VLÁKNA a TEXTIL

FIBRES AND TEXTILES

4

Volume 24.
December
2017

ISSN1335-0617

Indexed in:

Chemical Abstracts,

World Textile Abstracts

EMDASE

Elsevier Biobase

Elsevier GeoAbstracts

VÚTCH CHEMITEX

Trenčianska univerzita Alexandra Dubčeka v Trenčíne
Fakulta priemyselných technológií v Púchove

VÚCHV

Spoločnosť priemyselnej chémie
SSVCH

TECHNICAL UNIVERSITY OF LIBEREC
Faculty of Textile Engineering

STU
FCHPT

Fibres and Textiles
Vlákna a textil

Published by

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

Vydáva

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

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

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

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

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

Order of the journal from abroad – excepting Czech Republic
Objednávka časopisu zo zahraničia – okrem Českej Republiky
SLOVART G.T.G, s.r.o. EXPORT-IMPORT
Krupinská 4, P.O.Box 152, 852 99 Bratislava, SK
Tel: 00421 2 839 471-3, Fax: 00421 2 839 485
e-mail: info@slovart-gtg.sk

Typeset and printing at — *Sadzba a tlač*

FOART, s.r.o., Bratislava

Journal is published 4x per year — Časopis vychádza 4x ročne
Subscription 60 EUR — Ročné predplatné 60 EUR

ISSN 1335-0617

Evidenčné číslo MKCR SR Bratislava EV 4006/10

Fibres and Textiles (4) 2017
Vlákna a textil (4) 2017

December 2017

Content

TEXTILE TECHNOLOGIES

3 *J. Švecová, A. Havelka and L. Nagy*
MEASUREMENT OF PHYSIOLOGICAL PROPERTIES OF MILITARY CLOTHING IN SIMULATION OF CLIMATIC CONDITIONS IN SELECTED AREAS OF THE WORLD

9 *J. Barabáš, Ľ. Balogová, M. Gála and B. Babušiak*
CONDUCTIVE PATHS AND INFLUENCE OF THEIR INTERCONNECTION ON TRANMISSION OF ELECTRIC SIGNAL IN SMART CLOTHING

15 *M. Kolinova, M. Syrovatkova, P. Komarkova and R. Tresnak*
THE THERMAL AND POROUS PROPERTIES OF PROTECTIVE RUBBER BOOTS

22 *A.I. Rubanka, N.V. Ostapenko, M.M. Rubanka, O.V. Kolosnichenko and K.L. Pashkevich*
EXPERIMENTAL RESEARCHES ON DETERMINATION OF RELIABILITY INDEXES OF HEAT-PROTECTIVE MATERIALS

30 *V. Vlasenko, P. Smertenko, S. Bereznenko, S. Arabuli, V. Kucherenko*
SYNTHESIS OF METALS NANO-PARTICLES IN THE POROUS STRUCTURE OF TEXTILES FOR UV-SHIELDING

34 *O. Zakharkevich and S. Kuleshova*
DEVELOPMENT OF THE METHOD OF SCALING PATTERNS AND VIRTUAL GARMENTS FORMS

41 *O. Zhdanova, S. Bereznenko, N. Bereznenko and D. Novak*
TEXTILE MATERIALS MANUFACTURING FEATURES WITH THE USE OF ANTIMICROBIAL ADDITIVES

NANOMATERIALS

47 *N.P. Suprun, A.V. Brichka and S.Ya. Brichka*
SYNTHESIS AND INVESTIGATION OF AGAR-AGAR GELS FILLED BY HALLOYSITE NANOTUBES FOR MEDICAL USE

FIBRE-FORMING POLYMERS

51 *Z. Tomčíková, A. Ujhelyiová, P. Michlík, Š. Krivoš, and M. Hricová*
THE INFLUENCE OF FLUORESCENT PIGMENT ON STRUCTURE AND MECHANICAL PROPERTIES OF MODIFIED PP AND PLA FIBRES

