ki	*Kq*	*K*	
1	Dynamic conformity	0.03	0.20	0.006	1
2	Tensile loading of seams	0.05	0.31	0.0155	3
3	Static conformity	0.07	0.20	0.014	2
4	Cost of the product	0.11	0.37	0.04125	6
5	The level of technical performance of the product, all available structural elements to the external perception	0.13	0.31	0.0403	5
6	Ease of usage	0.16	0.20	0.032	4
7	Guaranteed lifetime	0.21	0.37	0.07875	8
8	Lining availability	0.24	0.20	0.048	7

The coherence of expert opinions is estimated through the coefficient of concordance *W* [3], which is defined as a generalized correlation coefficient for a group of m experts. The algorithm for calculating the coefficient of concordance has the following sequence:

Determine the variance of DR estimates, the value of which is characterized by the variation between rank estimates in individual professionals:

$$DR = \sum_{i=1}^{i=n} \left\{ \sum_{j=1}^{j=m} x_{ij} - \frac{1}{2} m(n+1) \right\}^2 \quad (3)$$

where $\sum_{j=1}^{j=m} X_{ij}$ *is* the sum of the rankings for each i^{th} factor received from all j^{th} experts; $\frac{1}{2} m(n+1)$ is the average sum of ranks.

The DR value is maximal if all the experts ranked the same and is determined by the formula:

$$(DR)_{max} = \frac{1}{12} \cdot n \cdot m^2 \cdot (n^2 - 1) \quad (4)$$

We define the concordance coefficient W as the ratio of the actual value obtained to its maximum value:

$$W = \frac{DR}{(DR)_{max}} \quad (5)$$

Estimate the significance of the concordance coefficient using the table values of Pearson criterion χ^2. Based on the calculations, calculate the criterion:

$$\chi_c^2 = m \cdot W \cdot (n - 1) \quad (6)$$

It is necessary that the found value $\chi^2{}_p$ exceeds the table value, which is determined by the number of freedom degrees f and the probability level α:

$$\chi_c^2 \geq \chi_{tabl}^2 \qquad f = (n - 1) \quad (7)$$

The results of the calculation of the concordance coefficient for each of the three stages of ranking are given in Table 5. Table 5 shows the definition of the conformation coefficient for the three calculations:

variant 1 - calculation results in Table 2;

variant 2 - expert assessment of requirements to the material;

variant 3 - expert assessment of product requirements.

Table 5 Concordance coefficient

Estimated parameters	**Variant 1**	**Variant 2**	**Variant 3**
Experts m	12	12	12
Factors n	4	14	26
Estimated dispersion DR	566	24 570	145 314
Maximum dispersion DR_{max}	720	32 760	210 600
Concordance coefficient W	0.78	0.75	0.69
Pearson criterion χ^2	**28**	**117**	**207**

As it can be seen from Table 5, the values of the calculated concordance coefficients are in the range *W=0.69÷0.78* for ranking tasks of three groups of factors. Such values indicate a high level of coherence of experts' opinions. The calculated values of Pearson criterion χ^2_c exceed the table values of χ^2_{tabl}=6.25…37.65 at the significance level α=0.1 [9].

2.5 The new models of railroad conductors' uniforms

According to the rating results, the specialists of different directions in further development of uniform suits have selected a sufficient number of indicators (8 for materials and 8 for products) that meet the requirements of reliability, ergonomics and economy.

Based on the ranking results, the choice of materials has been justified. When choosing fabrics for outerwear and lining, their physical-mechanical (breaking loading) and hygienic (breath ability) are determined. It has been determined that it is advisable to use the fabric of article I1013-045 for manufacturing men's and women's suits. Raw material composition is 90% wool and 10% elastin; surface density 212 g/m^2; kind of weave - satin. All products include a lining of material 434 (Bosfor Nextile) with a surface density of 75 g/m^2, containing 50% viscose, 47% acrylic and 3% elastin.

The dominant quality indicators of material I1013-045 are: crease-resistance 0.53 grade; breaking loading - warp 524 N, weft 397 N; air permeability 368 dm^3/(m^2.s); the content of natural fibers in the raw material composition 90%, abrasion resistance 1100 cycles, colors resistance to chemical treatments, wet treatments, ultraviolet radiation, sweat action as 4 grades; water permeability 30 g/(m^2.s); relative elongation - warp and weft 1.5%.

New design and technological solutions of conductors' uniforms have been proposed, which take into account definite dominant indicators (Figure 1).

Static and dynamic conformities are ensured by further determining the increments of static and dynamic dimensional features. During the design, incremental dimensions have been calculated taking into account the basic working positions and movements of the conductors. Estimates of the dynamic increments of the corresponding static dimensional features have made it possible to establish that additional increments should be introduced in the increments for back to waist, back width, arm length to wrist, thigh measuring. Tolerances that take into account ergonomic requirements are taken as the basis when constructing a conductor uniform.

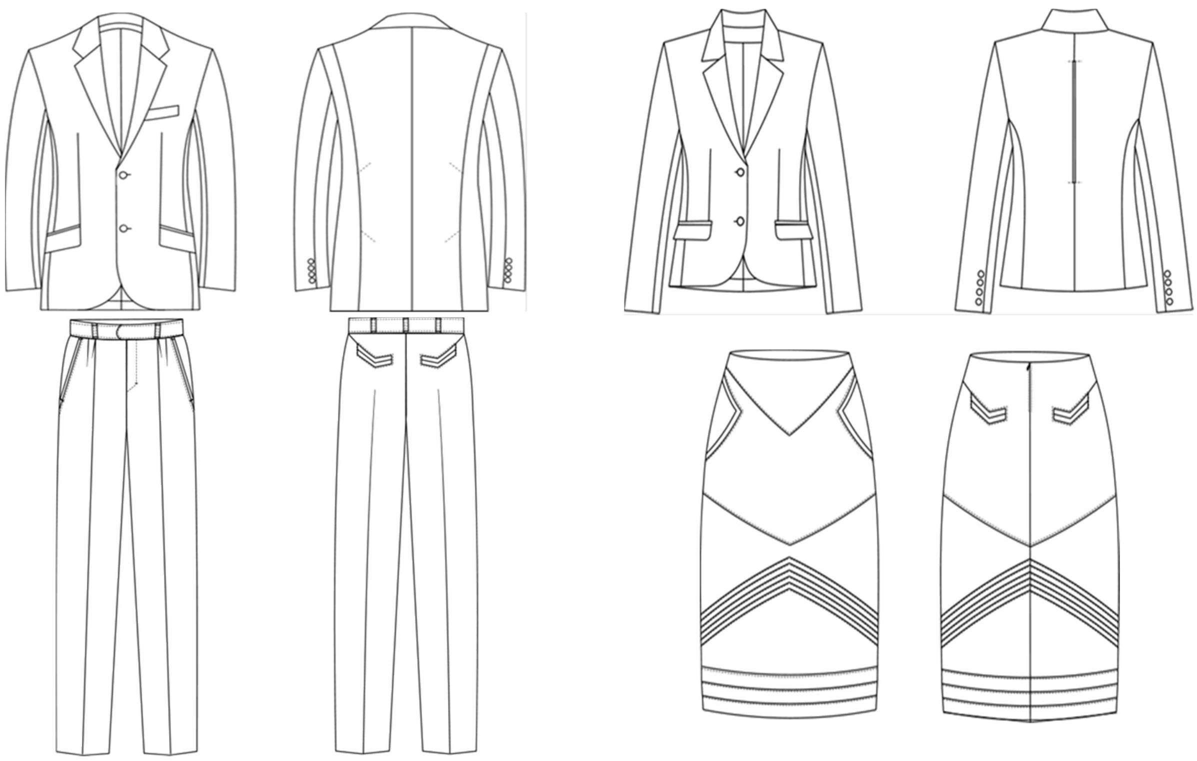


Figure 1 The general looks of the new suits

The absolute values of the tolerances are determined in accordance with the material indices and the design features of the shoulder and waist clothing. In the design of the women's jacket dynamic compliance is provided by the presence of a counter-fold at the back, in the men's jacket - two-sided folds from the shoulder to the waist. The technology of processing knots and elements of clothing through the use of reinforced threads and adhesive tapes has been improved. The guaranteed lifetime is increased up to 30 months. All products allow up to 15 cycles of dry cleaning.

3 CONCLUSIONS

The article deals with the development of advanced sets of conductors' uniforms of passenger rail transport, which have been developed on the basis of certain dominant requirements for materials, structures, manufacturing technologies and cost.

1. The requirements standardized and recommended by the consumers have been analyzed and their list has been compiled to the material, construction, manufacturing technology and economic indicators. It has been determined that while designing garments, the input information contains numerical indicators, statistics and factors that are not mathematically formalized.
2. Based on the conducted analysis, the nomenclature of indicators of conductors' uniforms of men's and women's clothing for shoulder (jacket and ladies' jacket) and waist (skirt and trousers) products has been proposed.
3. A careful analysis of the content task formulation, taking into account the specifics of designing uniforms, necessitated the modification of the original algorithm by the method of expert estimation. A method of ranking factors and indicators based on *normalized* weight coefficients in three stages has been proposed. In the first stage, the experts rank four factors that determine the requirements for material, structure, manufacturing technology and economic performance of the product. The second stage is the ranking of individual indicators of material and ready-made product. In the third stage, to estimate the reliability of the obtained results, the degree of concordance of experts' opinions has been estimated by the magnitude of the concordance coefficient.
4. According to the ranking results, dominant indicators for groups of factors have been established:
   - concerning the material - crease-resistance, breaking loading, air permeability, water resistance, the content of natural fibers in the raw material composition, abrasion resistance, colors resistance to chemical treatments, wet treatments, ultraviolet radiation, sweat action, relative elongation;

- concerning the structure - dynamic and static conformities, ease of usage of the product, lining availability;
- concerning the manufacturing technology - the breaking seams loading, the level of technical manufacturing of the product, all structural elements accessible to the external perception;
- economic - product cost, guaranteed lifetime.

5. The research obtained results were realized during the creation of advanced models of women's suit (ladies' jacket and skirt) and men's suit (jacket and pants).

4 REFERENCES

1. Kolosnichenko O.V., Ostapenko N.V., Kolosnichenko M.V.: The development of new forms of special clothes by design projecting methods, Vlakna a textil (Fibres and Textiles) 23(2), 2016, pp. 3-9
2. Pashkevich K.L.,. Kolosnichenko M.V, Ostapenko N.V.: Research of some physical and mechanical characteristics of suiting fabrics for designing the clothes, Vlakna a textil (Fibres and Textiles) 23(1), 2016, pp. 3-8
3. Prykhodko-Kononenko I.O., Kolosnichenko O.V., Ostapenko N.V., Vinnichuk M.S., Kolosnichenko M.V.: Research of topography of influence and classification of the requirements for uniform of passenger car attendants, Vlakna a textil (Fibres and Textiles) 24(2), 2017, pp. 11-17
4. Tretiakova L.D., Ostapenko N.V., Kolosnichenko M.V., Pashkevich K.L., Avramenko T.V.: Designing of rational structure of range of insulating protective clothing on the basis of the principles of transformation, Vlakna a textil (Fibres and Textiles) 23(4), 2016, pp. 27-35
5. Kolosnichenko M.V., Ostapenko N.V.: Hygiene clothing: Annotated lecture notes for students of "Design and Technology of garments" specialization "Designing garments" direction 6.051602 "Technology of light industry" full-time, KNUTD, Kyiv, 2012, 16 p., (in Ukrainian)
6. Pashkevich K., Yezhova O., Kolosnichenko M., Ostapenko N., Kolosnichenko E.: Designing of the complex forms of women's clothing, considering the former properties of the materials, Man-Made Textiles in India 46(1), 2018, pp. 372-380
7. Gutskova S.: Method of expert judgments, Litagenstvo, Moscow, 2011, 254 p., (in Russian)
8. Adler Y.R., Markova E., Granovsky Y.: Planning an experiment in the search for optimal channels, Science, Moscow, 1986, 286 p., (in Russian)
9. Alou N., Spenser J.: Probabilistic method, Binom, Moscow, 2011, 320 p., (in Russian)
10. Spiridonov A.A.: Planning the experiment, Mechanical Engineering, Moscow, 1988, 248 p., (in Russian)
11. Tretiakova L.: Numerical simulation and experimental study of electrostatic field near man with protective polymeric clothing, Universal Journal of Electrical and Electronic Engineering 5(1), 2017, pp. 20-26, DOI: 10.13189/ujeee.2017.050103
12. Pashkevich K., Kolosnichenko M., Yezhova O., Kolosnichenko O., Ostapenko N.: Study of properties of overcoating fabrics during design of women's clothes in different forms, Tekstilec 61(4), 2018, pp. 224-234
13. Yezhova O., Pashkevich K., Kolosnichenko M., Abramova O., Nazarchuk L.: Provision of the quality of decoration of semi-finished fashionable clothes, made of suiting fabrics with cotton content (denim type) Vlakna a textil (Fibres and Textiles) 25(4), 2018, pp. 94-102
14. Rubanka A.I., Ostapenko N.V., Rubanka M.M., Kolosnichenko O.V., Pashkevich K.L.: Experimental researches on determination of reliability indexes of heat-protective material, Vlakna a textil (Fibres and Textiles) 24(4), 2017, pp. 22-29

DESIGNING THE AUTHOR'S COLLECTION OF WOMEN'S CLOTHING WITH THE USE OF PAINTING AS THE SOURCE OF INSPIRATION

Larysa Krasniuk and Oleksandr Troyan

Khmelnytskyi National University, Department of Technology and Design of Garments
Instytuts'ka str. 11, 29016 Khmelnytskyi, Ukraine
krasnuklora@gmail.com; omtroyan@gmail.com

Abstract: *The search for ideas with the aim of creating new goods is an important problem of designer's projects. In this paper it is demonstrated that the sources of inspiration help designers to create elements and principles of the author's design. The major types of inspiration sources are determined, and the roles of the source of inspiration as well as its effect on the creative search for original ideas in clothing design are revealed. The purpose of this investigation is to elaborate the concept of the author's collection of women's clothing on the basis of application of paintings as the source of inspiration. Diverse techniques of transforming a particular inspiration source – a painting – from the sketch project to the ready-made article are suggested.*

Key words: *author's collection of clothing, sources of inspiration, transformation of the painting, print.*

1 INTRODUCTION

The competitiveness of the clothing industry production greatly depends on its attractiveness to customers as well as on the level of its artistic and designer development. One of the major ways of achieving competitiveness at the fashion market is a purpose-oriented and systemic costume design. Not only economic and technological factors but also fashion trends should be taken into consideration. Costume design is the response to the demands of the consumer society for aestheticization of its everyday life [1].

An important role in this process is played by the stimulation of creativeness in clothing design, as it is only an original creative thinking that can lead to significant results. In order to impart the artistic value to the created costume, it must satisfy the demands of harmony and contain an artistic image. Therefore, the designer must always follow the path of the colorful expressiveness of the costume. The use of the inspiration source is known to be one of the most efficient ways of making designer projects colorful and creative. It is exactly the source of inspiration which is the major and decisive factor of forming the stylistic, image-making and compositional characteristics of the designer's project [2].

The designer's development of the original clothing collection requires a thorough analysis of the source of inspiration. Also, it requires determining its major compositional characteristics for use in the images of the designed collection models [3-5]. The sources of inspiration for the designer to create new models of clothing are quite diverse. Each source possesses its peculiarities and its features which serve as a compositional basis for creating an individual costume image [6, 7]. The transformation of the inspiration source consists in selecting, rethinking and developing the chosen features and characteristics of the source with transferring them to the design object. Such transformation enables to create a unique and interesting artistic composition of the author's clothing collection

The researchers emphasize the fact that sources of inspiration are vital for the designer's creative process as the means for obtaining interesting ideas. They inspire designers to search for new landmarks in their art. However, it should be noted that no designer makes use and transforms the inspiration sources in the same way. Designers often demonstrate several methods of transformation used in their creative search [8]. Sometimes the final design of the object may not contain the features of the selected inspiration source [9].

The sources of inspiration can be either material (historic or folk costume, retro fashion, literary style or style of clothing, a famous designer's art, architecture, literary texts or works of decorative and applied art, natural objects), or nonmaterial (music, poetry, natural phenomena). Besides these traditional sources, designers can be inspired by antiquities, traveling, hikes and street fashion. Also, the designer's personal experience can serve as a source of inspiration. It is exactly this experience that can give excellent results in increasing creative ideas [10]. The author [11] states that the sources of inspiration are a form of knowledge having a decisive significance for the designer's art.

In the process of designing clothing collections the authors make use of not one but several sources of inspiration, without giving special preference to any of them. In such case the designers apply different methods and techniques of research and transformation of inspiration sources. In his investigation A. Payne [12] stresses that exactly this method of creating new clothing collections is the most successful.

One of the constant sources of inspiration of the designer's creative work is natural forms and natural motives [13]. Here one very important feature of the spatial structure and volume of the natural analog should be regarded – it is a general expediency of developing a natural form. That is why the investigation of natural forms enables to solve the problem of harmony of the functional and aesthetic aspects in the costume. The designers draw their ideas of harmony and beauty from nature, thus enriching the formal means of harmonization in search for the most expressive proportions, rhythm, symmetry and asymmetry, dynamic. The natural sources of inspiration are the objects surrounding people. Therefore, getting tired of different innovative technological ideas, the designers turn to natural analogs, again and again. While observing the world of nature, many designers experience the emotional associations of images which become the foundation for creating original clothing collections [14-16].

Another source of inspiration for designers to learn the harmonious unity of the costume and the environment is architecture. Studying architecture as the source of inspiration, the clothing designer, first of all, considers the characteristic lines of buildings – both internal which are related to proportions and correlation of parts, and also external which reflect the silhouette. As distinct from the architect who uses these elements of form creation in his/her art quite freely, the clothing designer is relatively limited in his/her work by the people's figure parameters. This peculiarity distinguishes the art of clothing designer from the architect's art [17].

Painting occupies a special place among various inspiration sources. We mean the works created by professional artists. Modern fashion analysts bring painting to the foreground as the source of inspiration for clothing designers [1, 7, 18]. The images created by the painters on their canvases possess special meaning for the designer. In their collections the clothing designers make a wide use of the motives of paintings by the great artists, in particular color, plastic lines, the principle of the painting composition, emotions. The art of painting can inspire the designer to recreate a perfect form, an incredible color or an interesting image in the costume.

The article [19] suggests an idea of the symbiosis of the contemporary art and the creations of the outstanding designers. O. Lahoda stresses that designing of clothing can be justly referred to as one of the spheres of contemporary art. The author also analyses the process of interaction between the artist and the designer which is particularly interesting for connoisseurs of literary texts and designer clothing collections.

Speaking about painting, it is impossible not recall the well-known French designer Yves Saint-Laurent. The maestro drew inspiration for his clothing collections from the paintings by Picasso, Van Gogh and Warhol. And his collection created on the basis of motives from the works by the Dutch abstract painting Piet Mondrian was a great success in its time. Until today the dresses from this collection are among the most famous designer works of the 1960s, both in fashion and in the art of searching for new ideas [20].

The Italian couturiers Dolce & Gabbana in their collection of winter-autumn 2013-2014 drew their inspiration from the world-known mosaic art of the Byzantine Empire. The models created in the imperial golden and purple colors and adorned with precious stones, icons and crosses are supplemented by incredibly beautiful decorations, exquisite footwear and accessories [21].

The supreme goal of art is the comprehensive development of personality, the formation of people's demands and values. Therefore, art, in particular painting, is capable of making scientific and technological progress more spiritual, enriching it with humanistic ideas and becoming a really inexhaustible source of inspiration for the fashion creators. So the aim of this research is to develop the creative concept for the author's collection of women's clothing on the basis of using painting as the source of inspiration.

2 METHODOLOGY

In this paper the source of inspiration is the painting called "The birth of planets". This work is performed in the technique of intuitive painting (Figure 1). The author of the picture is a young Ukrainian artist Svitlana Melnychuk.

The essence of the intuitive painting technique which is also called the method of the right cerebral hemisphere painting lies in revealing the person's creative potential by means of awakening the internal knowledge and the ability of listening to oneself. The technique of intuitive painting is one of the modern trends in teaching image-making and creative thinking in art. The method of the right cerebral hemisphere painting was scientifically substantiated by Roger Walcott Sperry who received the Nobel Prize in 1981 for his achievements in studying the operation of the brain, for the discoveries concerning the functions of specialization of the cerebral hemispheres [22].

Figure 1 The source of inspiration – the painting "The birth of planets"

The analysis of clothing collections created by the well-known designers who used the motives of paintings revealed that the major devices of transforming the painting as the source of inspiration are the following:

1. the transfer of the painting image onto clothing;
2. the transfer of the colors of the painting;
3. the transfer of the characteristic lines, proportions, geometrical forms onto clothing;
4. the use of the painting individual fragments for decorating clothing.

According to the aim of the paper, its main task is the transformation of the painting canvas, i.e. transferring its fragments onto clothing. The design of each model of the collection includes the following stages: first, the elaboration of the sketch of the model; second, the selection of a certain painting fragment to be transferred onto clothing.

The complicated character of the transformation process consisted in the fact that the painting has a plane composition which is inserted in the rectangular format while clothing is a voluminous object and possesses a complex spatial form. That is why, in the process of designing, such fragments of paintings were selected which made it possible to create a harmonious spatial composition of every article of clothing in particular and of every model as well as the whole collection in general.

Besides, every part of the collection articles has its scale. Therefore, another task of the investigation was "to insert" a fragment of the painting into the scale of the article such as a skirt, a waistcoat, a dress, or in small details, e.g. a pocket. For this purpose the computer technology was applied which included the following stages. First, a separate fragment of the painting was taken; then, an artistic-compositional search was performed when the selected fragment was extended, reduced, or used in its natural size.

To achieve this goal, in accordance with the sketch design of the collection, the constructions of all articles of the collection were created. Then the patterns of parts were elaborated. After that, in accordance with the pattern sizes, certain fragments of the painting were selected in the Photoshop graphic editor. At the next stage, the selected painting fragments were transferred onto the parts of the articles using the method of sublimation print. And finally, the clothing parts were sewn with the help of the sewing equipment.

The choice of the materials is an important factor influencing the design of garments [23, 24]. Fabrics made of synthetic fibers were used for printing, as fabrics with not less than 80% of synthetic fibers are recommended for high-quality sublimation printing. Therefore, satin fabric (100% polyester) was used for skirts, pockets, decorations and accessories of the models of the collection, and chiffon made of polyester fibers was used for the central dress.

Figures 2-5 demonstrate different techniques of transferring the painting fragments onto the articles of the collection. For example, Figure 2 demonstrates the transformation of the painting fragment into the waistcoat patch pocket. In order to create this model, the painting fragment was transferred onto the waistcoat patch pocket of natural size. The fragment was selected taking into consideration the spot sizes and the color harmony so that the print might look harmonious on a relatively small size pocket.

Figure 2 The transformation of the painting fragment into the waistcoat pocket part

Figures 3 and 4 demonstrate the stages of transforming the painting fragments into the parts of a two-seamed skirt (Figure 3 – a straight silhouette, Figure 4 – a trapezium-type silhouette). Firstly, the parameters of the skirt parts were set in the Photoshop software. Secondly, a necessary painting fragment was selected by means of selection and stretching.