REVIEW ARTICLE

58 *M. Azeem, A. Boughattas, J. Wiener and A. Havelka*
MECHANISM OF LIQUID WATER TRANSPORT IN FABRICS; A REVIEW

66 *O.V. Yezhova*
PROGNOSING DEVELOPMENT OF TEXTILE NANOTECHNOLOGIES

MEASUREMENT OF PHYSIOLOGICAL PROPERTIES OF MILITARY CLOTHING IN SIMULATION OF CLIMATIC CONDITIONS IN SELECTED AREAS OF THE WORLD

J. Švecová[1], A. Havelka[2] and L. Nagy[2]

[1]*Department of Logistics, University of Defence, Kounicova 65, 662 10 Brno, Czech Republic*
[2]*Department of Clothing, Technical University of Liberec, Studentska 2, 461 17 Liberec, Czech Republic*
jana.svecova@unob.cz; antonin.havelka@tul.cz; ladislav.nagy@tul.cz

Abstract: *The paper presents results of measurements of selected thermal-physiological properties of military clothing fabrics in simulation of climatic conditions in selected areas of the world. The aim of the research was to test and compare old and new sandwich structures of military clothing and provide description of their basic characteristics relating to selected utility properties such as heat resistance R, thermal conductivity λ and vapour resistance Ret. The result of the research is delivery of suitable sandwich structures of clothing according to real climatic conditions, under which they are used. The results of experimental measurement allow to verify functionality and suitability of military clothing used in various areas of the world by objective measurement in simulation of real climatic conditions under European standard EN 60721-2-1:2014 that sets the types of climate characterized by the values of air temperature and humidity.*

Keywords: *physiological properties, thermal conductivity, heat resistance, water vapour permeability, textile sandwich, military clothing.*

1 INTRODUCTION

Physiological comfort of a person is closely related to transport of air and liquid humidity, heat transfer through individual clothing layers and air flow in clothing. Utility properties and comfort of clothing influence physical processes in clothing as well as interactions of clothing with user's skin and with environment. Good thermal and physiological properties of military clothing are important, particularly if they cannot be easily replaced or postponed as it is common in clothing intended for casual wear or fitness. Suitable construction solution of clothing that also influences how clothing while being worn is adapted and allows free move is also important [1]. By assessing physiological properties we endeavour for more authentic and accurate presentation of actual functional value of the textile and clothing product [2]. We comprehensively assess comfort of the clothing product depending on the reaction of human organism, climatic environment and clothing system, which the surveyed person is wearing. The clothing system of military clothing consists of several layers of individual military clothing. The main objective of clothing layering is to achieve synergy during transport of heat, humidity in individual clothing layers and to avoid occurrence of unpleasant feelings under the conditions of hotness, cold or humidity.

Reference [4] is primarily focused on the possibilities for objective assessment of selected thermo-physiological properties and touch of the first layer of clothing, which is in direct contact with user's skin. Final assessment of comfort is based on common assessment according to the index of comfort because the first layer of clothing must not only transfer heat and humidity from skin to textile surface (or to other textile layers) but the users must also have good feelings when their skin touches the clothing. If one of the clothing layers is chosen incorrectly, a non-functional layer ensues and then the whole system does not function. Long-lasting state of user's discomfort, e.g. a soldier who feels uncomfortable, has negative effect not only on user's performance while executing tasks but due to hypothermia or hyperthermia of organism; the user's health can be endangered. Due to variable temperatures in various areas of the worlds, layering of individual clothing components needs to be adjusted. The number of clothing layers differs and is adopted according to given climatic conditions and equipment requirements and protection of the user-soldier. Correct function of the clothing barrier layer is also important for correct function of the textile sandwich, particularly if exposed to adverse ambient conditions. Membrane of this layer must show not only good capacity to let vapour through but also to have sufficient resistance to pressure water effect [5].

2 PERFORMED RESEARCH ACTIVITIES

The research builds on previous experiment, in which the effect of sandwich structure of military clothing of the old and new types of layering on the properties of physiological comfort was solved. Thermal insulation properties were measured in individual samples of military clothing textiles and in layered sandwich were measured to verify the effect. Thickness and permeability of the material were measured too. Measurements were carried out in the laboratory of the Department of Clothing of the Textile Faculty at the Technical University in Liberec within processing of a partial aim of a diploma project when solving the issues of Innovation of Special Functional Clothing for Army [3].

All measurements were carried out in compliance with ČSN EN ISO under standard conditions for testing of textiles at the temperatures of 20°C and 65% relative humidity. Thermal insulation properties were measured by device FOX 314. Device FOX 314 is a heat flow meter from a company TA Instruments which is designed for measuring thermal conductivity. Air permeability tester SDL M021S and fabric thickness tester SDL MO34A both from a company SDL Atlas were used for a measurement air permeability of samples and for measurement thickness according ISO standards. More details about devices and their characteristics could be find out on a website of theirs manufacturers or in a datasheets.

Measurements proved that thermal insulation properties of the old and new types of military clothing layering were maintained. In the new type of sandwich in protective layer, utility properties such as waterproofing and resistance to water penetration were improved. These new properties affected air permeability of the third barrier layers of clothing and of the entire sandwich structure of military clothing. Results of the experiment implied that the jacket of TERMO 2010 type can be worn without protective layer, without the sandwich structure consisting of individual layers losing its function. The above stated ascertained facts prove that each individual material has its unique functional properties.

Such particular characteristics of individual clothing layers need to be known exactly and they need to be composed into the correct system of textile sandwich structure by layering according to the users'/soldiers' needs for given environment, where they will function. There are many other factors that influence thermal insulation properties of clothing. Besides already mentioned permeability of the textile, it is occurrence of humidity, particularly liquid humidity in the textile and in layers. Textile structure, its compressibility, filling and other parameters of the textile are also important. For correct function of the clothing, it is equally important to know and follow correct maintenance of special clothing so that the clothing keeps its utility properties.

3 MATERIALS AND METHODS

3.1 Methodology

The following experiment was proposed to verify ascertained material properties and assumption for achieving optimum comfort of military clothing in simulation under real climatic conditions at various areas of the world. Assessment of clothing focuses on the most important thermal-physiological properties of clothing, i.e. its thermal insulation properties and vapour resistance. Testing samples of new military clothing that are used under field conditions by Czech Army (hereinafter AČR) were used for the experiment. In Table 1, there is an overview of military clothing that were used and their material composition.

Table 1 Overview of used military clothing and their material composition and origin

Marking	Material name	Material composition	Producer
1	Light thermo 2012	85% functional polyester with silver ions content, 9% antistatic fibre, 6% polyamide	Monitex Czech s.r.o., Tabor
2	Hard thermo 2012	91 % functional polyester with silver ions content, 9% antistatic fibre	Monitex Czech s.r.o., Tabor
3	Undershirt, short sleeve	100% cotton	Sintex a.s.
4	Undershirt, long sleeve	82% cotton, 18% polyamide	Sintex a.s.
5	Shirt 2000	50% polyester, 50% cotton	Marlway, s.r.o.
6	Blouse 95	50% polyester, 50% cotton	Koutny spol. s r.o., Prostejov
7	Blouse ripstop	50% polyester, 50% cotton	Koutny spol. s r.o., Prostejov
8	Sweater 95	30% wool, 70% polyacrylonitrile	Blazek Praha a.s.
9	Insert thermo	100% polyester	Jitex Comfort s.r.o., Pisek
10	Jacket thermo 2010	45% polyester, 45% polyamide, 10% elastane	Goldeck Textil GmbH, Austria
11	Coat 95	51% polyester, 49% cotton	Otavan Trebon, a.s.
12	Coat insert	100% polyester	Otavan Trebon, a.s.
13	Jacket ECWCS 2000	Top layer 100% polyamide, climatic membrane 100% PTFE (polytetrafluorethylene), under layer is laminate with a layer of lining knit of 100 % polyamide	Vyvoj, odevni druzstvo v Tresti
14	Jacket ECWCS 2012	Top layer 100% polyamide, climatic membrane 100% PTFE (polytetrafluorethylene), under layer is irregular polymeric coating of 100% polyamide	Goldeck Textil GmbH, Austria