Figure 3 The transformation of the painting fragment into the skirt of a straight silhouette

The fragment was selected considering the fact that the skirt shape should look perfect from the viewpoint of composition, ornamentation and color. It was also essential not to destroy the color spots depicted on the painting so that the article composition should look integral. The selected fragment of the painting for the trapezium-type skirt was turned to 90 degrees clockwise and stretched vertically (Figure 4). The back and front parts of both skirts are created in the mirror reflection.

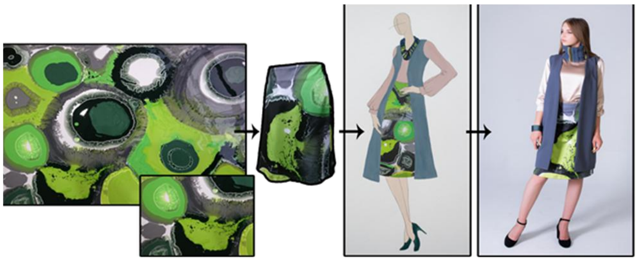


Figure 4 The transformation of the painting fragment into the skirt of a trapezium-type silhouette

Different techniques of transformations are applied in the skirt model shown on figure 5. The peculiarity of developing this model lies in the fact that the printer fulfilling the sublimation print can produce the print of a particular size. Therefore the skirt model was elaborated with the consideration of such peculiarity, namely: the skirt has a cut-out bodice, the skirt of the dress consists of front and back parts, the skirt bottom has a flounce. While elaborating the skirt design, the technique of stretching the painting was used, but with a smaller stretching coefficient than in the cut-out bodice of the dress. In order to create a print on the bodice, a necessary painting fragment was stretched making accent on the left shoulder. It enabled to emphasize the compositional center of the whole model. In order to make a print on the dress skirt, the whole painting was used. The front and back parts of the skirt were performed in the mirror reflection. The painting fragment for creating the skirt flounce was stretched lest this section should blend with print of the skirt. On the contrary, this section was to complete the skirt from the compositional point of view.

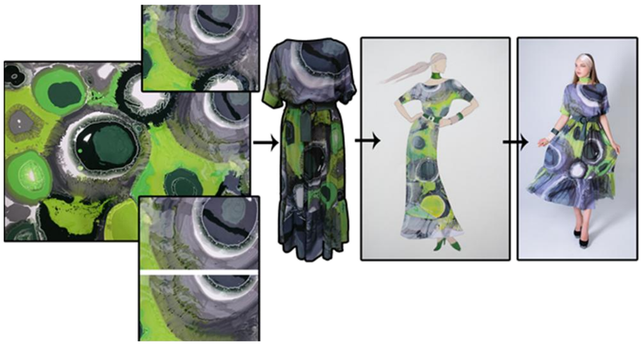


Figure 5 The transformation of the inspiration source into the dress

3 RESULTS AND DISCUSSION

As a result of designing, the artistic and compositional decision of the author's collection of women's clothing under the name "The birth of planets" was elaborated. The source of inspiration for this collection was the work of painting under the same name. The original character of the artistic and compositional decision lies in the fact that the prints on the articles of clothing remind fantastic space objects creating unique color range of the articles.

The main feature of the collection is its integrity which is achieved by making the models in a common stylistic decision. Such decision envisages the realization of the author's concept in every model of the collection inspired by paintings. That is, the selected artistic and compositional decision, namely the print based on the motives of the painting "The birth of planets", is repeated in each model in a different way. Thus, diverse possible variants of developing the author's idea have been used in the articles of the collection (Figure 6).

The integrity of the compositional elaboration of the collection is achieved by the presence of a clearly expressed compositional center represented by the dress model. This model embodies the main author's idea of the collection, while the other components of the collection complement the main idea. The collection is also characterized by the unity of color effect. The tonal and color center of the collection is emphasized in the central model, while the other models contribute to the creation of the tonal and color range. The connection between the models is achieved due to the identity and nuance of the color range, the nuance of lines and the contrast of forms.

Figure 6 The author's collection of women's clothing with the use of paintings as the source of inspiration

The fragments of the painting vary in size and are located on clothing to show the development of the idea - from small fragments in the lateral models, to large spaces that fill the details of clothes (for example, parts of skirt) and to the central model, which is the main focus of the collection. Such placing of clothes details allows you to create a harmonious composition of the collection and get a wavy spatial curved line, which gives the collection dynamism and special sophistication.

The models of the collection are interconnected by materials. For example, the gray fabric was used to make vests, cardigans and shorts; beige, green and black silk was chosen for blouses. A number of models of clothes in the collection have one constructive basis, for example, a cardigan and a vest, trousers and shorts, skirts and all blouses. This side of choicing materials and construction makes it possible to introduce the models of the collection into industrial production, which will help to update and expand the assortment of garment factories and fill them with original products.

Thus, the result of our work is the creation of the author's collection of women's clothing by means of transformation of the painting "The birth of planets". Figure 6 demonstrates the collection of articles of clothing created by different techniques of transforming this painting as the source of inspiration.

4 CONCLUSIONS

It is determined that the major techniques of transforming the painting source of inspiration are: the transfer of the painting image onto clothing; the transfer of the colors of the painting; the transfer of the characteristic lines, proportions, geometrical forms onto clothing; the use of the painting individual fragments for decorating clothing. The creative concept of the author's collection of women's clothing under the name "The birth of planets" has been developed where the painting under the same name was used as the source of inspiration. The transformation of the painting into the models of the author's collection of women's clothing has been performed by applying the techniques of partial or complete transfer of the painting fragments, stretching and mirror reflection. It is revealed that the works of painting are rather efficient and expedient sources of inspiration for searching for new ideas and producing creative garments.

The single concept and harmonious image are confirmed by models of the collection of women's clothing with the introduced dominant features of the source of inspiration, namely the painting "The birth of planets".

Thus, in the work were defined the artistic and compositional principles of designing new clothing models which based on a combination of paintings and sublimations printing. The use of this methodology will intensify the process of designing modern high-quality clothing which is oriented on social and industrial interests and cultural and aesthetic needs of society, will improve its aesthetic characteristic, and, as a result, the competitiveness of production.

5 REFERENCES

1. Ieremenko I.: Modern costume design: main directions and trends, Bulletin of Kharkov State Academy of Design and Arts 6, 2016, pp. 14-17 (in Ukrainian)
2. Halskov K.: Kinds of inspiration in interaction design, Digital Creativity 21(3), 2010, pp. 186-196, https://doi.org/10.1080/14626268.2010.502236
3. Jung S.L., Jirousek C.: The development of design ideas in the early apparel design process: a pilot study, International Journal of Fashion Design, Technology and Education 8(2), 2015, pp. 151-161, https://doi.org/10.1080/17543266.2015.1026411
4. Eckert C., Stacey M.: Sources of inspiration: a language of design, Design Studies 21, 2000, pp. 523-538, https://doi.org/10.1016/S0142-694X(00)00022-3
5. Ostapenko N.V., Verba S.V., Lutsker T.V., Antonyuzhenko A.Y., Avramenko T.V.: Design-development of collection of women's clothing using exclusive prints, Art and Design 1(01), 2018, pp. 114-125 (in Ukrainian)
6. Halskov K., Dalsgaard P.: The emergence of ideas: the interplay between sources of inspiration and emerging design concepts, CoCreation in Design and the Arts 3, 2007, pp. 185-211
7. Mete F.: The creative role of sources of inspiration in clothing design, International Journal of Clothing Science and Technology 18, 2006, pp. 278-293, https://doi.org/10.1108/09556220610668509
8. Strickfaden M., Stafiniak L., Terzin T.: Inspired and inspiring textile designers understanding. creativity through influence and inspiration, Clothing and Textiles Research Journal 3, 2015, pp. 213-228

9. Dazkir S.S., Mower J.M., Reddy-Best K.L., Pedersen E.L.: An exploration of design students' inspiration process, College Student Journal 47, 2013, pp. 394-404
10. Hwang Ja-Young: Fashion designers' decision-making process: The influence of cultural values and personal experience in the creative design process, Degree of doctor of philosophy, Ames, Iowa, 2013, 171 p.
11. Halskov K.: Kinds of inspiration in interaction design, Digital Creativity 21(3), 2010, pp. 186-196, https://doi.org/10.1080/14626268.2010.502236
12. Payne A.: Inspiration sources for Australian fast fashion design: Tapping into consumer desire, Journal of Fashion Marketing and Management: An International Journal 20(2), 2016, pp. 191-207, https://eprints.qut.edu.au/95228/
13. Syamwil R, Sugiarto E., Rohidi T.R., Nurrohmah S.: Weeds as a source of development idea on batik motive, Vlákna a textil (Fibres and Textiles) 26(2), 2019, pp. 69-73
14. Krasniuk L.V., Matrofailo M.V., Troyan O.M.: Design of author couture collection in eco-style with the use of printing technique, Art and Design 3(3), 2018, pp. 96-106 (in Ukrainian)
15. Krasniuk L.V., Troyan O.M., Turzhanska K.M., Hlushko Y.S.: Design of the author's collection of clothes in romantic style, Art and Design 3(7), 2019, pp. 77-88 (in Ukrainian)
16. Shokruta O.S., Ostapenko N.V., Kredenets N.D., Lucker T.V.: Design-development of collection of models of women's clothing, Bulletin of Khmelnitskyi National University 6(267), 2018, Part 2, pp. 68-73 (in Ukrainian)
17. Kolosnichenko O.V., Pryhodko-Kononenko I.O., Ostapenko N.V.: Design of new articles of clothing using principles of contemporary style directions in architecture and art, Vlákna a textil (Fibres and Textiles) 23(1), 2016, pp. 18-23
18. Vodzinska O., Kislenko K.: Art and painting in works as a creative source in the design of the industrial clothes collection, Bulletin of Khmelnitskyi National University 5(265), 2018, pp. 234-241 (in Ukrainian)
19. Lahoda O.: Representative potential of designer practices in symbiosis of art and fashion, Art and Design 3(3), 2018, 107-119 (in Ukrainian)
20. Sari S., Kodaman L.: Piet Mondrian effect in Yves Saint Laurent clothing, Website: https://dergipark.org.tr/en/download/article-file/275341
21. Phelps N.: Fall 2013 Ready-to-wear Dolce & Gabbana, Website of journal VOGUE: https://www.vogue.com/fashion-shows/fall-2013-ready-to-wear/dolce-gabbana
22. Sperry R.W.: Facts. The Nobel prize, Website of the Nobel Committee: https://www.nobelprize.org/prizes/medicine/1981/sperry/facts/
23. Pashkevich K., Kolosnichenko M., Yezhova O., Kolosnichenko O., Ostapenko N.: Study of properties of overcoating fabrics during design of women's clothes in different forms, Tekstilec 61(4), 2018, pp. 224-234, DOI: 10.14502/Tekstilec2018.61.224-234
24. Yezhova O., Pashkevich K., Kolosnichenko M., Abramova O., Nazarchuk L.: Provision of the quality of decoration of semi-finished fashionable clothes, made of suiting fabrics with cotton content (denim type), Vlákna a textil (Fibres and Textiles) 25(4), 2018, pp. 94-102

DEVELOPMENT OF INNOVATIVE TECHNOLOGIES FOR DESIGN-FORMATION OF WOMEN'S HATS FROM FABRIC IN LAWE

Nikolay Kushevskiy[1], Olena Yakymchuk[2], Roman Romanenko[3], Oleh Polishchuk[1], Olena Palienko[3], Svetlana Matviichuk[4], Nataliia Boksha[4], Svitlana Lozovenko[5], Larysa Bilotska[5] and Oksana Vodzinska[5]

[1]Khmelnytskyi National University, Instytutska Street 11, Khmelnytskyi, Ukraine
[2]Kherson National Technical University, Berislav highway 24, Kherson, Ukraine
[3]Kyiv National University of Trade and Economics, Kyoto Street 19, Kyiv, Ukraine
[4]Mukachevo State University, Uzhhorodska Street 26, Mukachevo, Ukraine
[5]Kyiv National University of Technologies and Design, Nemirovich-Danchenko Street 2, Kyiv, Ukraine
olenayakymchuk03@gmail.com

Abstract: *The article is devoted to the development of innovative technologies of design-forming of women's hats from fabrics in a special working environment. It is suggested to use water as a working environment, which creates a different forming effort. Seven original methods of hydroforming with the use of LAWE have been developed to ensure the quality design-formation of the three-dimensional parts of women's fabric hats. To test and implement the developed methods, appropriate experimental equipment is designed and features of its work are given. Based on the experimental studies, it is determined the optimal parameters for forming volumetric details of women's hats for each method. Examples of formed hats on the specified equipment are given. The prospects of further researches for work improvement of the developed equipment are offered.*

Keywords: *LAWE, women's hats, formation of the details from the fabric, methods of formation, pressure of LAWE, forming element, forming chamber.*

1 INTRODUCTION

Today, a significant stylistic disadvantage of suit forming is imbalance of consumer ensemble. The noted problem is arising as a result of limited set of basic artistic techniques for harmonizing the image. A significant role in visualizing of the idea of a costume is played by layout of the form, color and texture of its constituent elements [1, 2]. A main goal in this case is integrity of perception of created artistic and aesthetic image, which cannot be achieved without a harmonious combination of materials.

In the manufacture of outerwear, fabrics are in great demand, unlike more expensive leather, fur and materials with a film coating. Headset completion can be either embroidered or formed headgear made from fabric [3].

Light industry market fully meets the demand of consumers for hats made from fur, leather and felt. Also hats are sewn from fabrics, which are formed in a constructive way [4]. But for manufacture of these products, multi-operational and energy-intensive technologies are used. At the same time, there are no models of formed headwear, made from fabrics that are often the reason for headdress not to match the style, color and texture of the coat, dress and suit. The development of a new technology for forming parts of hats from fabrics needs a unique scientific method, which is based on an integrated approach to the system of technological preparation of production and design of highly productive equipment [5].

The processes of form creation and the form fixing of clothing parts made from polymer materials are largely determined by deformation-relaxation processes that occur in material under influence of various external factors, including mechanical load. The required strain can be achieved by extension, compression, bending and shear [6, 7]. The most difficult in the technology of clothing parts forming is a method of obtaining a three-dimensional shape, which approaches the surface of spherical segment. The complexity is primarily due to anisotropy of fabrics properties, which manifests in unequal directions of material along the warp, weft and at an angle to them during deformation. In this case, a surface form obtained by a mechanical method is different from segment of forming spherical organ [8]. Thus, the final shape of a part, obtained in the forming process, can be different from the shape of forming organ. The forming methods (planar or volumetric), magnitude and direction of deformation forces, nature of deformation have a great influence on the deformation mechanism in most of fabrics with “rough” structure.

A number of scientists [5-7] studied deformation properties of fabrics under the action of a flexible membrane and pressed on a hemispherical surface. The authors of [5-7] found that giving deformations to a textile material on a volumetric form is more difficult process, than on a plane one. In addition, deformation of the fabric on volumetric form will be different in the upper part of hemisphere and on its edges. That is, deformation is uneven over the entire area. As a result of research it was found, that upon action on the fabric of deformation in form of a load of pulsating character, which is formed by compressed air on the surface of hemisphere, there is a uniform deformation of the fabric (textile material) in two directions: warp and weft. That is, it can be argued that this type of load allows providing maximum activity of “rough” and “thin” structure of the fabric.

Based on this, it is possible to put forward the hypothesis that wet heat treatment (WHT), in its classical form, is advisable to modify to achieve the goals of forming hats. As the main factors of WHT process are moisture, mechanical force and temperature, when applying dynamic methods, the last factor, namely temperature, can be eliminated, which will also significantly reduce energy consumption of the process.

Design of forming parts of clothes can be carried out in a static, dynamic and centrifugal field using different equipment [9, 10]. Some forming methods take into account the protective properties of the materials [11]. In accordance with this, there are traditional and non-traditional methods of forming parts of clothes. Traditional forming methods include those, which are characterized by the action of static loads: use of irons, presses and steam-air mannequins.

The most common way of forming parts of hats under static loads is by pressing on press-forms [1, 4, 8]. The design consists of two parts, one of which is movable (punch), and the other is stationary (matrix). When press-form is closed, a gap between die and punch determines a final quality of formed product. Discrepancies between punch and die, and low activity of “rough” structure of material are disadvantages of this forming method.

The Widespread WHT for clothes also uses a variety of irons and presses. The pressure on semi-finished product, which is processed, is provided by a weight of iron and performer’s effort. When using this method, it is difficult to withstand necessary processing modes and obtain necessary level of quality of forming operations. From the above, it can be concluded that the use of traditional methods in clothes forming has certain disadvantages [4, 5, 8]:

- providing unequal pressure on textile materials with surfaces of press pillows and soles of irons;
- difficulty in reconstruction of the form conformity;
- combination of upper and lower press pillows;
- application of significant mechanical load on a fabric due to the action of press pillows or iron mass;
- the use of the same type of press pillows of different full-size groups for forming parts of clothes;
- las formation on the surface of material;
- lack of activity of the "rough" structure of textile materials and, as a result, a slight change in network of angles.

Taking into account the given disadvantages of traditional methods, it is appropriate to search for innovative methods of forming three-dimensional parts of clothes from textile materials in the field of dynamic forces, which to some extent departs from the classical WHT.

There are some works in the field of forming which take into account maximum of textile materials properties, including deformation. Their purpose is to provide accurately a designed headgear form and disadvantages of classic forming methods.

In this case, deformation of polymeric material can be performed in different working environments, when using different forming forces, in different planes, with different placement of forming element to the direction of deformation force.

Hydro-jet technology of forming details of women's hats made of textile materials is widely used today [12-14]. It is based on the action of a water jet on textile material under high pressure [15]. Due to the use of a special nozzle, considerable effort can be made in forming parts of various shapes [16]. The advantage of this technology is the ability to form parts of various shapes and layered of the fabrics [17]. However, due to the action of considerable efforts on textile materials, the quality of finished products deteriorates, which has a negative effect on their suitability and usability. These technologies do not fully provide the necessary characteristics of women's hats. Their formation is complex and requires the solution of many of technological tasks and problems. Thus, there is a need to develop innovative design technologies for the formation of women's hats made of fabrics.

2 EXPERIMENTAL

2.1 Developed of LAWE methods

One of the authors of the article, Professor Nikolay Kushevskiy, proposed to use water as a working environment, which, under the influence of external mechanical forces, creates a different formative effort. This environment is known as the Liquid-Active Working Environment (LAWE). A team of scientists, led by Professor Nikolay Kushevskiy, developed a number of ways to hydroforming the three-dimensional details of clothing, which allows expanding the design of the range of relevant industries. These methods are based on the plastic force formation of textile material in LAWE. To do this, a perforated forming element is used, on which the fabric is laid and secured with a clamping ring.

Then, the forming element, with the part attached to it, is immersed in the LAWE and the forming process is carried out. The criteria for evaluation of the quality of the formed part are its maximum height and degree of relaxation.

Seven original methods of hydroforming with the use of LAWE have been developed to ensure the quality design of the volumetric details of women's fabric hats. Appropriate experimental equipment is designed in the material for testing and implementation of the developed methods. Below is a description of each of the proposed methods.

1. Hydromechanical method of forming

With this method, the forming of the details of women's hats in three-dimensional shape is carried as follows (Figure 1): due to the work of the activator in the chamber, there appear forming vortices LAWE, which act on the fabric, fixed on the surface of the forming element.

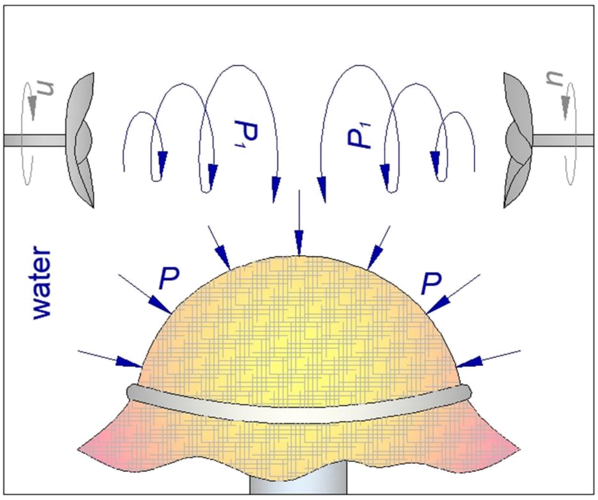


Figure 1 The action of forming loads with the hydromechanical method

The optimal parameters of the forming process are: distance from the forming element to the activator H_{act}=22 mm; rotation speed of the shaft with the activator n=3600 rpm; height of the LAWE column in the forming chamber h=100 mm; forming time t=300 s.

2. Pneumo-liquid forming method

In this case, the forming by a two-phase diffuse flow involves the use of air and LAWE flows as a force field. The compressor supplies a stream of air that is mixed with the LAWE in the forming chamber. For this purpose, a special jet is used. As a result, there is a sputtering of the LAWE onto the part of the fabric fixed to the forming element. The regulation of the kinetic energy of the two-phase flow comes from an increase-decrease in the pressure of the LAWE. This improves the dispersibility of the liquid, which as a result of combination with air has a finely dispersed state.

As a result, the penetration of the two-phase flow into the fabric structure is improved and catalyzed. As a result of the experiments, the optimal values of the parameters of the pneumo-fluidic forming (Figure 2) were obtained: the pressure of the air-water mixture P=0.12-0.16 MPa; distance from the nozzle end to the highest point of the forming element H=120-140 mm; forming time t=150-180 s.

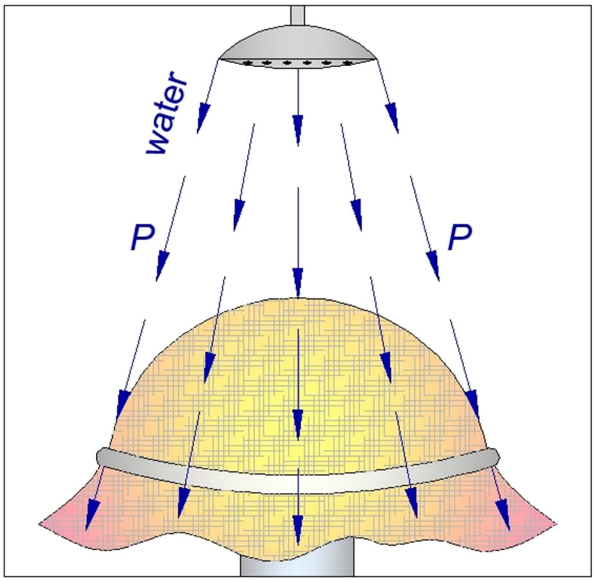


Figure 2 The action of forming loads with pneumo-liquid method

3. Hydro-jet forming method

The formation of the volumetric part occurs in a working chamber filled with LAWE due to the action of the flooded liquid jet (Figure 3).

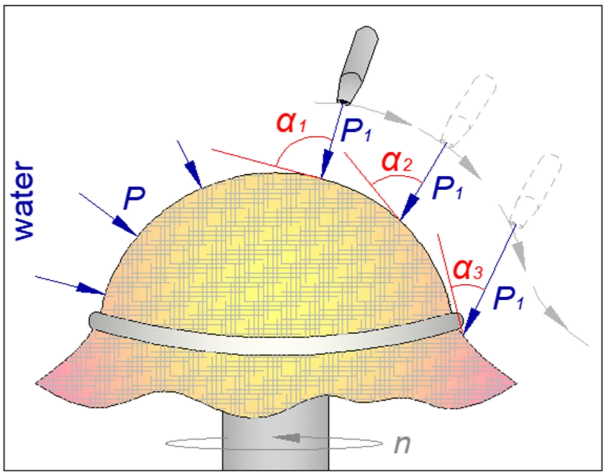


Figure 3 The action of forming loads with the hydrostream method

In the process of forming the end of the jet-forming nozzle automatically moves from the upper point to the bottom of the part. In this case, it is found at a given distance from the surface of the part and outlines a similar scaled figure of its contour. The forming element, with the part attached to it, is conditionally divided into five main sections. In each of these sections, the jet-forming nozzle further changes the angle of attack on the fabric during movement. This allows you to orient the fabric optimally during formation on the forming element. To ensure that the entire area of the part is covered by the active contact area with the controlled submerged hydro-jet, the forming element rotates about its axis. Another important factor in hydro-jet forming is the distance from the end of the jet-forming nozzle to the surface of the fabric. This value can also be changed automatically depending on the configuration of the part. The result is a different jet pressure on the surface of the part, which allows less catalyzing or inhibiting the forming process. The centrifugal loads, caused by the rotation of the forming element about its axis and the pressure of the LAWE column are also involved in the forming process. The automatization of the process is carried out by using an original computer programme and a programmed microcontroller.

The optimum parameters for hydraulic-jet forming are: pressure LAWE P=0.1-0.15 MPa; the area of the outlet of the jet forming nozzle S_{noz}=3.53 mm^2; distance from the end of the nozzle to the surface of the part l=5 mm; the rotation frequency of the shaft with the forming element and the part attached to it n=300 rpm; forming time t=140-180 s.

4. Hydrocentric forming method

With this method of molding in a chamber filled with LAWE, at the same time are found from two to four diametrically opposite forming elements (Figure 4). These elements are attached to the fabric of the hats. The forming chamber has a similar to a drum shape.

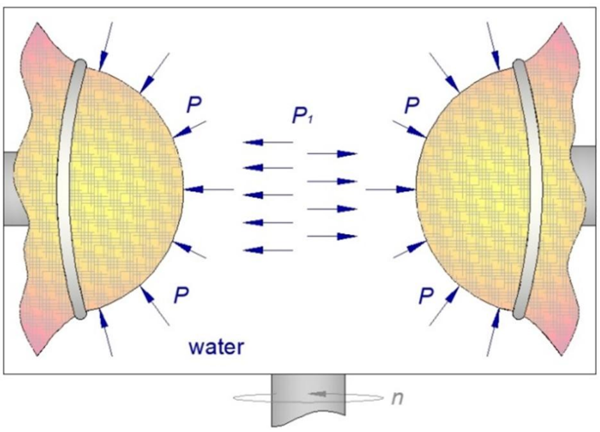


Figure 4 The action of forming loads with the hydro-centrifugal method

The main forming effort lies in the centrifugal force and circular flow of the LAWE. It occurs as a result of the rotation of the central shaft of the drum. Efforts press the fabric against the walls of the molding elements, intensely seeping it into LAWE. The optimum parameters of formation in the field of centrifugal forces are: the rotation frequency of the center shaft n=600 rpm; forming time t=120-160 s.

5. Hydraulic forming method

This method of formation involves securing of the fabric and forming element under the stage of the forming chamber (Figure 5).

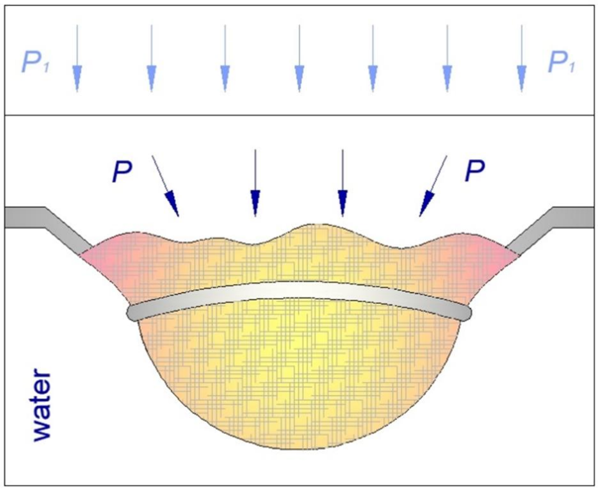


Figure 5 The action of forming loads in the hydraulic method

There are two efforts for fabric with the hydraulic method of formation of three-dimensional of hats. One of them is more intense - the pressure of the LAWE column, which acts on top P with the additional load P_1. There is no additional effort below. In this case, the process of volumetric mass transfer of LAWE to the "rough" fabric structure is performed. It promotes considerable plasticization of textile fibres.

As a result, the quality of forming improves. The nature of the forming effort is rather non-dynamic, due to its basic nature and the placement of the part below the surface of the forming element. The optimum modes for hydraulic forming under the action of LAWE pressure are: LAWE pressure P=0.13 MPa; forming time t=64 s.

6. Vacuum-liquid forming method

In this case, the main forming effort is the pressure of the LAWE column P on the fabric of the workpiece. The forming load that acts on the bottom of the fabric is vacuum pressure. As a result, LAWE filtration through the fabric occurs. In this way, the fabric of the part is placed under the forming surface. This is due to the specificity of the use of vacuum pressure.

The nature of the forming effort is quite stable. This method can be used in the formation of three-dimensional parts of women's hats, which require average indicators of fabricability. The optimal parameters of vacuum-liquid forming under the action of vacuum pressure are: vacuum pressure *V*=0.02-0.04 MPa; forming time *t*=64 s (Figure 6).

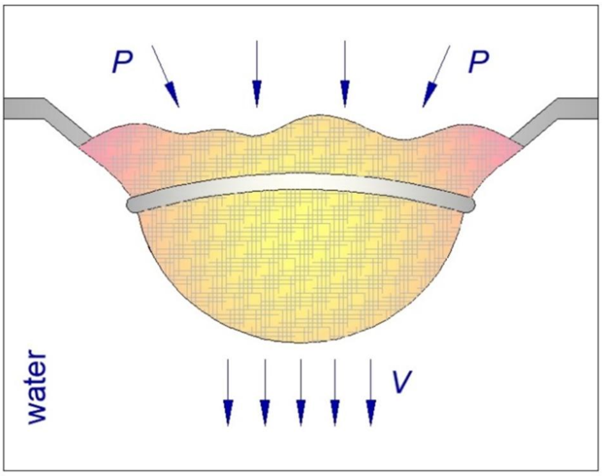


Figure 6 The effect of forming loads with a vacuum-liquid method

7. Hydro-vacuum forming method

This method involves the action of two forming loads on the fabric of the workpiece (Figure 7).

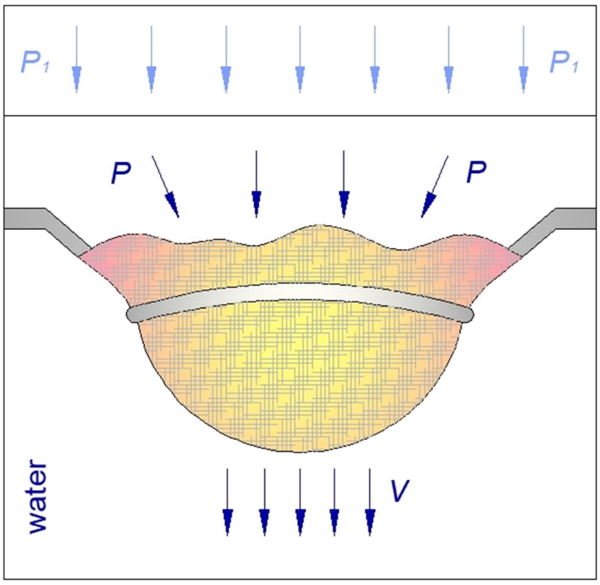


Figure 7 The effect of forming loads with the hydro-vacuum method

The forming forces, that acting on the top of the fabric part are the pressure of the LAWE column *P* with the additional load P_1. In the bottom is the vacuum pressure *V*, which also acts as a forming force. In this way, significant plasticization of the textile fibres of the part is found due to the volumetric mass transfer of LAWE to their macromolecules. The forming is performed under the plane of the forming element on which the fabric is fixed. Optimal values of the parameters of hydro-vacuum forming under the action of LAWE pressure and vacuum pressure: LAWE pressure *P*=0.22 MPa; vacuum pressure *V*=0.022 MPa; forming time *t*=140 s.

The developed technologies provide formation of a single layer of material. This is due the feature of mobility of fabric rough structure in the process of LAWE forming, by changing the network angles between the warp and weft threads. With increasing the number of fabric layers of headdress details, the optimal value of the network angle change in areas with a complex configuration is not provided. For researches were used a samples of fabrics with a diameter *d*=160 mm. This size is response to the economic aspect of technology and the proportional scale of the hat in full size.

2.2 Materials

When forming volumetric details of hats, it is necessary to take into account the physic-mechanical and physic-chemical properties of the material.

Seamless formation of volumetric details was performed by acting on the rough and thin structure of the fabric. The effect on rough structure of the fabric includes draping and shifting the angle between the systems of warp and weft threads. The methods of action on the thin structure are wet-heat treatment. They depend on the structural characteristics of the fabric. At the same time, it is necessary to use fabrics which provide mobility of threads and necessary deformation of a cell of the fabric, formed by threads of warp and weft. The paradox of the moment is determined by the fact, that with significant mobility it is need to provide a stable fixation of the detail form. Among of all existing textile fibers, wool fibers are the best option. Due to their structural construction and the presence on their surface of scales, the adhesion between the fibers is greatly increased. This allows to get a stable volumetric form. Therefore, the woollen fabrics of the suit and coat group were used to form volumetric details of the hats.

The ability to form improves with increasing fabric draping. Its degree depends on the weight and softness of material. Increasing the surface density of the fabric, weight, length of overlap of weaves and reducing the thickness contributes to improve draping. Fabrics made from plant fibers have the worst drapery, and animal - better. Stiffness is inversely proportional to the fabric draping. It increases with decreasing drapery.

The second argument for choosing woollen fabrics is to expand the possibilities of designing hats that are in harmony with clothing. The use of fabric, rather than felt or knitwear, will allow to compositionally combine all the elements of the costume.

3 suit fabrics (samples 1-3) and 3 coat fabrics (samples 4-6) were selected for the research. Fibrous composition of suit fabrics: 100% wool, coat 78% wool, 22% polyester. In the study it is taken into account a necessary structural characteristics of the fabrics, that effect on their ability to formation and form fixing: binding; binding coefficient F_1; connectivity coefficient C; filling coefficient F_2; spinning system; linear density of warp threads T_{wp} and weft T_{wf} [tex]; number of threads per 10 cm of fabric (warp P_{wp} and weft P_{wf}); surface density M_s [g/m^2]; thickness of fabric T_f [mm]; stiffness of fabric S [μH.cm^2] (warp S_{wp} and weft S_{wf}); drape coefficient Kd (warp Kd_{wp} and weft Kd_{wf}). The system of spinning of costume fabrics is comb, and coat - apparatus. The studied fabrics have the following values of structural characteristics:

Sample 1: twill binding 2/2; F_1=4; C=5.5; F_2=0.6; T_{wp}=25x2 tex; T_{wf}=25x2 tex; P_{wp}=228 threads/dm; P_{wp}=193 threads/dm; M_s=345 g/m^2; thickness T_f=0.95 mm; S_{wp}=8115 μH.cm^2 and weft S_{wf}=7582 μH.cm^2; Kd_{wp}=46 and Kd_{wf}=43.

Sample 2: basket binding 2/2; F_1=4; C=4.1; F_2=0.5; T_{wp}=33.3x2 tex; T_{wf}=33.3x2 tex; P_{wp}=163 threads/dm; P_{wp}=152 threads/dm; M_s=345 g/m^2; T_f=0.9 mm; S_{wp}=6888 μH.cm^2 and weft S_{wf}=6093 μH.cm^2; Kd_{wp}=48 and Kd_{wf} =45.

Sample 3: twill binding 2/2; F_1=4; C=4.2; F_2=0.5; T_{wp}=80 tex; T_{wf}=80 tex; P_{wp}=159 threads/dm; P_{wp}=132 threads/dm; M_s=390 g/m^2; T_f=1.45 mm; S_{wp}=13098 μH.cm^2 and weft S_{wf}=13069 μH.cm^2; Kd_{wp}=50 and Kd_{wf}=55.

Sample 4: twill binding 2/2; F_1=4; C=6; F_2=0.7; T_{wp}=125 tex; T_{wf}=125 tex; P_{wp}=140 threads/dm; P_{wp}=136 threads/dm; M_s=550 g/m^2; T_f=1.75 mm; S_{wp}=40407 μH.cm^2 and weft S_{wf}=42141 μH.cm^2; Kd_{wp}=35 and Kd_{wf}=39.

Sample 5: twill binding 2/2; F_1=4; C=5; F_2=6; T_{wp}=125 tex; T_{wf}=125 tex; P_{wp}=133 threads/dm; P_{wp}=121 threads/dm; M_s=500 g/m^2; T_f=1.56 mm; S_{wp}=12306 μH.cm^2 and weft S_{wf}=11926 μH.cm^2; Kd_{wp}=40 and Kd_{wf}=42.

Sample 6: twill binding 2/2; F_1=3; C=6.7; F_2=0.8; T_{wp}=100 tex; T_{wf}=100 tex; P_{wp}=138 threads/dm; P_{wp}=146 threads/dm; M_s=450 g/m^2; T_f=1.8 mm; S_{wp}=31535 μH.cm^2 and weft S_{wf}=31055 μH.cm^2; Kd_{wp}=36 and Kd_{wf}=31.

3 RESULTS AND DISCUSSION

The application of the seven developed methods for forming of volumetric details of women's hats in LAWE allows to diversify significantly the configurational spectrum of the use of forming elements in the technological process. This extends the design of the range of headwear for the enterprise. Consider in detail the advantages and areas that need improvement in the proposed forming methods (Table 1).

Table 1 Advantages and disadvantages of the developed methods of formation in LAWE

Developed method	Advantages	Disadvantages
1. Hydromechanical method	+ Simple design of test equipment; + Simplicity of work and formation process	- The use of static load, which does not provide active work of "rough structure" of the fabric and leads to the appearance of peeling; - The complexity of determining the process parameters at each part of the workpiece, in accordance with the properties of the fabric
2. Pneumo-liquid method	+ Prospects of use for forming fabrics that do not require significant plasticization of fibres, such as pile fabrics; + Possibility of spraying together with LAWE of apret and target penetration of its molecules to the optimum value	- Uneven distribution of static forming force, the greatest load of which falls on the lower part
3. Hydro-jet method	+ Ability to repeat the contour of the part of different configurations; + Additional loading and coverage of the entire area of the part due to the rotation of the forming element; + Ability to change the pressure and angle of attack of a flooded controlled jet as a major forming effort; + Flexibility, mobility and adaptation of the forming process due to its available automation	- Complication of the application of the apret directly in the process of forming a part due to the use of the pump for cyclic movement of LAWE
4. Hydrocentric method	+ Ability to put significant forming efforts on high density fabric	- Possibility of destructuration of low-density fabric from excessive forming efforts
5. Hydraulic method	+ Significant plasticization of textile fibres due to volumetric mass transfer of LAWE into the "rough" fabric structure	- Inhibition of the action of the forming force of the LAWE flow due to indirect contact with the surface of the fabric, as the first contact has the surface of the forming element
6. Vacuum-liquid method	+ Absence of fabric destruction due to the nature and effect of a small forming effort	- Difficulty in providing a stable shape to fabrics with low ability to form
7. Hydro-vacuum method	+ Active work of "rough" fabric structure due to the action of forming loads in the upper and lower plane of the chamber. + Significant plasticization of textile fibres due to volumetric mass transfer of LAWE into the "rough" fabric structure + Absence of fabric disruption due to the nature and effect of a small forming effort	- Effect of sufficiently static loads, which complicates the provision of a stable form to fabrics with low ability to form

After formation of volumetric part of a woman's hat, it is treated by the trim to give it steady shape. This operation is performed if it was not performed during forming process. Afterwards, the drying of the part is carried out on the forming element for 20-30 minutes. After that, the formed head of the woman's hat is ready for further technological operations. These could be connecting it to the fields, ears or visor, treatment of the open sections of the bottom. It depends on the design of the woman's hat.

The examples of the sewn women’s hats with the use of the volumetric parts formed in LAWE are shown on the Figure 8.

Figure 8 Design of the women's hats with heads formed in LAWE

The general prospects of technological processes automation of formation with LAWE include the following methods: hydromechanical, pneumo-liquid and hydrocentric.

As a result, were obtained a formed heads of hemispherical shape with a diameter d_h=175-188 mm and height h=80-110 mm. These geometric parameters are within the standard sizes of hats from S to L.

4 CONCLUSIONS

It is suggested to use water as a working environment, which creates a different forming force that acts on textile materials.

Seven original methods of hydroforming using LAWE have been developed. Appropriate experimental equipment is designed and peculiarities of its functioning are given.

According to the experimental studies, the optimal parameters for forming of three-dimensional details of women's hats were determined for each of the methods:

1. *hydromechanical method* – distance from the forming element to the activator H_{act}=22 mm; rotation frequency of the shaft with the activator n=3600 rpm; the height of the LAWE column in the forming chamber h=100 mm; forming time t=300 s;
2. *pneumo-liquid method* – the pressure of the air-water mixture P=0.12-0.16 MPa; the distance from the nozzle end to the highest point of the forming element H=120-140 mm; forming time t=150-180 s;
3. *hydro-jet method* – pressure of the LAWE P=0.1-0.15 MPa; the area of the outlet hole of the jet-forming nozzle S_{noz}=3.53 mm^2; the distance from the end of the nozzle to the surface of the workpiece l=5 mm; rotation frequency of the shaft with the forming element and the part attached to it n=300 rpm; forming time t=140-180 s;
4. *hydrocentric method* – rotation frequency of the central shaft n=600 rpm; forming time 120-160 s;
5. *hydraulic method* – pressure of the LAWE P=0.13 MPa; forming time t=64 s;
6. *vacuum-liquid method* – vacuum pressure V=0.02-0.04 MPa; forming time t=64 s;
7. *hydro-vacuum method* – pressure of the LAWE P=0.22 MPa; vacuum pressure V=0.022 MPa; forming time t=140 s.

On the developed equipment women's hats of the three-dimensional form are formed and examples are given. Prospects for further research on improving the operation of the equipment are offered.

5 REFERENCES

1. Pedro J., Rivero J., Urrutia A., Goicoechea J., Arregui F.: Nanomaterials for functional textiles and fibers, Nanoscale Research Letters 10, art. no. 501, 2015, https://doi.org/10.1186/s11671-015-1195-6
2. Choklat A.: Footwear design, Laurence King Publishing, 2012, 192 p.
3. Renfrew E., Renfrew C.: Basics Fashion Design 04: Developing a Collection, AVA Publishing SA, 2009, 167 p., ISBN 9782940373956
4. Gersak J.: Planning of clothing design, pattern making and cutting, in book: Design of clothing manufacturing processes, 2013, pp. 105-144, DOI: 10.1533/9780857097835.105
5. 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), 2016, pp. 16-26, doi. 10.15587/1729-4061.2016.71242

6. Kyleshova S., Zakharkevich O., Koshevko J., Ditkovska O.: Development of expert system based on kansei engineering to support clothing design process, Vlakna a textil (Fibres and Textiles) 24(3), pp. 2017, pp. 30-41
7. Zakharkevich O., Zhylenko T., Koshevko J., 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. Yakymchuk D., Dzyundzya O., Burak V., Shvets I., Shvets Y., Myrhorodska N., Polishchuk O., Karneyenka D., Krasner S.: Economic efficiency of textile materials cutting designer costumes of hospitality facilities, Vlakna a textil (Fibres and Textiles) 25(4), 2018, pp. 90-93
9. Horiashchenko S.: Research spray and device for polymer coatings on fabric, Mechanika 2015: Proceedings of the 20th International scientific conference, Kaunas, 2015, pp.101-104
10. Horiashchenko S., Golinka I., Bubulis A., Jurenas V.: Simulation and research of the nozzle with an ultrasonic resonator for spraying polymeric materials, Mechanika 24(1), 2018, pp. 61-64, https://doi.org/10.5755/j01.mech.24.1.20215
11. Diachok T., Bereznenko S., Yakymchuk D., Aleksandrov M., Bakal V., Budzynskyi M:. Development of equipment for complex man protection from artificial non-ionizing EM, Vlakna a textil (Fibres and Textiles) 26(2), 2019, pp. 9-13
12. Zege S., Broid I.: Procedural characteristics of the design of underground structures installed with use of jet technology, Soil mechanics and foundation engineering 46(2), 2009, pp. 53-58, https://doi.org/10.1007/s11204-009-9046-z
13. Zege S.O., Broid I.I.: Design features of soil-concrete structures built by means of jet geotechnology, Soil mechanics and foundation engineering 44(4), 2007, pp. 143-145, https://doi.org/10.1007/s11204-007-0026-x
14. Ibragimov M.N.: Characteristics of soil grouting by hydro-jet technology, Soil mechanics and foundation engineering 50(5), 2013, pp. 200-205, https://doi.org/10.1007/s11204-013-9234-8
15. Hulti E, Abouali S., Ben Hucine M., Mansour M., Nedeljković M., Ilić V.: Influence of hydrodynamic conditions and nozzle geometry on appearance of high submerged cavitating jets, Thermal Science 14(4), 2013, pp. 1139-1149, DOI: 10.2298/TSCI120925045H
16. Shimizu S.: Structure and erosive characteristics of water jet issuing from fan jet nozzle, 18th International conference on water jetting, Poland, 2006, pp. 337-345
17. Kang Y.L., Jiang J.W., Men S.Y.: Numerical study of charge jet formation end penetration into multi-layer with different liner material, Advanced Material Research 148-149, 2010, pp. 744-748, https://doi.org/10.4028/www.scientific.net/AMR.148-149.744

ANALYTICAL ASSESSMENT OF THE APPAREL INDUSTRY IN UKRAINE: PROBLEMS AND OPPORTUNITIES

Oksana Morhulets, Svitlana Arabuli, Olena Nyshenko and Arsenii Arabuli

Kyiv National University of Technologies & Design, N.-Danchenko srt. 2, 01011 Kyiv, Ukraine
arabuli.si@knutd.edu.ua

Abstract: *The article describes the current state and dynamics of business activity of the apparel industry in Ukraine. The quantitative and qualitative indicators of the activity of apparel enterprises in the period 2015-1019 are analyzed. The strengths and weaknesses of the Ukrainian apparel industry have been identified. It is shown that Ukrainian apparel manufacturers can be competitive both in the domestic and international markets. Geographical proximity to Europe and signed Free Trade Agreement with EU giving Ukraine a clear advantage against producers in Central Asia and Far East. However, there are a number of problems facing the apparel industry. Among the main problems are the improvements of the management system of the apparel enterprise. In article was proposed to use outsourcing services as one of the ways to improve the apparel enterprise management system.*

Keywords: *apparel industry, problems, opportunities, management system, outsourcing.*

1 INTRODUCTION

The European apparel industry is becoming increasingly innovative and competitive and it plays a significant role in economic development [1].