If we think of possible deployment of the AČR troops in all areas of the world except Arctic areas, we will work with four climatic types in compliance with ČSN EN 60721-2-1 (038900) [6]. The standard sets the types of climate characterized by the values of air temperature and humidity. In Table 2, there are the input values of environment simulation for measurements of thermal insulation properties according to the type of selected climate listed.

Table 2 Input values of environment simulation for measurement of thermal insulation properties according to the type of selected climate

Type of climate	Temperature of lower board [°C]	Temperature of upper board [°C]
Cold	35	-20
Temperate	35	5
Arid	35	10
Tropical	35	20

Thermal conductivity of the material represents capability of the material to conduct heat under given conditions. Heat resistance is capability of the material to resist to heat transmission. So a good thermal insulation material has low thermal conductivity and high heat resistance. On Figure 1, there is device FOX 314 used for measuring of thermal conductivity of the samples of sandwich materials.

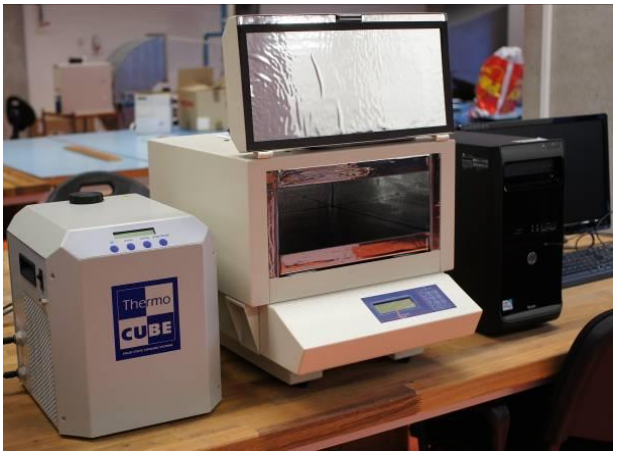


Figure 1 Machine FOX 314 for measurement the thermal properties of materials

Temperature of lower board of the FOX device simulates temperature of human skin and temperature of upper board simulated temperature of the environment according to selected climate. For calculation of thermal insulation properties of textile sandwich it is necessary to know thickness of the material. Thickness of material *t* [mm] was ascertained using digital thickness gauge SDL MO34A according to ČSN EN ISO 5084 (800844) - determination of thickness of textiles and textile products. Contact pressure was set at 70 Pa in accordance with the standard [7]. To measure the values of thermal flux the values of thermal conductivity λ [W/(m.K)] and heat resistance *R* [(m^2.K)/W] were counted. In Table 3, there are formulas for calculations of thermal conductivity and thermal resistance. The resulting value of thermal insulation of clothing is set using the calculation of heat resistance of textile sandwich (see Table 3) and it is expressed in the unit called 'CLO', where 1 clo equals to 0.155 [(m^2.K)/W]. In the thermal comfort standards it is recommended to use clothing with 1 clo in winter conditions and 0.5 in summer conditions under standard conditions at the temperature of 21°C, air flow of 0.1 [m/s] and relative humidity < 50%.