According data of the project Skills4SmartTCLF [2] the apparel industry in 2018 realized a turnover of almost EUR 80 billion, with exports reaching almost 27 billion EUR. The European apparel industry is the second biggest exporter, after China, representing 29% of the global market. As per category of exported goods 40% are womenswear and 23% for menswear. The countries with the largest apparel industry in terms of production value are Italy, Germany, France, Spain and Portugal, which together are responsible for 75% of the total EU production value. The sector employs in total over 1.1 million workers across Europe in 130,000 companies, out of which 99% are small or medium-sized companies. The largest countries in terms of apparel industry employment are Romania, Italy, Poland, Bulgaria and Portugal. As per gender balance at the workplace, the apparel industry is dominated by women (81% of all workers).

Looking at the composition of EU-28 household expenditure by consumption purpose by the main 10 COICOP categories based on current price figures (see Figure 1), 4.7% of total or 2.6% of GDP of EU-28 household expenditure was devoted to “clothing and footwear” [3]. The household consumption expenditure on “clothing and footwear” in the European Union in 2018, by country (in million Euros) are shown in Figure 2.

According [4] spending on clothing per capita in the EU is around 700 euros.

Existing competition from China, India and Turkey requires Ukrainian manufacturers have to care about quality and follow current trends as well as meet ever-increasing customer expectations, which should lead to the growth of the economic value of this sector and an increase Ukraine's share of the EU clothing market.

In Ukraine, the TCL industry (TCL is the acronym for the European industrial activity classification (NACE) sectors 13 to 15: Manufacture of textiles, - Manufacture of wearing apparel, - Manufacture of leather and related products) until 1991 provided up to 50% of the needs in textile and clothing products of the former USSR. During the last 18 years, the Ukrainian TCL industry has been in a state of protracted systemic crisis.

The lack of government regulation and the lack of potential investors contribute to deepening negative trends. Hard competition with foreign manufacturers and large volumes of “second-hand” imports into Ukraine, worsen the conditions of operation of domestic enterprises. Attraction of investors, modernization of production, government support and use of new management tools are the decisive factors for ensuring the competitiveness of Ukrainian TCL industry.

The Ukrainian market is dominated by products imported from Turkey, China and Poland. Ukraine ranks third in the world in terms of “second-hand” imports, ahead only of Pakistan and Malaysia [5].

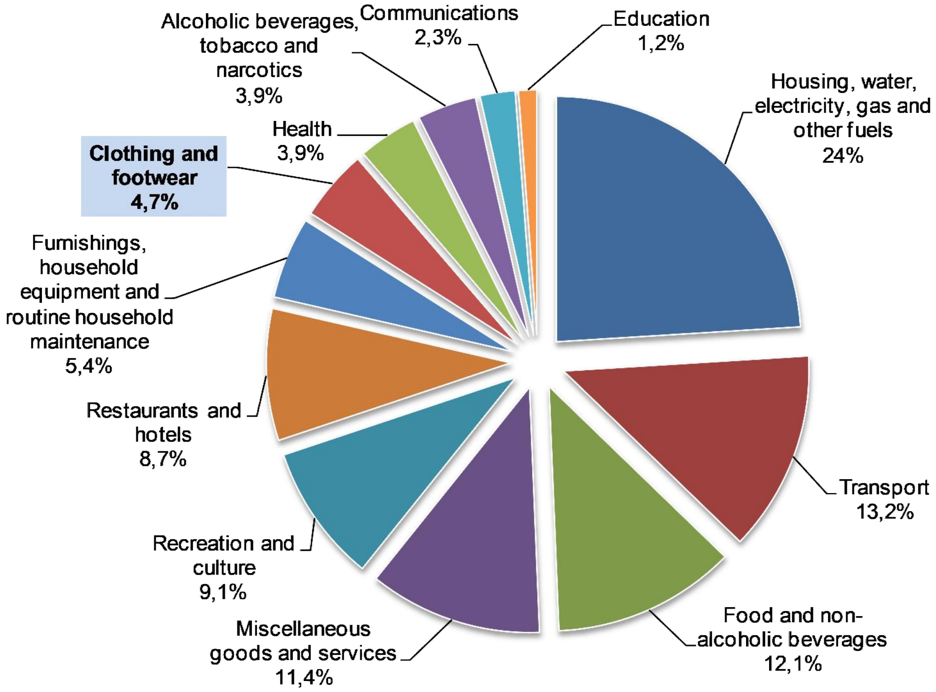


Figure 1 Household expenditure by consumption purpose - COICOP, EU-28, 2018, share of total (Source: Eurostat)

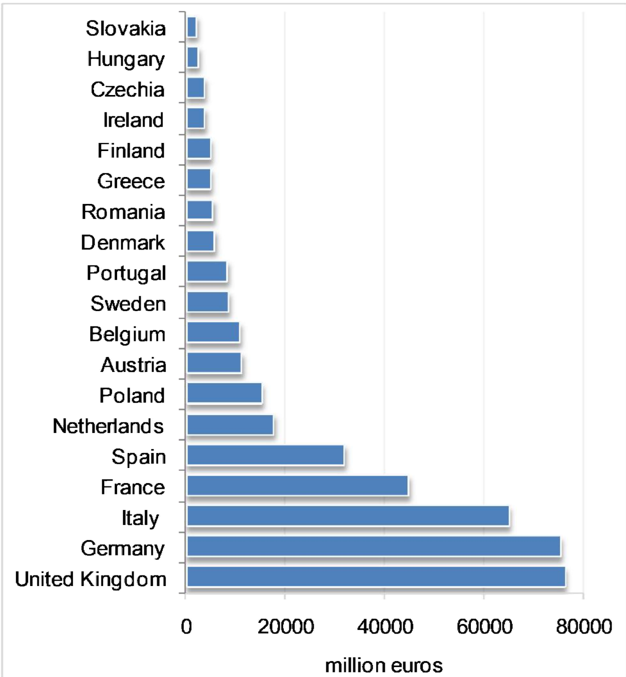


Figure 2 Household consumption expenditure on “clothing and footwear” in the European Union in 2018, by country (Source: Statista)

Today, the Ukrainian TCL industry provides 5% of budget revenues and 2.6% of Ukraine's export potential.

Ukrainian TCL industry is characterized by the following problems that limit its development [6-13]:

– reduction of the domestic market for domestic products;
– saturation of the market with products from Turkey and China, as well as “second-hand”;
– lack of government support;
– unfavorable investment climate;
– insufficient innovation activity;
– low competitiveness in price, quality and assortment;

– using tolling schemes;
– issues of taxation and shadow production;
– the lowest salary in the industry;
– narrowing of the raw material base;
– lack of effective business management schemes;
– lack of effective leasing financing for the purchase of equipment;
– low level of equipment and technology modernization.

This study is assessment and determines the problems and prospects of Ukraine apparel industry by analyzing key economic indicators of domestic enterprises.

2 RESEARCH AND RESULTS

Our analysis used dataset from the State Statistics Service of Ukraine (Ukrstat) and data of Ukrainian Association of enterprises of textile, apparel & leather industry. The subject of analysis is the apparel production (Sector C. Manufacturing (C.14.1 - Manufacture of wearing apparel, except fur apparel; C.14.2 - Manufacture of articles of fur; C.14.3 - Manufacture of knitted and crocheted apparel).

According to Ukrstat, at the beginning of 2019, 16 602 TCL industry enterprises were operating. This is 13.19% in the structure of all domestic industrial enterprises. The apparel enterprises make up 70.48% of the total number of TCL industry enterprises, the textile enterprises 16.70%, the enterprises for the production of leather and related products 12.82% (Figure 3).

Figure 3 Dynamics of the number of TCL industry enterprises in Ukraine during 2015-2019 (Source: Own elaboration based on Ukrstat data)

Among 11701 apparel enterprises: 1.96% - medium-sized enterprises, 6.46% - small, 91.58% - micro-enterprises. The dynamics of the number of apparel enterprises has a stable trend. The largest share in the regional structure of the apparel industry enterprises is: Kyiv region 20.16%, Kharkiv region 12.82%, Lviv region 10.83%, Khmelnitsky region 6.53% and Odessa region 5.61%.

These areas are historical centers of origin and development of the apparel industry. Other regions by number of economic entities were distributed in the structure up to 5% (Figure 4).

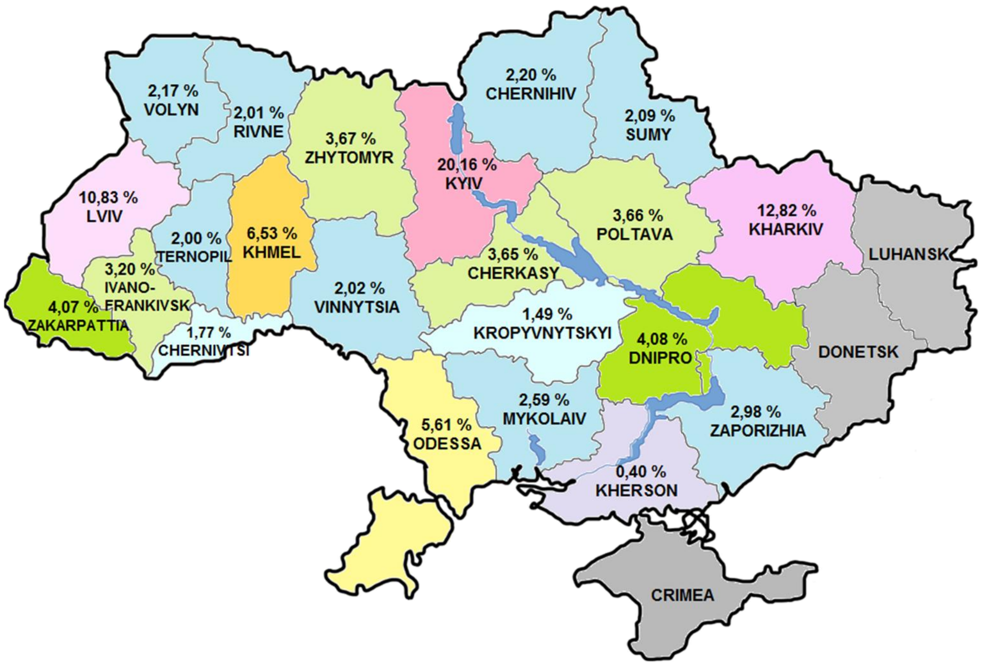


Figure 4 Territorial structure of the enterprises of the apparel industry of Ukraine (without enterprises located in the annexed territory of the Autonomous Republic of Crimea and in the temporarily occupied separate areas of Donetsk and Lugansk regions) (Source: Own elaboration based on Ukrstat data)

The share of the apparel industry in the total volume of industrial production for 2015-2019 has a steady trend (Figure 5a). At the beginning of 2019, the share of the apparel industry increased by 0.15% compared to the same period of 2015. This indicates a gradual increase role of the apparel industry in the industrial complex of Ukraine (Industrial complex of Ukraine consists of 4 sectors: sector B - Mining and quarrying, sector C - Manufacturing, sector D - Electricity, gas, steam and air conditioning supply, sector E - Water supply; sewerage, waste management and remediation activities). A positive growth trend of the apparel industry share is also observed in the total sales of Ukrainian TCL industry (Figure 5b).

The preliminary results are confirmed by the data presented in Figure 6. Figure 6 shows the volumes of sales of apparel products in the respective year on 01.01.

The volume of sold products of the apparel industry is increasing every year. At the beginning of 2019, the volume of sold products amounted to 13629.03 million UAH and compared to 2015 it increased by 8403.83 million UAH (in 2.61 times). The annual growth average is 27.3%. However, the dynamics of production by the nomenclature of goods does not have clearly defined trends and patterns. This is due to fashion trends and consumer demand (Table 1).

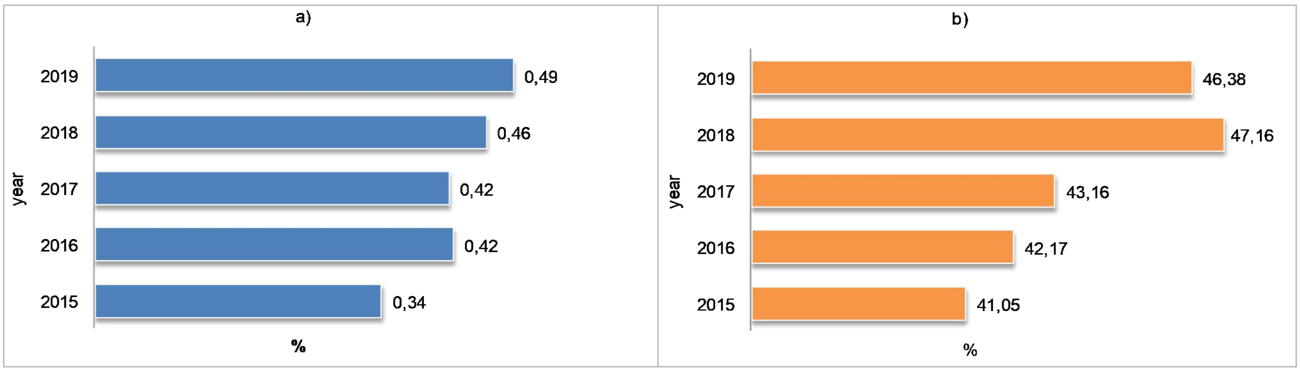


Figure 5 The share of the apparel industry in Ukraine in the total volume of industrial production in 2015-2019: a) industrial enterprises; b) TCL enterprises (Source: Own elaboration based on Ukrstat data)

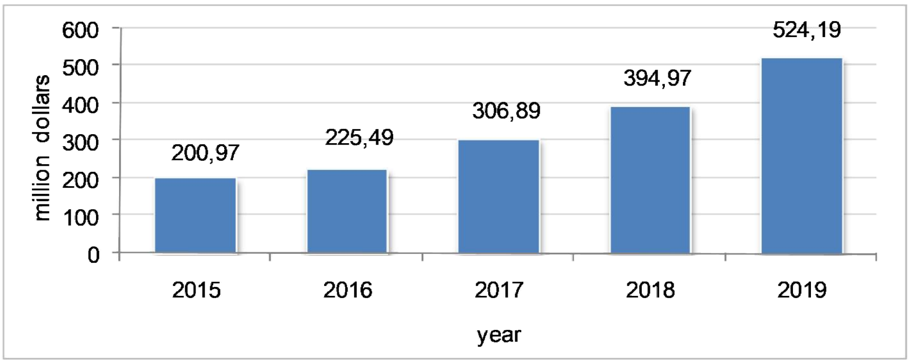


Figure 6 Volume of sold products of the apparel industry of Ukraine in 2015-2019 (Source: Own elaboration based on Ukrstat data)

Table 1 Dynamics of volume production of the main types of garments for the period 2015-2019

Types of garments	Volume production compared to the previous year [%]				
	2015 to 2014	*2016 to 2015*	*2017 to 2016*	*2018 to 2017*	*2019 to 2018*
Coats, raincoats, capes, etc	85.05	87.04	101.93	96.05	93.92
Vests, anoraks, etc	99.69	132.49	120.24	148.91	100.49
Suits and ensembles, etc	81.06	67.19	125.04	101.36	94.77
Coats, jackets, blazers, etc	92.96	115.36	91.58	103.85	93.55
Dresses, ets	100.00	92.59	120.00	103.33	104.87
Skirts, etc	97.95	117.42	94.96	76.98	100.00
Blouses, etc	93.33	85.71	133.33	106.25	93.88
Shirts, ets	85.71	108.33	107.69	107.14	86.67

Source: Own elaboration based on Ukrstat data

Table 2 Dynamics of financial result of apparel enterprises activity after taxation for the period 2015-2019

Enterprises	On 01.01 corresponding year	Enterprises that have received profit		Enterprises that have received loss	
		In % to the total number of enterprises	*Financial result [million UAH]*	*In % to the total number of enterprises*	*Financial result [million UAH]*
Industry*	2015	62.4	59910.7	37.6	238641.6
Apparel industry		69.1	366.4	30.9	424.0
Industry*	2016	72.6	75334.3	27.4	263602.2
Apparel industry		75.9	638.8	24.1	398.7
Industry*	2017	72.5	117202.7	27.5	141927.4
Apparel industry		75.3	609.4	24.7	146.8
Industry*	2018	71.4	195352.2	28.6	139228.2
Apparel industry		71.1	698.1	28.9	188.5
Industry*	2019	72.4	233568.7	27.6	124279.9
Apparel industry		70.9	637.8	29.1	180.3

*Mining and quarrying + manufacturing + electricity, gas, steam and air conditioning supply + water supply; sewerage, waste management and remediation activities (Source: Own elaboration based on Ukrstat data)

In 2015-2019, the largest increase in apparel production was observed in 2017. In 2019, there was a certain reduction in the apparel production. The largest increase in volumes has the production of dresses - in 2019 it increased by 4.87%. The greatest decline in production was observed in production of shirts (in 2019 decreased by 13.33%) and suits, jackets, blazers (decreased by 6.45%).

The positive trend is also confirmed by the dynamics of the financial result of the activity of the apparel industry enterprises after taxation (Table 2).

At the beginning of 2019, the number of employees in the garment industry amounted to 79.9 thousand people (59.85% of those employed in the light industry) (Figure 7). This is significantly higher than in other sectors of Ukrainian TCL industry. During the period under review, the number of employees in the apparel industry has a tendency to increase. This trend is typical for TCL industry in general. Traditionally, TCL industry with high shares of females, not only in services and administration, but also in production activities. This did not change between 2015 and 2019. Today 75% of all persons employed in TCL industry are female.

The salary of workers in the Ukrainian apparel industry increased in 2.6 times during the surveyed period (Figure 8). The salary growth rate is 29.30% annually. The salary of workers in the apparel industry at the beginning of 2019 increased by 10.90% compared to 2018 and exceeded the minimum salary by 1.79 times. The gap in salary of female compared to men is 11%.

Despite the positive trend, monthly salary in apparel industry as well as the TCL industry in general is the lowest in the industrial complex of Ukraine. Thus, the salary of apparel industry worker is less than the average salary in total industry in 1.58 times (in the food industry - 1.34 times; in pharmaceuticals - 2.59 times; in the wood industry - 1.24 times). This leads to an outflow of highly skilled personnel into businesses with stable and competitive salary.

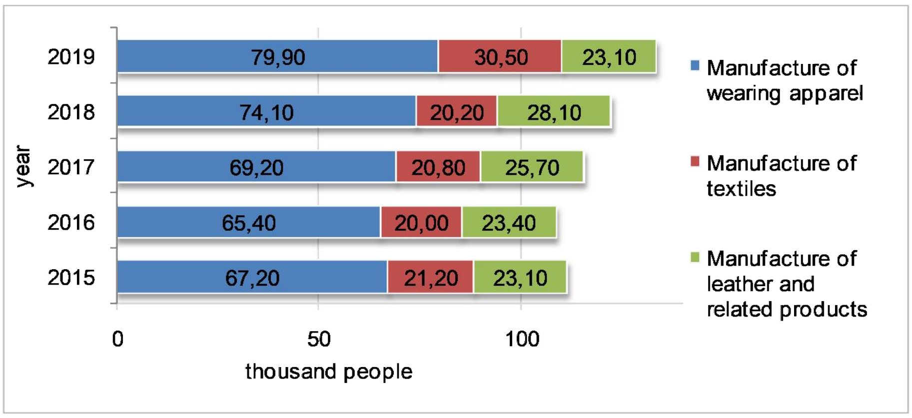


Figure 7 Dynamics of the number of employees in apparel industry in Ukraine for the period 2015-2019 (Source: Own elaboration based on Ukrstat data)

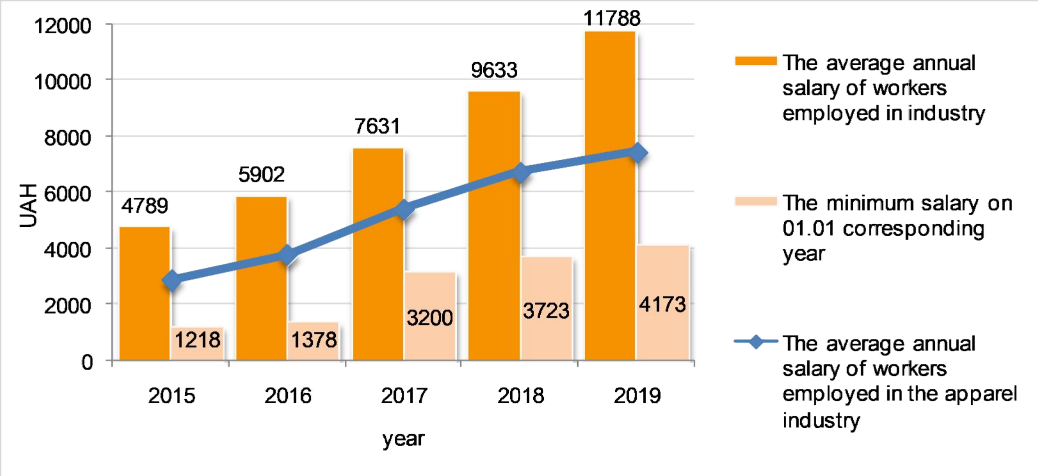


Figure 8 Dynamics of the average annual salary of the Ukrainian apparel industry in 2015-2019 (Source: Own elaboration based on Ukrstat data)

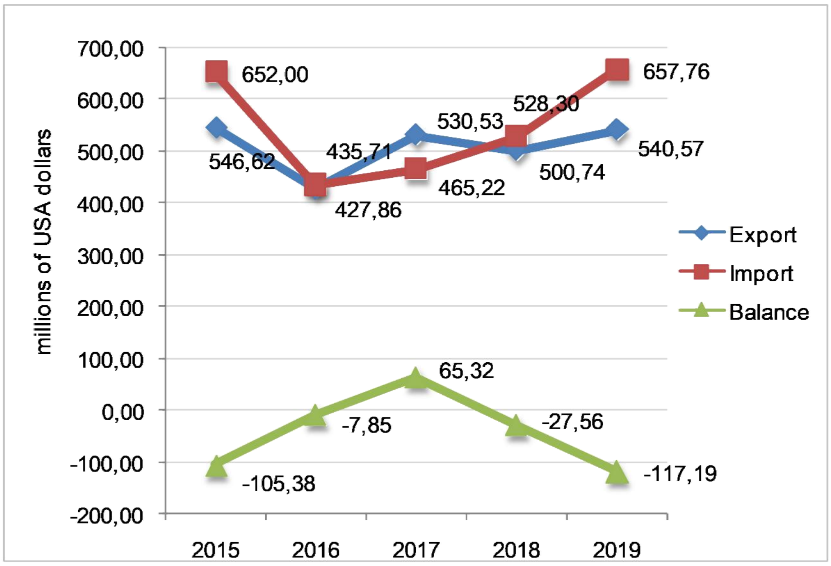


Figure 9 Dynamics of foreign trade in the apparel industry of Ukraine for the period 2015-2019 (Source: Own elaboration based on Ukrstat data)

Ukraine's export-import activity is characterized by a negative balance of foreign trade in the apparel industry. Imports are dominated by exports (Figure 9).