Table 3 Formulas for calculation of thermal conductivity λ and thermal resistance R (User Manuals FOX 314)

Formula for calculation	Description of the quantity and properties
$U1 = \lambda L \times 10$	U1 – value of thermal flow through the sample + air [W/(m^2.K)] λL – thermal flux of the lower board [W/(m^2.K)]
$U2 = \frac{Ubp \times U1}{Ubp - U1}$	Ubp ≈ 6.67 [W/(m^2.K)] U2 – heat permeability through the sample [W/(m^2.K)]
$\lambda = U2 \times \frac{t}{1000}$	λ – thermal conductivityof material [W/(m.K)] t – thickness of material [mm]
$R = \frac{1}{U2}$	R – thermal resistance of textile sample [m^2.K/W]

Water vapour resistance *Ret* [m^2.Pa/W] was measured using Sweating Guarded Hotplate (hereinafter SGHP) according to ISO 11092 [8]. Model 8.2 is located in the laboratory of the Department of Clothing. It was developed by Measurement Technology Northwest, Seattle, USA (hereinafter MTNW USA) and it is designed for measuring of thermal insulation properties (heat resistance *Rct*) and resistance to water vapour (vapour resistance *Ret*) of textiles and other materials according to ČSN EN 31092, ISO 11092 [8] and ASTM F 1868 in their entirety [9]. Overall view of the SGHP device built in climate chamber Vötsch VC 0018 is in Figure 2 and detail of the SGHP device is in Figure 3.

Measured lower Ret value indicates better utility properties of the material. Material has better capability to let vapour through, i.e. material resists less to water vapour penetration. So we can deem the measured values of textile sandwiches *Ret*<6 excellent and the values of *Ret*<12 good and the values of *Ret*<20 sufficient. The value of *Ret*>20 represents an almost non-permeable material.

3.2 Clothing used for the experiment

Based on comparison and analysis of used kinds of clothing and knowledge of the AČR members from previous foreign missions, 13 types of the systems

of layering military clothing (hereinafter "sandwiches") for experimental measurement were identified. Two types of sandwich can be used for cold and temperate types of climate. 3 kinds of sandwiches were identified for cold type of climate, 5 kinds of sandwiches were identified for temperate type of climate, 2 kinds of sandwiches were identified for arid type of climate and 5 kinds of sandwiches were identified for tropical type of climate. The sandwiches consist of fourteen parts of military clothing that are layered on each other as required for given climatic area. Combination of different types of military garments including comparison of new and old type of a sandwich of clothing is in Table 4. It is evident that the new type of clothing layering for a cold climate contains one layer of the clothing less than in the old type.

Figure 2 The SGHP 8.2 device located in climate chamber Vötsch VC 0060

Figure 3 Detail of the SGHP 8.2 device

4 RESULTS AND DISCUSSION

Based on the methodology suggested, measurement of thermal-physiological properties of the sandwiches made of the military clothing material stated in Table 1 was carried out. Measured results of the experiment in simulation of real climatic conditions in various areas of the world are stated in Table 5. Stated results of the thermal conductivity, water vapour resistance are the average of three samples and are stated with the accuracy of 4 decimal places. Based on the values measured using the FOX device, thermal resistance of textile sandwich samples was set and dimensionless quantity of clothing insulation CLO was calculated. Resulting values for individual textile sandwiches of clothing are stated in Table 5.

Table 4 Type and combination of military garments used for measuring of textile sandwich divided according type of climate