Leaders of imports of goods apparel industry in Ukraine are the countries of Asia (over 85%), China, Turkey, Bangladesh, Cambodia and Vietnam. More than 90% of exports garment industry accounts for the EU (Germany, Poland, Denmark, Belgium, Lithuania and Italy).

One of the important problems in the development of the Ukrainian apparel industry is the import of “second-hand”. On 01.01.2019 in Ukraine imported “second-hand” in the amount of 154.97 million $ USA. This is on 50.43 million $ USA more than on 01.01.2015 (Figure 10).

“Second-hand” is popular both poor and a wealthy population. Among the “second hand” can find products of world famous brands of high quality. The cost of these products in branded stores is too expensive for most ordinary Ukrainians. The problem is as follows: “second-hand” are imported as humanitarian aid, and new products are imported as “second-hand”. This leads to the loss of the annual budget about 3 billion $ USA. According to the latest data, the volume of “second-hand” imported from the EU amounted to 99.38% (Poland - 37.18%, Germany - 35.09%, Switzerland - 15.37%, other EU countries - less than 3.5%), from other countries - 0.62% [14, 15].

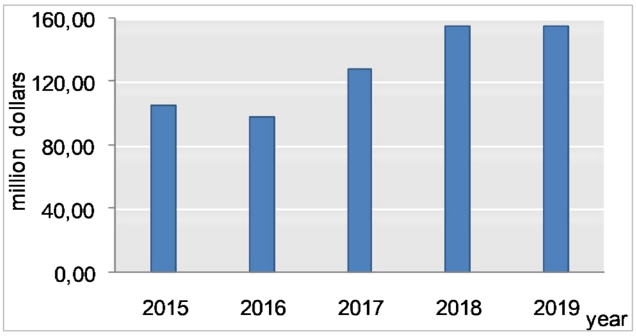


Figure 10 Volume imported to Ukraine clothes and other goods that were used in 2015-2019 (Source: Own elaboration based on Ukrstat data)

One way to improve the efficiency of TCL industry in Ukraine is to attract investment. Direct investment in Ukrainian TCL industry in 2015-2019 is shown in Figure 11.

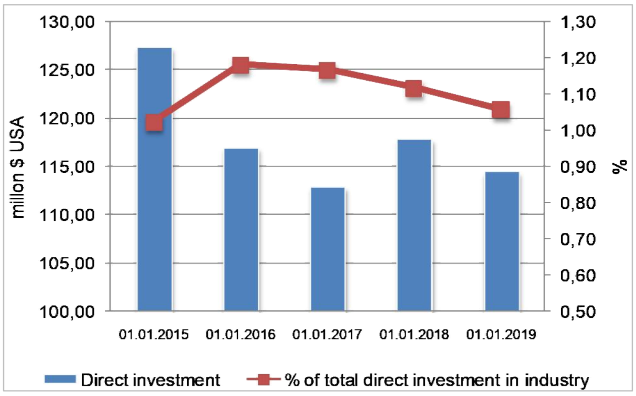


Figure 11 Direct investment in Ukrainian TCL industry in 2015-2019 (Source: Own elaboration based on Ukrstat data)

According to Ukrstat data on 01.01.2019 direct investments in TCL industry account for 1.06% of the total direct investment in the industry. This indicator is characteristic of the apparel industry too. The main investors in Ukrainian TCL industry and apparel including is the EU (Figure 12).

The dynamics of profitability of the operating activity of the garment industry enterprises in 2015-2017 showed a positive trend, but declined from 2018 (Figure 13). Throughout the study period, the level of profitability was positive, and therefore, on average, the apparel industry was profitable.

As shown in Figure13 in the period 2015-2017, the level of profitability of industrial enterprises was low. This is due to the difficult political and economic situation in the country. Sewing companies in this period showed high profitability, this is explained by tolling schemes.

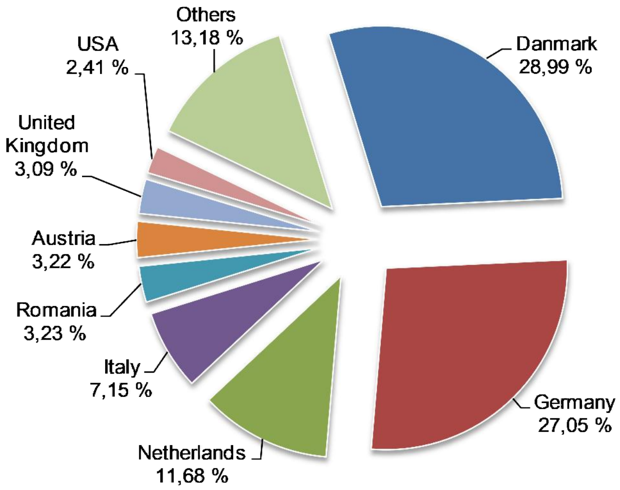


Figure 12 Geographical structure of direct investments in TCL industry of Ukraine on 01.01.2019 (Source: Own elaboration based on Ukrstat data)

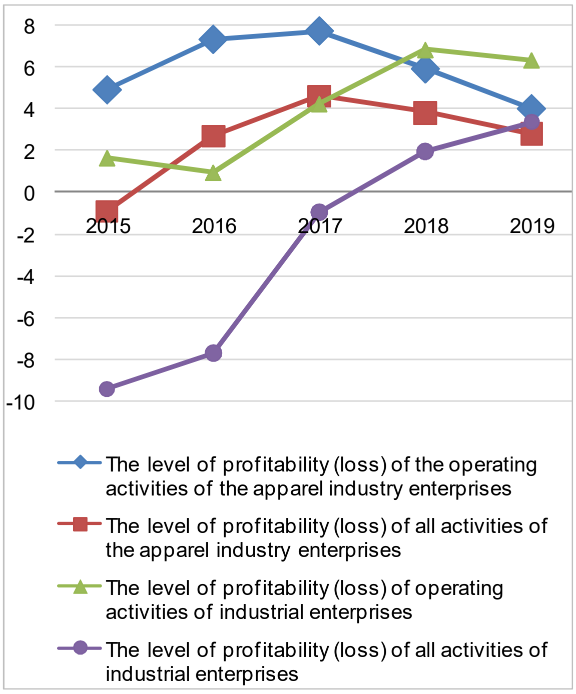


Figure 13 The level of profitability of the operating and all activities of apparel industry enterprises in 2015-2019 [%] (Source: Own elaboration based on Ukrstat data)

3 CONCLUSION

The Ukrainian apparel industry is in a difficult phase of coming out of the crisis. The Ukrainian domestic apparel market is filled with cheap, low quality foreign goods. These goods are displacing domestic products of Ukrainian apparel market. Enterprises cannot operate effectively due to lack of investments and high-tech equipments. The apparel industry needs government support in the form of government programs and improvement of management system of the apparel enterprise.

On our opinion, one of the ways to improve the management system at apparel enterprises is to take advantage of outsourced enterprise management. Outsourcing in the world is recognized as an effective management tool and a key element of business strategy, both small and large enterprises. An example of the successful use of outsourcing is the global brand Marks & Spencer, which produces clothing, footwear and accessories. The company began to make extensive use of outsourcing services in the early 2000s, first outsourcing IT support. It allowed to optimize staff and increase the effectiveness of e-commerce worldwide. Subsequently, they outsourced HR-audit, payroll, inventory, opening new stores and other business processes. Another example of the use of outsourcing in various areas is the Inditex group of companies, the owner of the Zara retail chain. This company also conquered the world market by actively attracting outsourcers on different continents. We do not mean production outsourcing, as almost all well-known European brands use the services of Asia, Turkey and Ukraine, as the cost of labor there is much lower. Outsourcing has also contributed to the rapid development of China, India, the Philippines and Mexico. The global outsourcing market is growing rapidly, and according to forecasts by international experts in 2020 will reach 1.1 trillion $ USA. Analysis of the outsourcing market in Ukraine indicates a rapid pace of its development (18% annually). It is now 10 billion $ USA. The most popular among Ukrainian business owners are: IT outsourcing services, logistics, production process resourcing, marketing and asset security. Ukrainian apparel enterprises have high chances to effectively use outsourcing as a tool for business process management. At the same time, apparel companies can outsource by offering their manufacturing facilities for production apparel to outside companies within and outside the country.

4 REFERENCES

1. Dziuba R., Jabłońska M.: Competitiveness of the textile sector of Croatia in trade with the European Union, FIBRES & TEXTILES in Eastern Europe 25(6), 2017, pp. 14-18, https://doi.org/10.5604/01.3001.0010.5
2. Skills 4 Smart TCLF Industries 2030, Available from https://www.s4tclfblueprint.eu
3. Statista, Available from https://www.statista.com
4. Eurostat, Available from https://ec.europa.eu/eurostat
5. Ukraine: roadmap for the development of clothing and footwear industries, Available from https://ukrlegprom.org/files/ukrlegprom-roadmap.pdf
6. State Statistics Service of Ukraine, Available from http://www.ukrstat.gov.ua
7. Ukrainian Association of enterprises of textile & leather industry, Available from https://ukrlegprom.org/ua
8. Kiiko V., Votchenikova O., Halushchak O.: Current state and prospects of garment industry of Ukraine. Materials of International scientific conference “Modern Directions of Theoretical and Applied Researches”, 2016, pp. 231-238
9. Hryshchenko I. et al.: Light industry of Ukraine: realities and prospects of development, Expert-analytical report, Kyiv: KNUTD, 2015, 82 p., (in Ukrainian)
10. Mazaraki A., Melnyk T., Izovit V.: Light industry of Ukraine: state, problems of export and import of goods (Легка промисловість України: стан, проблеми експорту та імпорту товарів), Bulletin of KNTEU, issue 3, 2011, pp. 5-12, (in Ukrainian)
11. Plotnichenko I.: Current state and prospects of garment industry of Ukraine, Bulletin of the Lviv Polytechnic National University, Series: Management and Entrepreneurship in Ukraine: Stages of Development and Development, issue 739, 2012, pp. 109-114
12. Pokras O., Voitko S.: Analysis of Ukrainian apparel industry international competitiveness using Porter’s Diamond, Actual Problems of Economics and Management, issue 8, 2014, pp. 23-35, (in Ukrainian)
13. Fedorenko V., Gryshchenko I., Bondarenko I., Novikova O., Olshanska A., Melnyk A., Voronkova T., Denysenko N., Voytovych R., Gaidutskiy A., Palytsya S., Fedorenko S., Gryshchenko A., Iankovets T., Shatskaya Z., Patyka N., Pan'kova O., Zaplitna T., Vasilenko L., Levishchenko O., Pyaskivska M.: Ukraine in the global economy: monograph; Fedorenko V., Gryshchenko I., Voronkova T. (Eds), Kyiv: "ДКС центр" Ltd, 2017, 300 p., (in Ukrainian)
14. Ministry of social affairs wants to ban the “second-hand” import as humanitarian aid in the territory of Ukraine, Available from https://ua.interfax.com.ua/news/economic/632711.html
15. Imports of second-hand to Ukraine may be banned, Available from https://racurs.ua/ua/n131342-vvezennya-sekond-hendu-v-ukrayinu-mojut-zaboronyty.html

EVALUATION OF FEELING OF COMFORT OF MILITARY SPORTSWEAR USERS DURING PHYSICAL ACTIVITY

Jana Švecová, Radka Lopourová and Simona Halatová

Faculty of Military Leadership, University of Defence in Brno, Kounicova 65, 662 10 Brno, Czech Republic
www.unob.cz, jana.svecova@unob.cz, radka.lopourova@unob.cz, simona.halatova@unob.cz

Abstract: *The article deals with the evaluation of the feeling of comfort of the user of the equipment during his physical activity. It is a subjective evaluation of the clothing comfort of a soldier dressed in selected military sportswear while simulating physical activity on an exercise bike, based on a questionnaire construction. The aim of this article was to test selected samples of sporting military equipment together with other suitable materials in order to get the closest possible experience with testing of military clothing in real conditions. Based on the evaluation of the results of the simulated load of tested soldiers to suggest a possible upgrade of equipment to improve the utility properties of sports equipment and ensure optimal conditions of clothing comfort of soldiers. The results are a source of important information for the stage of design and innovation in the introduction of new sports gear, leading to improved military equipment.*

Keywords: *clothing comfort, proband, sports military clothing, subjective evaluation.*

1 INTRODUCTION

Military clothing comfort is important for the soldiers of the Czech Armed Forces (CAF) because it helps them to achieve the best results not only within their physical preparation but also while executing tasks in military operations. Today high quality and more products, that are expensive, are replaced by cheaper and less smart. Comfort of the clothing material wearers is one of the most important aspects influencing mainly the performance of the occupant under physical strain and wearer's mental state. Quality and functional clothing material is important for professional soldiers performing highly strenuous activities and is vital for their ability to continue with this performance.

Comfort means absence of discomfort for the user while wearing the apparel. It is the status of organism when uncomfortable perceptions are felt by our senses and when we aren´t able to perform activities for longer time. Skin temperature 33.2±1°C, relative humidity of the ambient environment 50±10%, speed of air flux 25±10 cm/s, absence of water on the skin and content of CO_2 0.07% represent clothing comfort optimal conditions. If 25% of the skin surface moistened with sweat, an occupant feels heat or cold. It comes to physiological discomfort, which perceived by each human organism subjectively. It is a situation when the apparel user is not able to work for required period. It is obvious, that clothing assemblies should designed in a way to assure the above-mentioned conditions [1].

Clothing comfort separates into psychological and functional comfort. Psychological comfort involves climatic, economic, historical, cultural, social and group or individual aspects. It is a state of mind. Functional comfort includes thermophysiological, sensory and pathophysiological comfort. Sensory comfort implies direct perceptions and feelings of humans while their skin is in direct touch with the textile. Feelings can be pleasant or on the contrary unpleasant, irritating, scratchy, pricking or sticking. Thermophysiological comfort comes with the perception of the user`s thermal comfort. It closely relates to the transport of the air and liquid humidity, heat transfer in individual layers of the clothes and air fluxion in the apparel. Corresponding thermophysiological properties of military clothing are important especially if it is not possible to change it easily or take it off just like with the clothes intended for casual wear or fitness. Fitting clothing design is also important. It influences the way that the apparel adjusts while wearing and how it enables free movement [2]. Pathophysiological comfort is connected with the action of microorganisms occurring on human skin. Effect of these influences depends on the human skin resistance against chemical substances contained in particular fabrics.

Sportswear as the first contact layer should to fulfil following requirement. The first layer should firstly distribute the liquid sweat into large area (by capillary action in grooved polyester or polypropylene fibres), in order to reduce the local fabric humidity and consequently keep the friction coefficient between the skin and the fabric as low as possible. Simultaneously, in this large area, sweat should evaporate easily, provided the adhesion between the fabric fibres and water is low. Unfortunately, cotton and viscose fibres exhibit high adhesion hence pure non-treated natural fibres will not offer good level of contact comfort (low friction). From the study [3] follows that thermophysiological comfort properties of underwear in dry state can be substantially lower than their comfort properties in real conditions in their use due to the absorbed sweat. This surprising observation emphasizes the importance of testing of thermal comfort properties of fabrics (thermal resistance and water vapour permeability) in dry and wet state by means of special instruments, as are non-destructive Czech fast testing instruments PERMETEST and ALAMBETA.

Subjective sensations of the individual are important within clothing comfort assessment and they can highly influence his or her performance. Clothing discomfort affects mental state of the sportsman and can result in a stressful situation, which leads to the augmentation of body temperature and worsens the individual performance. Using physiological properties assessment, we tried to describe more precisely the functional values of the particular textiles and clothing products. Evaluation can be conducted objectively using various gauges such as, e.g. thermal manikin or Sweating Guarded Hotplate (SGHP) or also subjectively by means of the group of probands simulating physical activity or combination of both of these approaches can be used. Reference [4] states, that subjective evaluation of comfort while wearing particular garments can be conducted in real conditions and also in laboratory by means of the study with probands, while group of probands simulates physical activity, e.g. on an exercise bike. Feelings of the apparel wearers can evaluated via subjective evaluation by means of the questionnaires. Tested proband perceives and distinguishes various feelings as hot (mild heat – heat – hot) and cold (cold – colder – congealing), moisture, sensory perceptions such as prickliness or irritation of the apparel and evaluates particular t-shirt design. After finishing physical activity, each proband notes the values related to the above-mentioned parameters according to the assigned scale into the questionnaire. The values are connect to three phases of the test (before the test, during the test, at the end of the test). The group of probands has to be acclimated to the climatic conditions in the laboratory and it is necessary to choose the appropriate level of load.

The paper is concentrated on the subjective evaluation of soldiers' comfort while wearing the clothing material. The assessment was conduct by means of probands measurement according to the precisely defined methodology in the laboratory of the Physical Training and Sports Centre of the University of Defence in Brno (CTVS). The research by focused only in the evaluation of the first layer of the sportswear, sport t-shirts. Basic clothing ensemble of the t-shirts was chose aiming at thermal feelings, humidity resistance and overall sensory feelings of probands such as prickliness or irritation. Subjective comfort evaluation and recommendations related to the clothing material innovations in order to improve feeling of comfort of soldiers wearing sports military clothing represent the results of the research.

2 EXPERIMENTIAL

2.1 Materials and probands

Basic clothing ensemble of the t-shirts for experimental testing was chose according to the material composition of commonly used either artificial or 100% natural fibres. T-shirts determined for military clothing support of the CAF form the basis of the clothing ensemble. Military t-shirts being use for the research are defined as the basic equipment for the professional soldiers by the standards of the CAF. Standards are defined for military clothing support of active soldiers and students according to their service rank [5].

Table 1 Overview of used military and other clothing

Marking	Material composition	Thickness [mm]	Square mass [g/m^2]	Structure of t-shirt	Producer and price
T-shirt 1	57% polyamide, 43% polypropylene	0.96	160	Weft double jersey (smooth)	MOIRA, a.s., Czech Republic 899,00- CZE
T-shirt 2	100% polypropylene	1.15	106	Weft double jersey with ribs	MOIRA, a.s., Czech Republic 699,00- CZE
T-shirt 3	100% merino wool	0.94	170	Weft single jersey	MOIRA, a.s., Czech Republic 1499,00- CZE
T-shirt 4	82% cotton, 18% polyamide	1.10	214	Weft double jersey (smooth)	Sintex a.s., Czech Republic 105- EP
T-shirt 5	85% functional polyester with silver ions content, 9 % antistatic fibre, 6% polyamide	0.91	125	Double-faced patterned binding made of profiled polyester fiber	Monitex Czech s.r.o., Czech Republic 125- EP
T-shirt 6	100% cotton	1.18	220	Weft single jersey	ALEA wear s.r.o., Czech Republic 150- EP

Examined t-shirts ensemble is complete with t-shirts commonly used for sport activities. Objects of the research are state in Table 1 together with material composition and their producers. Indicative price in CZK can be seen in the table as well and the value in equipment points (EP). The value of garments is determined in equipment points and derives from acquisition costs but it does not have to express the exact recalculation of the financial value [6].

Six students of the University of Defence in Brno participated physiological comfort testing. Students of all of the performance groups were chose in terms of statistically appropriate sample. All of the characteristics of probands are state in Table 2 and in the Figure 1; there is the presentation of testing of probands on exercise bikes in the laboratory of the CTVS. The tested group became acquainted with the details of the questionnaires before evaluation.

Table 2 Characteristics of probands

Marking	Age	Height [cm]	Mass [kg]	BMI*
1	19	178.5	98.5	30.9
2	20	174.5	66.2	21.7
3	20	180.5	64.6	19.8
4	20	182.5	79.7	23.9
5	20	179.8	101.7	31.5
6	20	182.7	66.9	20.0

*BMI - body mass index

Figure 1 Example of tested probands

2.2 Methods

The experiment of measurement of probands' subjective feelings of comfort was carried out within simulation of physical strain on exercise bike in the laboratory of the CTVS. Subjective evaluation of feeling of comfort was performed by probands via system of questionnaires.

The results of the experiment were analysed and evaluated by means of mathematical – statistical methods. The experiment was conduct in February 2020. Monitoring of the temperature and humidity of the first layer of the sports military clothing, sensory feelings and written record of the overall comfort of t-shirts made by probands formed the bases of the experiment. The climatic conditions of the experimental environment were fulfilled with according to ISO EN 139 Standard atmospheres for conditioning and testing. During the experiment, the air temperature range was 20±2°C and relative humidity 65±2%. Subjective evaluation of probands' comfort perception was carry out in three phases. Testing of the ensemble of the t-shirts before the start of the physical activity on exercise bike presented the first phase. The experiment continued with the subjective evaluation of comfort feeling by probands while reaching heart rate frequency (HRF) 150 of permanent load on stationary bike and after the end of the test, which took 15 minutes. Analysis of data being measure and its evaluation represented the next phase.

Changes in the temperature of the first clothing layer and in its humidity, sensory perceptions and written record of the overall comfort being prepared by probands were monitor. Assessment via questionnaires was perform in order to verify the above-mentioned assumptions. System of questionnaires was focus on the four main evaluation fields from the point of view of clothing comfort perception. Subjective evaluation can also include individual preference of the user and garment design. Tested persons subjectively evaluated their thermal, moisture and sensory feelings. The overall subjective assessment of the t-shirt made by proband formed the part of the questionnaire as well. Probands noted their opinions to the questionnaire according to the scale that had 10 degrees of sensitivity before the test, in the middle of testing and at the end after finishing their physical activity. The highest value 10 represents optimal evaluation (excellent) within particular field of interest and degree 1 is the worst evaluation (unsatisfactory). To conclude, the overall subjective point evaluation was complete for each t-shirt. Data was obtained based on point evaluation of particular fields of clothing comfort perception.

Ten degrees ordinary scale was using for statistical evaluation of thermal, humidity, sensor and overall subjective feelings of probands. The median of ordinary scale and its 95% confidence interval was using for evaluation of resulting data. Data was classification into categories 0-10 and relative frequencies (f_i) and cumulative relative frequencies (F_j) were calculated according to the equations:

$$f_i=n_i/n \quad (1)$$

$$F_j=\sum_{i=1}^{j} fi \quad (2)$$

where n_i is the number of subjective evaluation of textile comfort classification into „i“ category and n is the total number of evaluators.

Median X_M was calculated based on the 2 steps approach. Median category M was determined in the first step F_M-$1<0.5$ and $F_M \geq 0.5$.

Median X_M was calculated in the second step:

$$X_M=M+0.5-(F_M-0.5)/f_M \quad (3)$$

95% confidence interval of the median *Med* was constructed for the assessment of classification significance into median category in the following way.

Cumulative frequencies F_D*, F_H* were determined that are, used for the construction of 95% confidence interval. For $\alpha=0.05$, $u1\text{-}\alpha/2=1.96$ is chosen, where $u1\text{-}\alpha/2$ is the quantile N (0.1).

$$(F_D^*, F_H^*)=0.5\pm0.5u1\text{-}\alpha/2/\sqrt{n} \quad (4)$$

Categories D a H were defined, in which F_D* and F_H* lie and correction coefficients were established according to the equations:

$$d=(F_D^*-F_{D-1})/f_D; \quad h=(F_H^*-F_{H-1})/f_H \quad (5)$$

Finally, interval of median confidence was calculated:

$$D-0.5+d\leq Med\leq H-0.5+h \quad (6)$$

3 RESULTS AND DISCUSSION

Subjective evaluation method represents highly important assessment of clothing comfort perception. Subjective evaluation is suitable for assessment of apparel appropriateness in particular conditions in which proband can occur and can directly express his or her feelings of comfort or discomfort. However, each individual prefers different material or clothing design and that is why it is really demanding to suggest sports military clothing, which meets the requirements of the whole group of probands.

3.1 Subjective evaluation by questionnaire system

The overall subjective point evaluation was compiled for each t-shirt. The assessment was acquired based on point evaluation of particular fields of comfort perception.

Probands comfort or discomfort perception while wearing specific t-shirt was express via graphical analysis by means of radar charts in the Figures 2-7.

Diagrams come out on the average values of all of evaluations made by probands for each t-shirt. In the radar charts, it is obvious that feeling of comfort from the point of view of moisture sensation has strongly decreased for the t-shirts No. 2, 4 and 6 within all of the evaluation phases. The smallest differences in comfort feeling within all of the evaluation fields are visible for t-shirt No. 1.

Thanks to the total point evaluation that is illustrated in the Figure 8, it is possible to analyze the behavior of each testing sample in all of the phases of the test. It can be observed how the tested t-shirt behaved within particular period of time and how the comfort perception of proband got worse or improved. Maximum of points possible to reach was 120. The rule was establish, the more points particular t-shirt obtains, the more conditions and assumptions to reach optimal comfort are met with no matter what physical strain in a short or long time.

Subjective t-shirts’ evaluation was divided into point assessment before the test, during the test and at the end of the test and the total evaluation for the whole period of testing. T-shirts reaching more than 90 points met determined conditions and assumptions to achieve optimal comfort during physical activity.

At the beginning of the test, the completely clothing ensemble of t-shirts achieved excellent or sufficient point evaluation. During the process of testing, t-shirts No. 6, 4 and 3-stated worse subjective feeling of comfort that was also evaluate by probands at the beginning of the test. Thermal feelings and moisture sensations also got worse for t-shirt No. 6. For the t-shirt No. 2, the values of subjective feeling of comfort were more than sufficient at the beginning but in the course of the test, the feeling of comfort strongly worsened. On the other hand, t-shirts No. 1 and 3 had the best results during the whole period of testing and they met all of the conditions to keep thermal, moisture, sensory feelings and total subjective feeling of clothing comfort during physical activity. T-shirts No. 6 and 4 proved critical values of moisture sensations and total subjective feelings at the end of the testing. They met given conditions and assumptions to reach optimal comfort during physical activity.

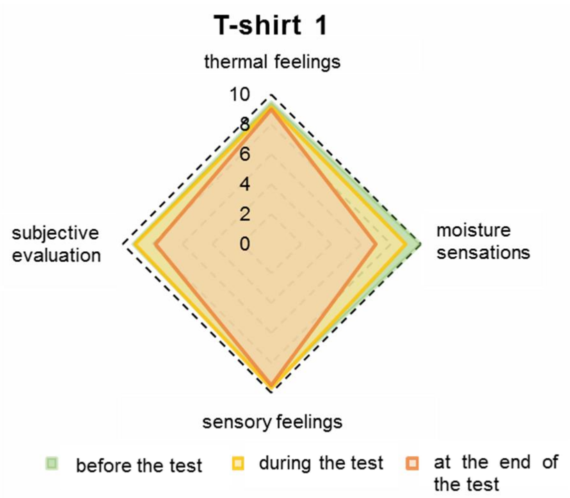


Figure 2 Diagram of testing T-shirt 1

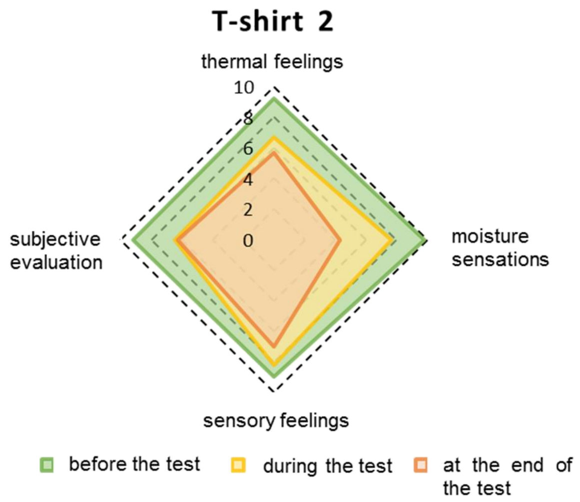


Figure 3 Diagram of testing T-shirt 2

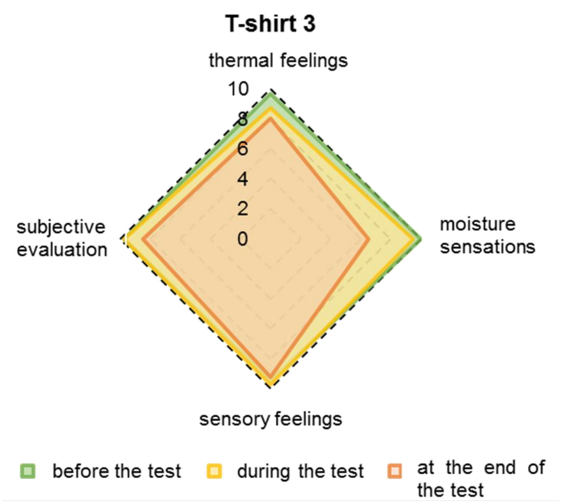


Figure 4 Diagram of testing T-shirt 3

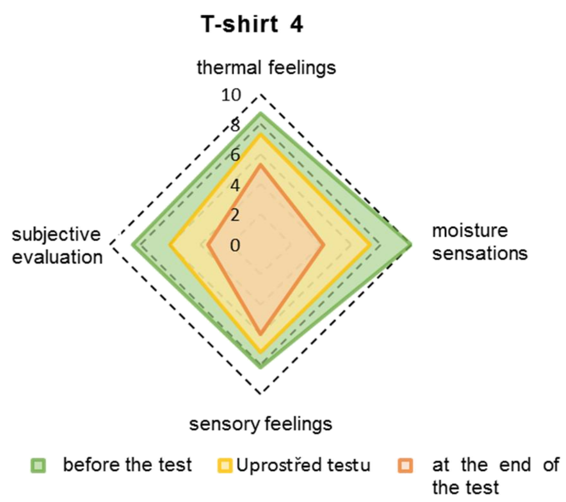


Figure 5 Diagram of testing T-shirt 4

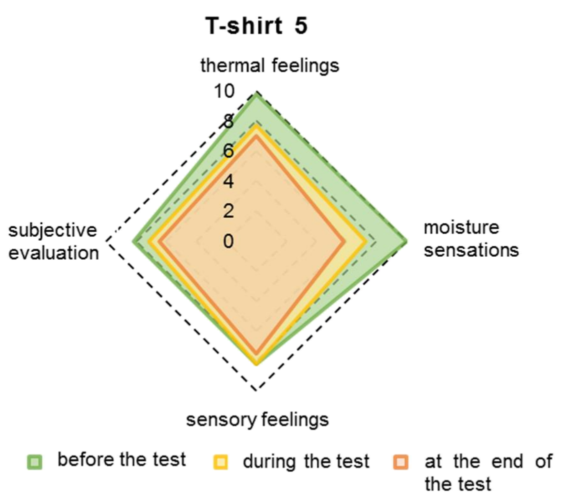


Figure 6 Diagram of testing T-shirt 5

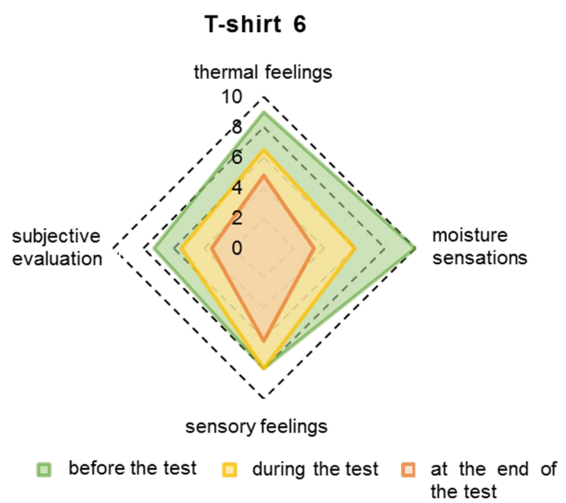


Figure 7 Diagram of testing T-shirt 6

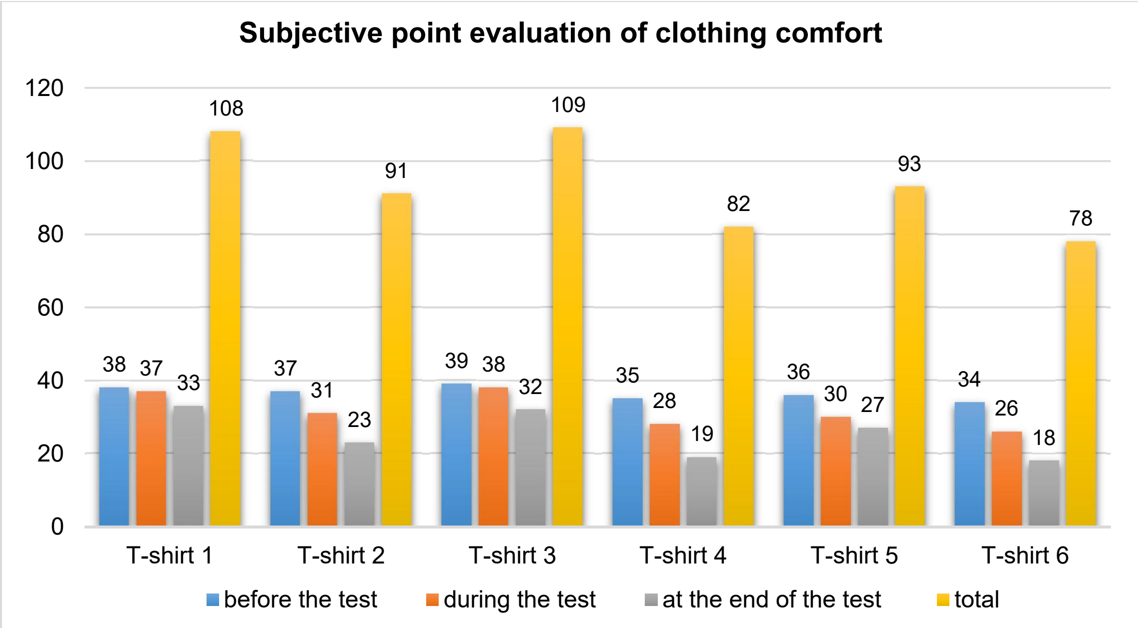


Figure 8 Total subjective point evaluation for all of the t-shirts

3.2 Statistical processing of results

The median of ordinary scale and its 95% confidence interval is using for statistical processing of results of subjective evaluation of comfort by probands in the course of physical strain on the exercise bike and for the verification of the analysis results' correctness. Values of medians being ascertain and classification into 10-degree scale are state in Table 3 and Figure 9 illustrates values of medians for all of the t-shirts within confidence intervals.

Table 3 Median value classification into 10 degree scale

Marking	T-shirt 1	T-shirt 2	T-shirt 3	T-shirt 4	T-shirt 5	T-shirt 6
Value of median	9.56	8.21	9.54	6.9	8.14	6.75
Evaluation scale description	excellent	above-average	excellent	average	above-average	average

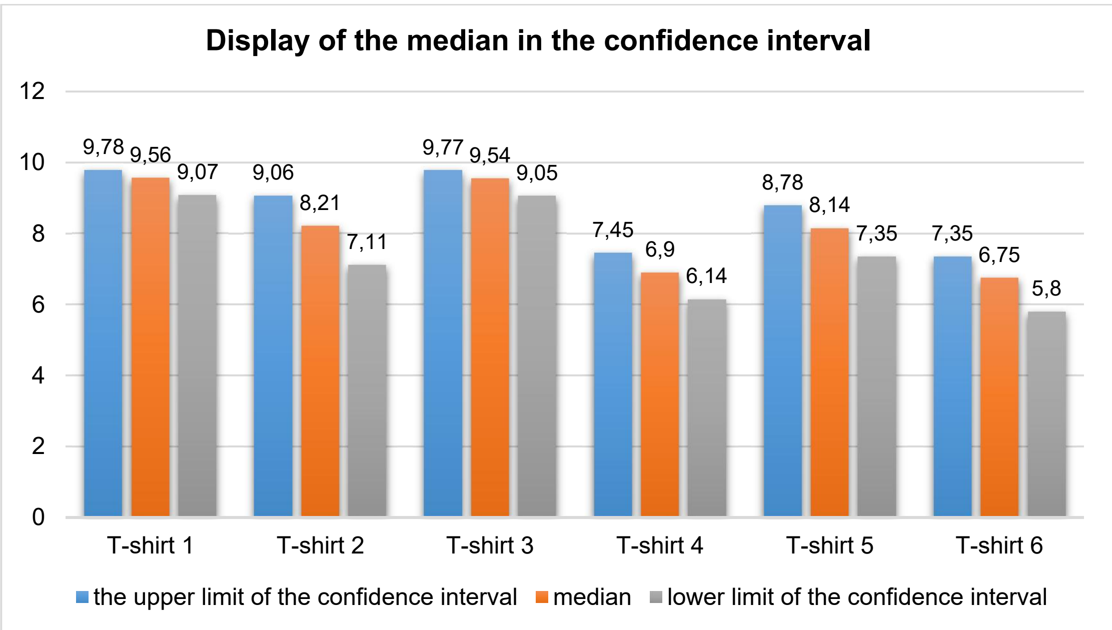


Figure 9 Median in the confidence interval for all of the measurements

If the confidence intervals overlap (which is the case of the t-shirts No. 1, 2, 3 and 5), they are not consider different from the point of view of clothing comfort level. It means that pursuant to the ascertained median values we can confirm the results of the analysis and evaluation of questionnaires.

3.3 Evaluation of the experiment

T-shirt samples No.1 and 3 are considered the best (excellent) based on the results of testing and its statistical processing. T-shirt No. 1 benefits from material properties of the front side and backside of knitted fabric so appropriate transfer of moisture and heat and free and comfortable sticking to the human body is suppose. T-shirt No. 1 is suitable not only for outside soft physical activities but also for the training in fitness center. T-shirt No. 3 is made of very soft and elastic knitted fabric and 100% merino wool, which while moistening, releases high quantity of sorption heat and assures breathability and comfort that is need for physical activities practising. Company Moira, a. s. is the producer of both of the evaluated t-shirts with the best results.

Next two t-shirts comparable from the point of view of comfort evaluation are the t-shirts No. 2 and 5, which were assess according to the same scale as above average. T-shirt No. 2 produced by the company Moira, a. s. is usable rather for winter season because it is warming. The same with the t-shirt No. 5, military garment with the specification Light thermo 2012, which is mainly use as the first layer on the body for layering of the other military garments for all of the seasons of the year.

T-shirts No. 4 and 6 were evaluated as average. Both of them are using as military clothing garments. T-shirt No. 6 is made of 100% cotton. It is necessary to count with the creation of significant amount of heat and moisture in the course of physical activity that intensifies feeling of discomfort caused by worsening of thermal, moisture and total subjective sensations. The research therefore proved that this military clothing garment does not meet appropriate conditions to reach comfort and it can be suppose that the performance of soldiers would be strongly influence by feeling of discomfort.

3.4 Further development of research

Capability of t-shirt material to keep the skin surface dry without sweat as long as possible is important to reach optimal clothing comfort. The longest period during which the t-shirt is able to take away and transport moisture without changing or significant increase of humidity in interlayer skin-clothes is required. During this process, the smallest increase of the body surface temperature is required at the same time. In case of significant temperature changes, it could come to the organism overheating and after the end of the physical activity and creation of heat in muscles to virulent body cooling and hypothermia. Therefore, it would be useful in future to conduct the evaluation via heat load determination (risk of the organism overheating) according to the WBGT index, as stated in the reference [7].

Future research in this particular field will be focus on the possibility to monitor temperature and moisture changes development inside the microlayer of the sportswear by means of the central wireless unit FlexiGuard. Based on the evaluation of temperature and moisture changes inside the microlayer of the sportswear, it is possible to determine heat load of the organism/ risk of the organism overheating according to WBGT. Risk of the organism overheating can be calculated and evaluated based on the index WBGT for the total evaluation of the clothing comfort of the first layer and it can be carry out separately for the front and backside of the t-shirt. Evaluation could be than divided in the average risk of the organism overheating and maximal risk of overheating. The other military sportswear garments, i.e. sport shoes, sweatpants and tracksuit jacket should be included in the further research activities.

4 CONCLUSIONS

If the soldier is required to reach appropriate performance and results during physical activity, military clothing of sufficient quality should be assure for him/her. The material of the clothes should be able to drain moisture away out of the body (sorption heat) in the form of vapour and at the same time, the material should become dry as fast as possible so as not to endanger the soldiers' health. Thermophysiological properties are influence not only by the clothing material composition but also by the standards of the clothing maintenance.

Based on the research being perform, materials made of merino wool or mixture of polyamide and polypropylene meet requirements placed on physiological comfort of soldier from the point of view of material composition and maintenance possibilities. That is why these textiles are recommended for the production of suitable quality sports clothing.

Generally, military clothing has to assure the best thermophysiological comfort of the user in highly different conditions and under physical strain. Especially sandwich structure of military clothing that means layering of particular clothing garments on each other should stay functional for the whole period of using. The first layer of clothes that takes sweat and vapour away out of the skin surface to the next clothing layers forms the basis of the clothes structure functionality. The first layer is in direct touch with skin, which is why the evaluation is focus not only on thermophysiological properties of the material from the point of view of its construction and material composition but also on evaluation of sensory feelings of a particular textile.

Based on the experiment results we can conclude that sports military t-shirts being implement and use in practice are on the average level from the point of view of comfort feeling evaluation under physical strain. Especially t-shirt No. 6 made of 100%cotton does not meet criteria determined to keep optimal conditions of clothing comfort. The wearers evaluated T-shirt No. 5 as above average so we suppose that it meets clothing comfort conditions.

Our team suggests substituting currently used sports military t-shirt (tested t-shirt No. 6) for the new garment in order to meet criteria of clothing comfort optimal conditions during soldiers' physical activities. Data related to evaluated t-shirts with the best results can be used as the source of information for the technical specification of material of personal use of soldiers, material composition and technical parameters' values and it should be involved in the tender documentation for the new clothing equipment. T-shirts No. 1 and 3 produced by the company MOIRA, a. s. obtained the best results.

5 REFERENCES

1. Hes L., Sluka P.: Introduction to the comfort of textiles, 1st edition, Liberec: Technical University of Liberec, 2005, 109 p., ISBN 80-708-3926-0 (in Czech)
2. Havelka A.: Transport properties of smart textiles, In the Proceedings of 13th International Conference Strutex, Faculty of Textile Engineering, Technical University of Liberec, 2006, IBSN 80-7372-135-X2
3. Hes L., Bajzik V., Dolezal I.: A new index of thermal comfort of sport dresses and underwear in wet state, In the International Conference on Emerging Trends in Traditional and Technical Textiles ICETT 2014, Jalandhar (India), 2014, IBSN 978-93-5156-700-4
4. Švecova J.: Conditions and evaluation of the physiological comfort of users of military clothing, Brno: University of Defence in Brno, 2019, pp. 87-98, ISBN 978-80-7582-305-2 (in Czech)
5. Ministry of Defence. NVMO no. 58/2017, Equipment prescription, Praha: Ministry of Defence, 2017
6. Ministry of Defence. NVMO no. 125/2014 Determination of equipment requirements and cash compensation, Praha: Ministry of Defence, 2018
7. Nagy L.: Evaluation of physiological properties of the first layer of clothing, Dissertation thesis, Liberec: Technical University of Liberec, 2015 (in Czech)

INFLUENCE OF PLASTICIZER AND BIOPLASTICIZER ON THE STRUCTURE AND MECHANICAL PROPERTIES OF THE PLA FIBRES

Zita Tomčíková[1], Anna Ujhelyiová[2], Katarína Holcová[1] and Marcela Hricová[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: *Nowadays, when great accent is placed on the ecology and thus also on biodegradable materials, the polylactic acid (PLA) proves to be one of the prospective materials for packaging and fibre industries. Brittleness of the PLA has a negative effect on the physical-mechanical properties of the fibres, which prevents its mass utilization in this field. Therefore, new solutions to reduce the brittleness of PLA fibres are constantly being sought. In this work, the influence of plasticizer and bioplasticizer contents on the structure and mechanical properties of PLA fibres was studied and compared. The advantage of the bioplasticizer is to ensure complete degradation of the PLA fibres under special conditions. From the structural properties, the birefringence and crystallinity were investigated and from the mechanical properties, the tensile strength, elongation at break and Young's modulus were studied. The modified PLA fibres were prepared by a discontinuous process of spinning and drawing.*

Keywords: *modified PLA fibres, structure, mechanical properties, plasticizer, bioplasticizer.*

1 INTRODUCTION

The high increase in global polymer production in the 20th century has led to the depletion of oil reserves, increased greenhouse gas emissions and the accumulation of polymer waste which also include textile materials made from synthetic polymers such as polypropylene, polyamide and polyester, which have excellent resistance to external influences. Due to the current crisis in the accumulation of solid polymer waste, the resistance of polymers is becoming a disadvantage and therefore the 21st century is focused on materials that will decompose in the natural environment, in soil or compost [1-4]. One of them is also fully biodegradable polymers polylactic acid (PLA) [5] which attract of various markets e.g. textile, packaging and automotive industries, as an eco-alternative to traditional petroleum-based commodity polymers [6-8].

Plasticizers or dispersants are additives that increase the plasticity or decrease the viscosity of a material. These 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 [9, 10]. Over the last 60 years more than 30,000 different substances have been evaluated for their plasticizing properties. At present, about 100 different plasticizers are produced worldwide, although only about 50 of these are classified as commercially important. According to 2014 data, the total global market for plasticizers was 8.4 million metric tonnes including 1.3 million metric tonnes in Europe [11, 12].

This paper represents the influence of two modificators, namely plasticizer and bioplasticizer on the properties of PLA fibres and also the influence of degree of uniaxial deformation on the supermolecular structure and basic mechanical properties of modified PLA fibres. The undrawn and drawn modified PLA fibres by discontinuous technological process were prepared. The obtained experimental results were compared with unmodified PLA fibre prepared under the same technological conditions.

2 EXPERIMENTAL AND METHODS

2.1 Materials

Polylactic acid produced by NatureWorks LLC (PLA) with MFI=27.7 g/10 min (210°C/2.16 kg) and two modifiers: 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 Fibre preparation

The modified PLA/PL fibres were prepared from mechanical mixing blend of PLA granulated polymer and plasticizer using the classical discontinuous process of spinning and drawing. The same process for preparation of PLA/BioPL fibres was used.