Type of climate	Sandwich type	Combination of garments (marking- name), according layers of clothing					Sandwich thickness under load 70 [Pa] t [mm]
		1st Layer	2nd Layer	3rd Layer	4rd Layer	5th Layer	
Cold	A-Old type	4-Undershirt, long sleeve	8-Sweater 95	6-Blouse 95	12-Coat insert	11-Coat 95	17.48
	B-New type	1-Light thermo 2012	2-Hard thermo 2012	10-Jacket thermo 2010	14-Jacket ECWCS 2012		4.55
	C-New type	1-Light thermo 2012	2-Hard thermo 2012	9-Insert thermo	13-Jacket ECWCS 2000		6.08
Temperate	B	1-Light thermo 2012	2-Hard thermo 2012	10-Jacket thermo 2010	14-Jacket ECWCS 2012		4.55
	C	1-Light thermo 2012	2-Hard thermo 2012	9-Insert thermo	13-Jacket ECWCS 2000		6.08
	D	1-Light thermo 2012	2-Hard thermo 2012	10-Jacket thermo 2010			4.1
	E	4-Undershirt, long sleeve	8-Sweater 95	6-Blouse 95			6.15
	F	4-Undershirt, long sleeve	2-Hard thermo 2012	6-Blouse 95			3.17
Arid	G	1-Light thermo 2012	2- Hard thermo 2012	7-Blouse ripstop			2.32
	H	1-Light thermo 2012	2-Hard thermo 2012	6-Blouse 95			2.54
Tropical	I	3-Undershirt, short sleeve	7-Blouse ripstop				1.07
	K	1-Light thermo 2012	7-Blouse ripstop				1.17
	L	5-Shirt 2000	7-Blouse ripstop				0.87
	M	3-Undershirt, short sleeve	6-Blouse 95				1.28
	N	1-Light thermo 2012	6-Blouse 95				1.46

Table 5 Measured and calculated values of made textile sandwiches of military clothing for selected types of climate

Type of climate	Sandwich type	Vapour resistance *Ret* [(m^2.Pa)/W]	Thermal conductivity λ [W/(m.K)]	Thermal resistance *R* [(m^2.K)/W]	Clothing insulation CLO [-]
Cold	A	44.9470	0.0366	0.4782	3.09
Cold	B	**28.2147**	0.0256	0.1775	**1.15**
Cold	C	32.2843	0.0297	0.2047	1.32
Temperate	B	28.2147	0.0263	0.1730	1.12
Temperate	C	32.2843	0.0304	0.1989	1.28
Temperate	D	**11.9686**	0.0298	0.1375	**0.89**
Temperate	E	19.1776	0.0382	0.1611	1.04
Temperate	F	**11.1580**	0.0339	0.0934	**0.60**
Arid	G	**9.1494**	0.0293	0.0791	**0.51**
Arid	H	10.2198	0.0317	0.0802	0.52
Tropical	I	**5.1906**	0.0247	0.0432	**0.28**
Tropical	K	**5.3310**	0.0312	0.0374	**0.24**
Tropical	L	5.5925	0.0251	0.0346	0.22
Tropical	M	7.0702	0.0299	0.0428	0.28
Tropical	N	7.0311	0.0316	0.0462	0.30

4.1 Clothing insulation

Dimensionless quantity 'CLO' reaches, depending on the type of clothing, various values and under common conditions it typically ranks between the values of 0-2 [-]. The value of 1 clo represents thermal balance at ambient temperature of 21°C. For example the value of 0 clo is stated for naked body, 0.6 clo for summer clothing, 2 clo for skiing equipment, 3 clo for light polar equipment, 4 clo for hard polar equipment. Required values of clothing insulation clo for achieving the thermal balance and feeling of comfort depends not only on ambient conditions but also on occurrence of humidity, physical activity, i.e. production of heat and other conditions.

Measured values of clothing insulation clo stated in Table 5 are only slightly different for arid type of sandwiches number 7, 8 that achieve insulation of c. 0.5 clo and for tropical type of climate of sandwich number 9-13 that have clothing insulation at the level of 0.2-0.3 clo. More significant differences in clothing insulation according to clo are shown in textile sandwiches tested for temperate type of climate that rank from 0.6 clo to 1.28 clo. The above stated clo values comply with the requested value of insulation according to the standard and with conditions and type of climate, in which they are commonly used. The CLO values of insulation for textile sandwiches number 2 and number 3 tested for cold type of climate are low/insufficient and reach only the values of 1.15 and 1.32 clo. Only the old type of sandwich number 1 consisting of 5 layers shows sufficient insulation of clo at the level of 3.09. Sandwich number 1, however, does not comply with regard to low vapour permeability. No significant difference in clo clothing insulation in sandwiches No. 2 and No. 3 for two different types of climatic conditions was recorded at the experiment.