The constant processing conditions for preparation of both types modified PLA fibres were following: spinning temperature of 210°C, spinning die plate of 2x25 holes with diameter of 0.3 mm, final spinning process speed of 1500 $m.min^{-1}$, the drawing temperature of 80°C and final drawing process speed of 100 $m.min^{-1}$. The different drawing ratios (DR) DR = 1.2, 1.4, 1.6 and DR_{max} for modified PLA fibres were used.

2.3 Methods used

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

Crystallinity of fibres β represents the crystalline portion of fibre which may be evaluated using various methods. In this work DSC-Q20 apparatus TA Instruments was used for the evaluation of thermal properties of unmodified and modified PLA fibres. The non-isothermal process of analysis was performed. All samples of PLA fibres were heated by rate of 10°C.min^{-1} from 60 to 200°C under nitrogen flow. From melting endotherm of 1st heating of PLA fibres the melting enthalpy (ΔH_m) was determined. The crystallinity β of PLA fibres was calculated according to the following equation 1 [13]:

$$\beta = \frac{\Delta H_m - \Delta H_{cc}}{\Delta H_{m,0}} \cdot 100\% \tag{1}$$

where: ΔH_{cc} is the cold crystallization enthalpy of PLA fibres obtained during heating scan and $\Delta H_{m,0}$ is the melting enthalpy of a 100% crystalline PLA (93.6 $kJ.kg^{-1}$) [14].

Mechanical properties of unmodified and modified PLA fibres were measured using Instron 3345 equipment in accordance with the EN ISO 2062 and fineness was measured in accordance with the EN ISO 2060.

3 RESULTS AND DISCUSSION

In the preparation of PLA fibres, it was found that the modifiers PL and BioPL do not affect the spinning process. The spinning of all samples was technologically stable in the whole evaluated range of 1-5 wt.% of modifiers and was comparable with the preparation of the PLA standard fibre without modifiers.

By a discontinuous unidirectional deformation procedure, the modified fibres together with the standard fibre were drawn to drawing ratios of 1.2, 1.4, 1.6 and DR_{max}. The effect of plasticizer (PL) content on fibre drawing did not appear. PLA/PL fibres were drawn to the same maximum drawing ratio as the standard fibre at all plasticizer concentrations of 1-5 wt.%, DR_{max} 1.8. The effect of the bioplasticizer (BioPL) on the process of unidirectional deformation of PLA/BioPL fibres was manifested at higher concentrations of BioPL - 4 wt.% and 5 wt.%, at which the fibres were drawn to DR_{max} 1.82.

The measured structural parameters of undrawn and drawn PLA/PL and PLA/BioPL fibres are given in Table 1. The mechanical properties (tenacity and elongation) of undrawn modified fibres are given in Table 2 and drawn fibres are put into Figures 1-3. The changes in properties of modified PLA fibres are compared to the standard fibre of the respective sample series (fibres with 0% modifier).

3.1 Structure properties

At higher contents of PL in PLA polymer matrix 3-5 wt.%, the total orientation of the segments of macromolecular chains (birefringence) of undrawn fibres increased by 16-24% compared to the standard undrawn fibre (Table 1, columns for PLA/PL fibres). This is due to the plasticizing effect of the modifier, which facilitates the straightening of the segments of the macromolecular chains of the PLA polymer melt during fibre spinning. The crystallinity of the undrawn PLA/PL fibres is practically unchanged, which may be due to the amorphous nature of the plasticizer. Similarly, in undrawn PLA/BioPL fibres, the total orientation of the segments of macromolecular chains increased by 10-18% with BioPL content above 3 wt.%, while crystallinity did not change significantly even with this type of modifier (Table 1, columns for PLA/BioPL fibres).

Unidirectional deformation (drawing) causes the macromolecular chains and their segments to be straightened in the direction of the fibre axis, thus creating a fibrillar structure. This results in an increase in the structural parameters of birefringence and crystallinity. A significant increase in the orientation of the segments of macromolecular chains occurs already at the lowest drawing ratio DR 1.2, where the increase of birefringence of PLA fibres is about 100% compared to undrawn fibres DR 1.0 (Table 1).

Due to PL, there is a further increase in the orientation of the segments of macromolecular chains of the drawn fibres compared to the standard fibre even at the lowest PL content of 1 wt.% at all drawing ratios. The most significant increase in birefringence was recorded at contents of 3 and 4 wt.% of PL and on the other hand the higher contents of PL - 4 and 5 wt.% slightly reduced the crystallinity of the fibres (Table 1, columns for PLA/PL fibres).

Table 1 Supermolecular structure parameters of PLA fibres modified by PL and BioPL

Modifier content [%]	Drawing ratio (DR)	PLA/PL fibres			PLA/BioPL fibres		
		$\Delta n.10^3$	$CV_{\Delta n}$ [%]	β [%]	$\Delta n.10^3$	$CV_{\Delta n}$ [%]	β [%]
0	1.0	6.11	1.34	0.323	6.62	1.32	0.308
0	1.2	10.54	1.94	0.343	12.71	2.41	0.330
0	1.4	16.67	2.29	0.355	15.32	2.12	0.349
0	1.6	19.41	1.49	0.364	19.91	2.84	0.354
0	max	22.81	1.32	0.381	21.78	2.55	0.372
1	1.0	6.34	2.03	0.326	7.18	2.27	0.313
1	1.2	14.85	2.28	0.347	13.94	3.05	0.351
1	1.4	18.15	2.73	0.350	19.45	3.10	0.358
1	1.6	21.55	2.11	0.354	20.71	2.28	0.362
1	max	23.57	1.71	0.383	22.66	2.84	0.394
2	1.0	6.21	2.14	0.327	6.53	3.08	0.322
2	1.2	16.53	2.81	0.350	12.59	3.12	0.347
2	1.4	18.63	1.15	0.356	17.63	2.75	0.356
2	1.6	21.35	1.31	0.370	20.87	2.91	0.364
2	max	22.67	1.63	0.387	23.79	3.15	0.396
3	1.0	7.59	2.86	0.336	7.82	3.14	0.320
3	1.2	10.34	2.41	0.345	14.74	3.55	0.347
3	1.4	18.85	2.23	0.357	18.77	3.08	0.356
3	1.6	22.21	1.85	0.369	21.87	2.64	0.371
3	max	23.01	1.53	0.389	23.14	2.77	0.404
4	1.0	7.29	2.20	0.333	7.28	3.33	0.312
4	1.2	16.67	2.82	0.340	13.83	3.17	0.344
4	1.4	21.42	2.64	0.353	18.07	3.09	0.363
4	1.6	23.17	2.32	0.362	21.04	2.87	0.370
4	max	24.11	1.44	0.378	24.21	2.99	0.415
5	1.0	7.09	2.71	0.321	7.76	3.17	0.338
5	1,2	15.95	1.19	0.335	16.65	2.77	0.355
5	1,4	18.17	2.25	0.351	19.02	2.84	0.373
5	1,6	21.03	2.63	0.359	22.57	3.27	0.380
5	max	23.08	2.44	0.376	24.55	3.19	0.422

Table 2 Mechanical properties (tenacity and elongation) of undrawn PLA/PL and PLA/BioPL fibres

Modifier content [%]	PLA/PL fibres				PLA/BioPL fibres			
	Tenacity [cN/dtex]	CV_T [%]	Elongation [%]	CV_E [%]	Tenacity [cN/dtex]	CV_T [%]	Elongation [%]	CV_E [%]
0	1.07	5.4	121.0	5.9	1.03	2.8	136.7	3.9
1	1.09	5.4	136.0	6.5	1.00	5.8	121.3	5.1
2	1.08	4.3	124.3	5.6	1.04	7.5	115.9	5.2
3	1.13	5.1	112.6	3.2	1.03	3.8	116.7	9.9
4	1.14	5.4	109.1	5.5	1.14	8.0	112.9	5.9
5	1.05	5.0	116.1	7.9	1.21	4.9	104.5	5.5

Higher content of BioPL above 3 wt.% caused a significant increase in the orientation of the segments of macromolecular chains of drawn fibres by an average of 15% (Table 1, columns for PLA/BioPL fibres).

The crystallinity of the PLA/BioPL fibres with content of bioplasticizer 4 wt.% and 5 wt.% in fibres, increased by 13% compared to the standard fibre at the maximum drawing ratio (DR_{max}). It is partly due to the higher DR_{max} achieved with the stated BioPL contents.

The slight increase in crystallinity of the drawn PLA/BioPL fibres compared to the standard fibre may be due to the content of the crystalline component of the bioplasticizer, which acts as a nucleating agent.

3.2 Mechanical properties

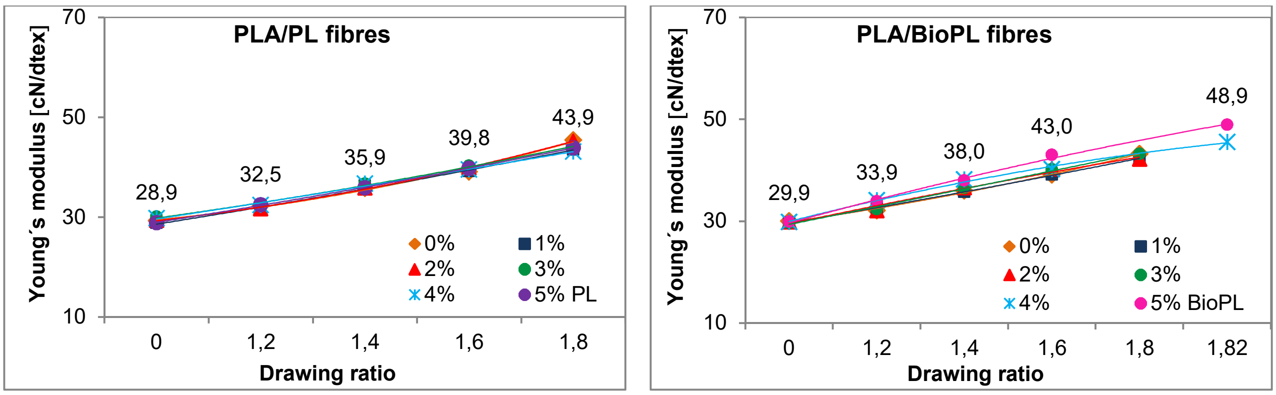
From the mechanical properties of undrawn PLA/PL fibres was found that, the effect of the plasticizer was not more pronounced in any of the evaluated mechanical properties (Table 2). For undrawn modified PLA/BioPL fibres, at higher bioplasticizer contents of 4 wt.% and 5 wt.% in the PLA polymer matrix, the tenacity was increased by 10-17% while reducing elongation by 24-32% absolute compared to the undrawn standard PLA fibre (Table 2).Young's modulus of elasticity was practically unchanged by the addition of the BioPL (Figure 1). Unidirectional deformation (drawing) leads to an increase in Young's modulus (Figure 1) and tenacity (Figure 2) which corresponds to the structural properties of the fibre (Table 1). Reciprocally, the elongation of the fibres decreases with the drawing ratio (Figure 3).

The tenacity of the drawn modified PLA/PL fibres was practically unchanged compared to the drawn unmodified PLA fibres at the same drawing ratios, which is probably related to the amorphous character of the plasticizer as already mentioned in the evaluation of the fibre structure. The highest tenacity of 2.24 and 2.25 cN/dtex was achieved for PLA/PL fibres containing 2 wt.% and 5 wt.% PL at their DR_{max}. Due to PL, the elongation decreases compared to the standard fibre at all drawing ratios up to a maximum of 28% absolute (Figure 3a). Young's modulus of elasticity of drawn modified PLA/PL fibres practically does not change with increasing plasticizer content (Figure 1a).

Unlike the plasticizer, the bioplasticizer positively affected the tenacity of PLA fibres. The tenacity of the drawn PLA/BioPL fibres was significantly increased by the influence of BioPL, at its content of 4 wt.% and 5 wt.% up to 50% compared to the standard fibres at the same drawing ratio (Figure 2b).

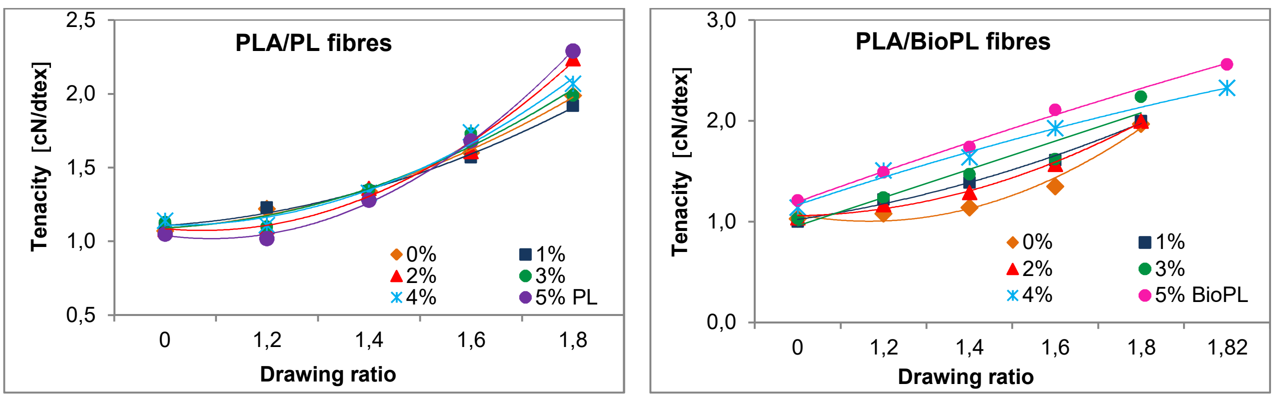
We can even state that with increasing BioPL content above 1 wt.%, the tenacity of the fibres also increases. This is probably due in part to the crystalline nature of the bioplasticizer, where the higher the bioplasticizer content, the more nucleation centers are formed, which has a positive effect on increasing the tenacity. The highest tenacity of 2.56 cN/dtex was achieved with a fibre containing 5 wt.% BioPL at its DR_{max} (Figure 2b).

With an increase in tenacity, there is a slight decrease in elongation up to max. 17% absolute compared to PLA standard fibres at the same drawing ratio. The Young's modulus of elasticity of the drawn modified PLA/BioPL fibres increased at 5 wt.% bioPL at DR_{max} by 13%, due to the effect of a higher drawing ratio compared to the standard fibre at DR_{max}. In other cases, the Young´s modulus of elasticity practically unchanged under the influence of the BioPL modifier (Figure 1).



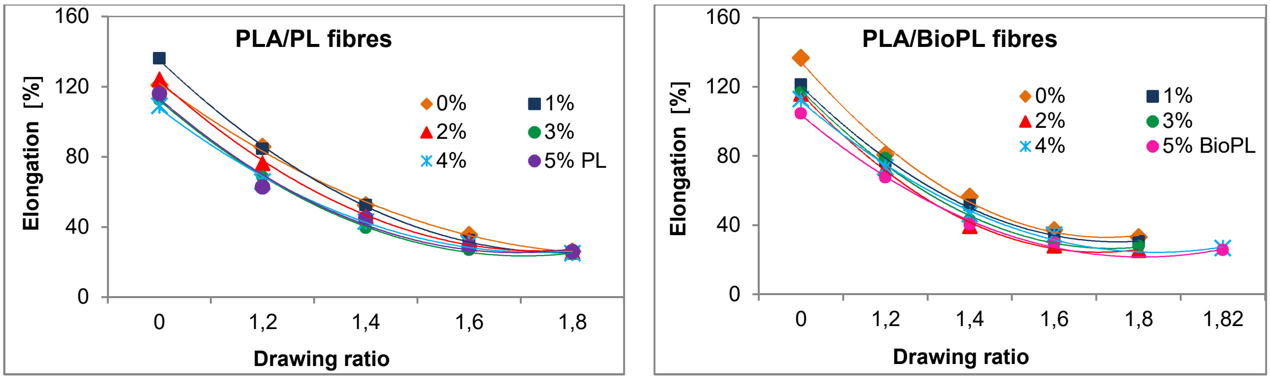
a) b)

Figure 1 The dependence of Young's modulus of PLA fibres on drawing ratio: a) fibres with the content of plasticizer (PL) and b) fibres with the content of bioplasticizer (BioPL) together with standard fibre; content of modifier is 1-5 wt.% in fibre. The values shown in the Figure 1 correspond to fibers containing 5 wt.% of modifier



a) b)

Figure 2 The dependence of tenacity of PLA fibres on drawing ratio: a) fibres with the content of plasticizer (PL) and b) fibres with the content of bioplasticizer (BioPL) together with standard fibre; content of modifier is 1-5 wt.% in fibre



a) b)

Figure 3 The dependence of elongation PLA fibres on drawing ratio: a) fibres with the content of plasticizer (PL) and b) fibres with the content of bioplasticizer (BioPL) together with standard fibre; content of modifier is 1-5 wt.% in fibre

4 CONCLUSION

The preparation of PLA fibres containing modifiers PL and BioPL was performed under the same conditions as the preparation of standard fibres. It was found that the addition of modifiers of 1-5 wt.% to the PLA polymer matrix did not affect the spinning process. Plasticizer PL also did not affect the discontinuous drawing process, modified PLA/PL fibres were drawn to the same drawing ratios as the standard fibre 1.2, 1.4, 1.6 and DR_{max}. PLA/BioPL fibres achieved a higher DR_{max} 1.82 at 4 wt.% and 5 wt.% of bioplasticizer.

The evaluation of the structural and mechanical properties of modified PLA fibres shows that the bioplasticizer has a more significant effect on the change of structural and mechanical properties compared to the plasticizer. This is probably due to their different nature, the plasticizer has an amorphous character and the bioplasticizer contains a small part of crystalline component. BioPL increases birefringence, slightly increases crystallinity in the fibres, and significantly increases tenacity while decreasing elongation. PL significantly increases the birefringence PLA fibres and slightly reduces the elongation of the fibres. PL has no significant effect on the tenacity. Young's modulus was practically unchanged by both modifiers.

ACKNOWLEDGEMENT: This work was supported by the Slovak Research and Development Agency under the contracts No. APVV-17-0078 and No. APVV-18-0187.

5 REFERENCES

1. Spierling S., et al: Bio-based plastics – A building block for the circular economy? Procedia CIRP 69, 2018, pp. 573-578, https://doi.org/10.1016/j.procir.2017.11.017
2. Auras R., et al (Eds.): Poly (lactic Acid): Synthesis, Structures, Properties, Processing and Applications, Published by John Willey & Sons, Inc., Hoboken, New Jersey, USA, 2010, 528 p., ISBN: 978-0-470-29366-9
3. Mochizuki M.: Synthesis, properties and structure of polylactic acid fibres, chapter 8 in Handbook of Textile Fibre Structure, Woodhead Publishing, 2009, pp. 257-275, https://doi.org/10.1533/9781845696504.2.257
4. Bauer J., et al: PLA in the post-consumer-recycling stream, Bioplastics Magazine 13 (06), 2018, pp. 18-19, ISSN 1862-5258
5. Sin L.T., et al: Overview of polylactic acid, chapter 1 in Polylactic Acid: PLA Biopolymer Technology and Applications, 2012, pp. 1-70, https://doi.org/10.1016/C2010-0-65966-9
6. Liu H., Zhang J.: Research progress in toughening modification of poly(lactic acid), Journal of Polymer Science Part B: Polymer Physics 49(15), 2011, pp. 1051-1083, https://doi.org/10.1002/polb.22283
7. Tan K.L.; et al: Overview of poly(lactic acid) production with oil palm biomass as potential feedstock, International Journal of Engineering and Applied Sciences 5(4), 2014, pp. 1-10
8. Li D., Jiang Y., et al: Preparation of plasticized poly (lactic acid) and its influence on the properties of composite materials, PLoS ONE 13(3), 2018, pp. 1-15, https://doi.org/10.1371/journal.pone.0193520
9. Cadogan D.F., Howick Ch.J.: Plasticizers, Ullmann's Encyclopedia of Industrial Chemistry, Wiley-VCH, Weinheim, 2000, doi:10.1002/14356007.a20_439
10. Malveda M.P.: Chemical Economics Handbook Report on Plasticizers, 2015, Available from https://ihsmarkit.com/products/plasticizers-chemical-economics-handbook.html
11. Godwin A.D.: Plasticizers, chapter 28 in Applied Plastics Engineering Handbook, Processing and Materials, Plastics Design Library, 2011, pp. 487-501, https://doi.org/10.1016/B978-1-4377-3514-7.10028-5
12. Drieskens M., et al: Structure versus properties relationship of poly(lactic acid). I. Effect of crystallinity on barrier properties, Journal of Polymer Science Part B: Polymer Physics 47(22), 2009, pp. 2247-2258, https://doi.org/10.1002/polb.21822
13. Cayuela D., et al.: Variation of microstructure of textured and fixed polylactide fibres with the texturing conditions, In: Book of Proceedings of the 5th International Textile, Clothing & Design Conference, Magic World of Textiles, Dubrovnik, Croatia, October 3-6, 2010, pp. 48-53

FIBRES FROM BIODEGRADABLE POLYMERS AND ADDITIVES FOR TEXTILE APPLICATIONS

Anna Ujhelyiová[1], Kristína Baníková[1], Jozef Ryba[2], Roderik Plavec[1], Veronika Hrabovská[1] and Marcela Hricová[1]

[1]Slovak University of Technology in Bratislava, Faculty of Chemical and Food Technology, Institute of Natural and Synthetic Polymers, Department of Plastics, Rubber and Fibres, Radlinského 9, 812 37 Bratislava, Slovak Republic
[2]Slovak University of Technology in Bratislava, Faculty of Chemical and Food Technology, Institute of Natural and Synthetic Polymers, Department of Polymer Processing, Krškanská 21, 949 05 Nitra, Slovak Republic
anna.ujhelyiova@stuba.sk

Abstract: *Poly-(lactic acid) (PLA) is a biodegradable polymer from renewable resources produced as potential alternative to the synthetic polymers. One of the alternative applications is a preparation of PLA fibres. The PLA fibres prepared by classical spinning technology do not have good mechanical properties, especially elongation at the break. The prepared PLA fibres are very brittle with bad processability. The modification of the PLA fibres with plasticisers and additives/nanoadditives is one of the perspective ways for improvement of processability of the PLA fibres and increasing of multi-functional properties of these fibres. This work focuses on the preparation of fibres from various types of PLA modified with nucleating agent talc. The effect of content of various PLAs and additives on rheological properties of blends was evaluated. The thermal, mechanical and thermo-mechanical properties of prepared fibres from PLAs and modifiers were monitored.*

Keywords: *poly-(lactic acid) fibres, talc, rheological behaviour, viscosity, mechanical and thermal properties.*

1 INTRODUCTION

Today, the use of polymeric materials is an essential part of human life. The products made from them are used in various fields. Increase of their consumption also brings the increasing waste at the end of their life/consumption cycle. This increases the global problem of waste accumulation that due to pollution of nature, oceans and other ecological areas. At the same time, there is a reduction of the fossil resources from which synthetic polymers are produced, too. One of the solutions of this problem is alternative to the synthetic polymers which are biodegradable polymers, primarily from renewable raw materials.

Biodegradable polymers can be defined as polymers that decompose into low-molecular products by the action of microorganisms and their enzymes. By combining the production of polymers from renewable sources and biodegradability, the possibility of extending the lifecycle of plastic products has emerged [1].

Poly-(lactic acid) (PLA) is highly universal, biodegradable, aliphatic polyester derived from 100% renewable resources. It is a thermoplastic polymer which may be partially crystalline or completely amorphous depending on the polymer backbone stereochemistry. Stereoisomers affect the properties of the polymer itself, its processing conditions, and the properties of the end product. Therefore, the processing by spinning and melt drawing is complicated. The preparation of monofilaments and multifilaments as well as non-woven textile structures is feasible in several ways, the processing conditions which are reflected in different properties of the fibres obtained [2, 3]. PLA is a unique polymer, which in many ways behaves like polyethylene terephthalate (PET) but also has many similarities to polypropylene (PP) [4].

This work focuses on the preparation of fibres from various types of PLA modified with nucleating agent. The effect of content of various PLAs and additives on rheological properties of blends was obtained. The thermal, mechanical and thermo-mechanical properties of prepared fibres from PLAs and modifiers were monitored.

2 MATERIALS AND METHODS

2.1 Materials

<u>Poly-(lactic) acid fibres</u>

In this paper the virgin poly-(lactic) acid INGEO^{TM} Biopolymer 6202D (PLA6) and INGEO^{TM} Biopolymer 4043D (PLA4) polymers produced by NatureWorks LLC., USA and nucleating agent talc Plustalc H05 (M) with particle size 1.8 μm and specific surface 12 $m^2.g^{-1}$ producer by Mondo Minerals were used for the preparation of PLA6/PLA4 or PLA6/PLA4/M fibres. The various types of PLA and/or nucleation agent were mechanically mixed and spinning using a laboratory line with single screw extruder having ratio screw of L/D=32, a spinning nozzle of 35 holes with diameter 0.3 mm, at the spinning temperature of 190°C and final spinning process speed of 250 m.min^{-1}. The undrawn fibres were drawn on the drawing ratio λ=2.5 at drawing temperature of 100°C.

The characterization of prepared PLA4/PLA6 and PLA4/PLA6/M fibres is in the Table 1.

2.2 Characterization methods

Rheological properties

Measurement of the rheological properties was evaluated by the capillary rheometer Gottfert RG20 at defined temperature 190°C. There was capillary with circle diameter with L/D = 30/1 in the range of shear rates from 360 to 9000 s^{-1}. On the basis of various rate of shifting of piston and measurement of pressure gradient there were generated uncorrected dependences of shear stress and viscosity on the shear rate for the evaluated blends for the determination of flow consistency index K and flow behaviour index n from Ostwald de Waele power (1):

$$\tau = K.\dot{\gamma}^n \tag{1}$$

where: τ is shear stress and $\dot{\gamma}$ is shear rate.

All blends are materials with the Non-Newtonian behaviour therefore all measured rheological parameters were corrected using Rabinowitsch correction.

Supermolecular structure

Differential scanning calorimetric (DSC) measurement:

DSC 1/700 STAReSystem DSC 1/750 from Mettler Toledo was used for the evaluation of the thermal properties of pure and dyed PLA fibres. Non-isothermal analysis of prepared PLA4/PLA6 and PLA4/PLA6/M fibres was performed. A sample of original fibre was isothermally held for 3 minutes at the 30°C and next heated at a rate of 10°C.min^{-1} from 30 to 190°C. All measurements were carried out in a nitrogen atmosphere. There was measured only 1st heating to the determined structure of prepared fibres during the spinning and drawing. From melting endotherms of 1st heating the glass temperature (T_g), enthalpy relaxation (ΔH_{ER}), temperature (T_{cc}) and enthalpy (ΔH_{cc}) of cool crystallization, melting temperatures (T_m) and melting enthalpies (ΔH_m) were determined.

The sound speed in fibres:

The internal structure arrangement of PLA4/PLA6 and PLA4/PLA6/M fibres affects the sound speed in substances. Higher arrangement of super-molecular elements of structure gives the higher sound speed in fibre. It is used for the determination of the level of fibre anisotropy that characterises the super-molecular structure of observed fibres. The sound speed in fibres is given the ratio of fibre length and the time needed for the transfer of acoustic nodes across this length (named c and expressed in km.s^{-1}).The sound speed in PLA fibres dyed in mass was measured by Dynamic Modulus Tester PPMSR (USA).

Mechanical properties

The mechanical properties are represented by tenacity at the break, elongation at the break and Young′s modulus. The mechanical properties (tenacity at the break σ, Young′s modulus E_Y and elongation at the break ε) of PLA4/PLA6 and PLA4/PLA6/M fibres were analysed using Instron 3343 equipment (USA). Measuring conditions were the fibre length of 125 mm and the clamping rate of 200 mm.min^{-1}. The average of at least 10 individual measurements was used for each fibre. The mechanical characteristics (tenacity at break, Young's modulus and elongation at the break) were determined in accordance with standard (Standard ISO 2062:1993).

Thermo-mechanical properties

Thermo-mechanical characteristics of PLA4/PLA6 and PLA4/PLA6/M fibres were measured by equipment Schimadzu TMA-50 (Japan). The deformation (extension l_2 or shrinkage l_1 [%]) and the temperature of first distortion of the fibres (T) were measured. The fibre was heated in the temperature range 30°C and 100°C, at the heating rate of 5°C.min^{-1}, fibre length 9.8 mm and at constant load; the dependence of the dimensional stability of fibre on the temperature was obtained from which the thermo-mechanical characteristics were determined.

Table 1 The characterization and fineness of the prepared PLA4/PLA6 and PLA4/PLA6/M fibres

PLA4/PLA6	c_{PLA4} [wt.%]	c_{PLA6} [wt.%]	T [tex]	PLA4/PLA6/M	c_{PLA4} [wt.%]	c_{PLA4} [wt.%]	c_M [wt.%]	T [tex]
10/90	10	90	85.6	30/70/0.25	30	70	0.25	103.6
20/80	20	80	87.1	30/70/0.5	30	70	0.50	86.8
30/70	30	70	106.3	30/70/0.75	30	70	0.75	85.6
40/60	40	60	83.1	30/70/1	30	70	1.00	79.3

3 RESULTS AND DISCUSSION

There were prepared two series of variously modified PLA fibres - PLA fibres with different contents of PLA4 and PLA6 and PLA fibres modified with various nucleation agent - talc content. Subsequently, the influence of PLA4 and nucleation agent on rheological, thermal, mechanical and thermo-mechanical properties of prepared fibres will be monitored (Tables 2-3, Figures 1-4).

Based on measurements of rheological properties, the higher PLA4 content decreases of the flow behaviour index *n* and increases the viscosities at two shear rates (1000 and 6000 s^{-1}) in comparison with the pure PLA6 that is the polymer produced for spinning process (Table 2). The higher talc content does not affect the flow behaviour of PLA4/PLA6/M (30/70/0-1) blends but the viscosity decreases significantly with the increasing of talc. The lower viscosity of PLA4/PLA6/M blends could provide their improved processability at the spinning and drawing and the preparation of fibres with the better structure and properties.

From the PLA4/PLA6 and PLA4/PLA6/M blends were prepared the fibres at the same conditions of spinning and drawing process. The observed properties – sound of speed, thermal parameter (glass temperature T_g, temperature T_{cc} and enthalpy ΔH_{cc} of cool crystallization, melting temperature T_m and melting enthalpy ΔH_m), mechanical (elongation at the break, tenacity at the break, Young′s modulus) and thermo-mechanical (temperature of first distortion of the fibres, deformation - shrinkage or extension) was evaluated for the PLA4/PLA6 and PLA4/PLA6/M fibres with drawing ratio λ=2.5. For the PLA4/PLA6 (30/70 and 40/60) and PLA4/PLA6/M (30/70/0.25-1.00) fibres the drawing ratio λ=2.5 represents the maximal drawing ratio. The PLA4/PLA6 fibres with composition of 10/90 and 80/20 the drawing ratio λ=2.5 does not represent the maximal drawing ratio. It is possible to draw these fibres to the higher drawing ratio λ=3.0. The drawing ratio λ=2.5 was selected to compare properties of all prepared fibres.

The super-molecular structure of the prepared PLA4/PLA6 and PLA4/PLA6/M fibres was evaluated on the basis of the estimate of orientation by the sound of speed as well as of the thermal parameters - glass temperature, temperature and enthalpy of cool crystallization, melting temperature and enthalpy by DSC analysis (Table 3). The sound of speed of PLA4/PLA6 fibres was decreased with the increase of PLA4 content. But at same composition of PLA4/PLA6 (30/70) in PLA4/PLA6/M the sound of speed was increased after incorporation of nucleating agent compared with the sound of speed of PLA4/PLA6 (30/70) fibres. This may be the result of different crystallization ability of PLA in presence of the nucleating agent. The glass temperature for the all prepared PLA4/PLA6 and PLA4/PLA6/M fibres is more or less the same. The difference can be observed at the temperatures and enthalpies of cool crystallization and melting enthalpies of the prepared fibres. The temperatures and enthalpies of cool crystallization decrease with the increase of PLA4 content in PLA4/PLA6 fibres. In the PLA4/PLA6 fibres with the 30% PLA4 there were achieved the lowest temperature and highest enthalpy of cool crystallization. After addition of nucleating agent, the PLA crystallization process was changed. The single peak of cool crystallization with value of 98.9°C obtained for the PLA4/PLA6 fibre was divided into double peak of cool crystallization for the PLA4/PLA6/M fibres with the temperatures of about 77°C and 101°C. There was also observed the decrease of enthalpies of cool crystallization after the incorporation of nucleating agent that was reduced with the increase of content of nucleating agent (from 6 to 70%). Similarly, melting enthalpies of PLA4/PLA6 fibres were decreased with the increase of the PLA4 content. The addition of nucleating agent in the PLA4/PLA6/M fibres increased the melting enthalpies in comparison with the PLA4/PLA6 (30/70) fibre but the growth of content of nucleating agent did not cause a change in the melting enthalpies of PLA4/PLA6/M fibres.

Table 2 The rheological parameters (n, η) of the prepared PLA4/PLA6 and PLA4/PLA6/M fibres

PLA4/PLA6	n	η [Pa.s]		PLA4/PLA6/M	n	η [Pa.s]	
		$\dot{\gamma}$ =1000 s^{-1}	$\dot{\gamma}$ =6000 s^{-1}			$\dot{\gamma}$ =1000 s^{-1}	$\dot{\gamma}$ =6000 s^{-1}
0/100	0.33	405	68	30/70/0	0.28	534	89
10/90	0.29	413	69	30/70/0.25	0.27	449	75
20/80	0.29	414	69	30/70/0.5	0.28	437	73
30/70	0.28	431	72	30/70/0.75	0.29	446	74
40/60	0.26	477	79	30/70/1	0.30	439	73
100/0	0.24	534	89	-	-	-	-

Table 3 The sound of speed (C), glass temperature (T_g), temperature (T_{cc}) and enthalpy (ΔH_{cc}) of cool crystallization, melting temperature (T_m) and melting enthalpy (ΔH_m) of prepared PLA4/PLA6 and PLA4/PLA6/M fibres

PLA4/PLA6; PLA4/PLA6/M	C [m.s^{-1}]	T_g [°C]	T_{cc} [°C]	ΔH_{cc} [J.g^{-1}]	T_m [°C]	ΔH_m [J.g^{-1}]
10/90	2246	63,1	104.9	14.7	164.4	31.8
20/80	2148	63.6	101.9	13.8	163.5	33.1
30/70	2067	62.6	98.9	17.4	161.8	26.3
40/60	2141	63.9	102.8	13.3	163.1	27.4
30/70/0.25	2264	62.9	76.9 100.6	16.1	162.6	30.2
30/70/0.5	2270	62.9	77.1 102.3	5.8	162.5	30.1
30/70/0.75	2191	63.1	76.8 100.8	12.2	162.4	30.6
30/70/1	2129	62.6	76.6 101.8	13.6	162.4	29.7

For the prepared PLA4/PLA6 and PLA4/PLA6/M fibres there were evaluated the mechanical properties like elongation at the break, tenacity at the break, Young′s modulus in accordance with standard (Standard ISO 2062:1993) (Figures 1, 2). With the growth of PLA4 in the PLA4/PLA6 fibres the tenacity at the break and Young′s modulus were reduced with the highest decrease for PLA4/PLA6 fibre with the PLA4 content of 30%. At the same the elongation at the break of PLA4/PLA6 fibres was decreased with the growth of PLA4 content. This is in conflict with the theory that expects that increase of tenacity and Young′s modulus decreases elongation. This can be explained by the higher values of the elongation at the break. The high values of the elongation at the break and the lower values of tenacity at the break and Young′s modulus can show that the drawing process was not realised at the optimal preparation conditions.

At the evaluation of the mechanical properties (elongation at the break, tenacity at the break, Young′s modulus) of PLA4/PLA6/M fibres with the content of 30% PLA4 and 0.25-1.00% nucleating agent it can be stated that elongation at the break decreases and tenacity at the break and Young′s modulus increase. This may be the result higher orientation and crystallinity of PLA4/PLA6/M fibres in comparison with the PLA4/PLA6 fibres.

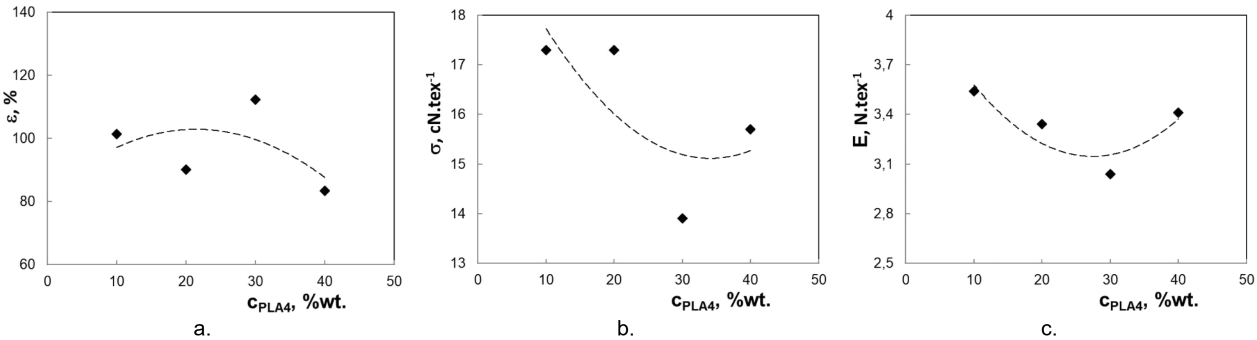


Figure 1 Dependencies of elongation at the break ε (a), tenacity at the break σ (b), Young′s modulus E_Y (c) on the PLA4 content of PLA4/PLA6 fibres

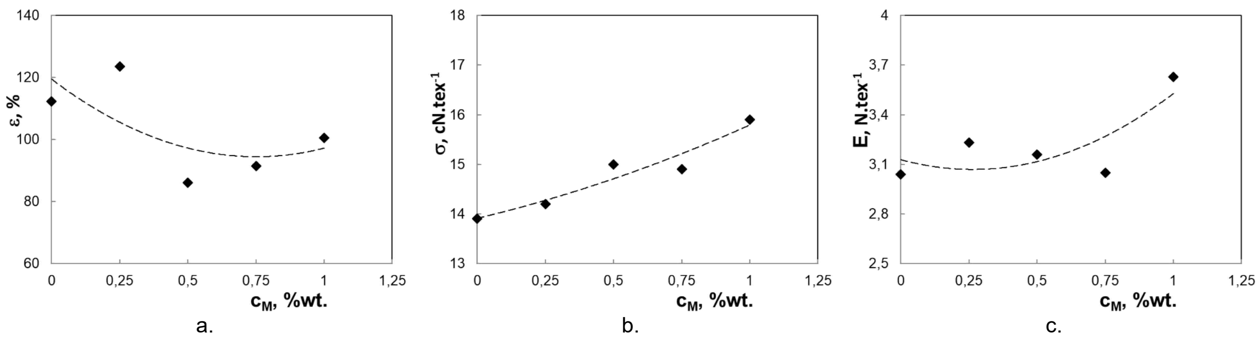
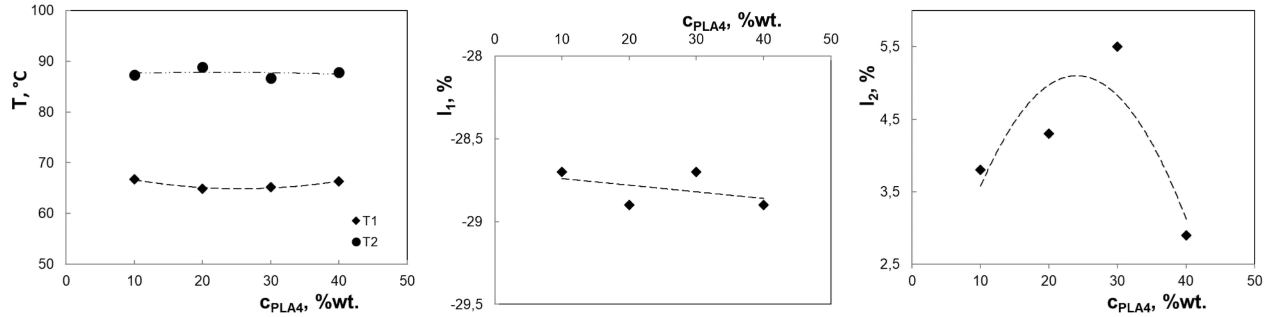
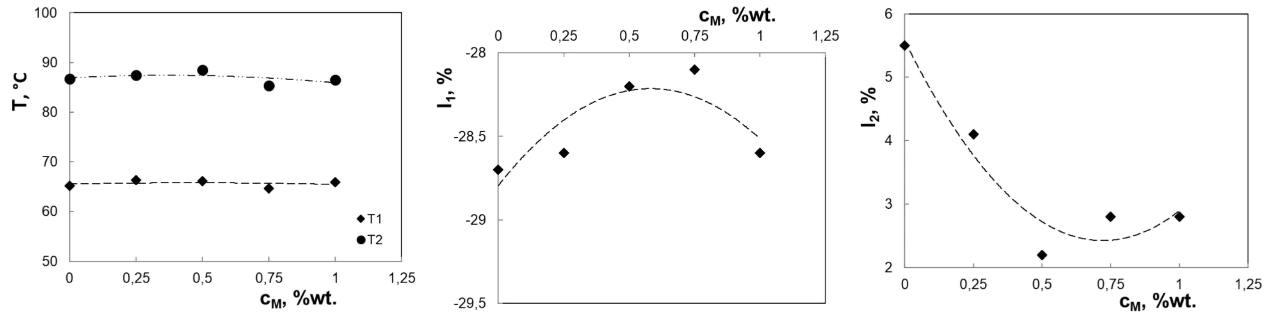


Figure 2 Dependencies of elongation at the break ε (a), tenacity at the break σ (b), Young′s modulus E_Y (c) on the talc (M) content of PLA4/PLA6/M fibres



a. b. c.

Figure 3 Dependencies of temperature of first distortion of the fibres T (a), deformation (shrinkage l_1, b), deformation (extension l_2, c) on the PLA4 content of PLA4/PLA6 fibres



a. b. c.

Figure 4 Dependencies of temperature of first distortion of the fibres T (a), deformation (shrinkage l_1, b), deformation (extension l_2, c) on the talc (M) content of PLA4/PLA6/M fibres

At the evaluation of thermo-mechanical properties (temperature of first distortion of the fibres, shrinkage/extension) there were observed the different behaviour of PLA4/PLA6 and PLA4/PLA6/M fibres (Figures 3, 4). The temperatures of shrinkage as well as temperatures of extension of all prepared PLA4/PLA6 and PLA4/PLA6/M fibres did not change in the full observed range of PLA4 (10-40%) and nucleating agent (0.25-1.00%) content. At the heating process of all prepared PLA4/PLA6 and PLA4/PLA6/M fibres temperature (about 65°C) it was observed as the first shrinkage at the temperature about 65-68°C and as the second extension at the temperature about 88-90°C. At the PLA4/PLA6 fibres the shrinkage was increased with the increase of PLA4 content. But the increase of nucleating agent content caused the reduction of shrinkage. This can be explained by the reinforcing effect of particles of nucleating agent at the lower temperatures. At the higher temperature during the heating process PLA4/PLA6 as well as PLA4/PLA6/M fibres were deformed. The extension of PLA4/PLA6 fibres rises with the increase of PLA4 to the 30% content. At the 40% PLA4 there were observed the reduction of extension of PLA4/PLA6 fibres. But the increase of content of nucleating agent induced the reduction of extension of PLA4/PLA6/M fibres. On the basis of obtained results from thermo-mechanical properties it is possible to say that the PLA4 affects as the plasticizer in the PLA6 and the nucleating agent affects as the reinforcement in the PLA4/PLA6 systems for preparation of fibres.

4 CONCLUSION

The experimental work was focused on the preparation of fibres from various types of PLA and nucleating agent. There were prepared the PLA4/PLA6 and PLA4/PLA6/M fibres with the various content of PLA4 (10-40%) and various content of nucleating agent (0.25-1.00%). There was evaluated orientation, thermal, mechanical and thermo-mechanical properties. On the basis of obtained results following conclusions can be stated:

- the orientation of PLA4/PLA6 and PLA4/PLA6/M fibres was decreased with the increase of PLA4 content as well as with the increase of content of nucleating agent;
- the addition of nucleating agent changes the thermal behaviour - crystallization ability of PLA6 in PLA4/PLA6/M fibres in comparison with crystallization ability of PLA6 in the PLA4/PLA6 fibres;
- the tenacity at the break, elongation of the break and Young's modulus decrease with the increase of PLA4 content;

- the tenacity at the break and Young′s modulus increase and elongation at the break decreases with the increase of content of nucleating content;
- on the basis of obtained thermo-mechanical properties it can be to say that the PLA4 behaves as plasticiser in PLA4/PLA6 fibres and nucleating agent behaves as reinforcement in the PLA4/PLA6/m fibres.

ACKNOWLEDGEMENT: *This work was supported by the Slovak Research and Development Agency under the contract No: APVV-17-0078.*

5 REFERENCES

1. Sin L.T.; Rahmat A.R., Rahman W.A.W.A.: Polylactic Acid; PLA Biopolymer Technology and Applications, Elsevier, Oxford, UK, 2013, ISBN: 978-1-4377-4459-0
2. Drumright E.R.; Gruber P.R., Henton D.E.: Polylactic Acid Technology, Advanced Materials 12(23), 2000, pp. 18411846, https://doi.org/10.1002/1521-4095(200012)12:23<1841::AID-ADMA1841>3.0.CO;2-E
3. Gupta V.B., Kothari V.K.: Manufactured Fibre Technology, 1st edition, Chapman and Hall, (eBook), 1997, 661 p., DOI 10.1007/978-94-011-5854-1
4. Avérous L.: Polylactic Acid: Synthesis, Properties and Applications, chapter 21 in Monomers, Polymers and Composites from Renewable Resources, Elsevier, Oxford, UK, 2008, pp. 433-450, ISBN: 978-0-08-045316-3

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