4.2 Water vapour resistance of textile sandwiches

Low vapour resistance of the clothing is important for achieving good comfort of the user while wearing the clothing. So a decisive utility property for reaching optimum comfort while wearing the clothing is low value of water resistance of textile sandwich *Ret* [(m^2.Pa)/W]. Based on this requirement, the most suitable type of clothing sandwich for given climatic conditions is clothing with as low vapour resistance *Ret* [(m^2.Pa)/W] as possible. In subsequent Table 6, there are the most suitable sets of the clothing textile sandwiches for individual climatic conditions selected according to this criterion.

Table 6 The most suitable types of the textile sandwiches of clothing according to thermal insulation CLO [-] and vapour resistance *Ret* [(m^2.Pa)/W]

Type of climate	Sandwich type	Vapour resistance *Ret* [(m^2.Pa)/W]	Clothing insulation CLO [-]
Cold	B	28.2147	1.15
Temperate	D	11.9686	0.89
Temperate	F	11.1580	0.60
Arid	G	9.1494	0.51
Arid	H	10.2198	0.52
Tropical	I	5.1906	0.28
Tropical	K	5.3310	0.24

5 CONCLUSIONS

The decisive utility property inevitable for reaching good comfort of the user while wearing military clothing under various climatic conditions is particularly low water vapour resistance of clothing *Ret* and, with regard to ambient conditions, sufficient insulation of clothing during given activity of the user.

Particularly in the areas, where increased emphasis is in thermal insulation properties of clothing such as the areas of temperate and cold zones, good thermal insulation capacities of clothing are, besides low vapour resistance of clothing, important requirements

for clothing. Another requirement for clothing is resistance to external weather adverse effects, particularly water waterproofness, i.e. resistance to pressure water. Assuming that layers of clothing are selected properly, lower number of clothing textile layers means achieving better vapour permeability through clothing, i.e. lower vapour resistance *Ret*. The other way round, higher number of clothing layers leads to better thermal insulation property of clothing. However, with higher number of clothing layers the vapour permeability worsens and there is a risk of dew point origination. Vapour condensation in inner layers of clothing or directly on barrier layer of clothing subsequently causes further worsening of vapour permeability and overall decreasing of user's comfort.

Based on comparison of selected textile sandwiches of military clothing and comparison of two of their utility properties - vapour resistance *Ret* [(m^2.Pa)/W] and clothing insulation CLO [-], we can recommend the following combinations of clothing for individual zones:

- For tropical zone: sandwich type I (Light thermo 2012/ Blouse ripstop).
- For arid zone sandwich type G (Light thermo 2012/ Hard thermo 2012/ Blouse ripstop).
- For temperate zone sandwich type D (Light thermo 2012/ Hard thermo 2012/ Jacket thermo 2010).
- For cold zone sandwich type B (Light thermo 2012/ Hard thermo 2012/ Jacket thermo 2010/ ECWCS 2012). However this type has relatively low thermal insulation, which is given by its small thickness of only 4.55 [mm].

Selection of suitable (optimal) parameters, i.e. the ratio of utility properties '*Ret'* and 'CLO', is very individual and it depends on other conditions such as, e.g. planned application of clothing and period for using clothing, and so each of the types of sandwiches mentioned herein has its alternative stated in Table 6 or 5 allowing suitable selection of clothing according to specific requirements and preferences. Water vapour permeability, i.e. low vapour resistance '*Ret'*, is the most important utility property for highly functional clothing and that is why it determines suitability of selection of individual layers of clothing.

6 REFERENCES

1. Havelka A.: Transport properties of smart textiles, In the 13th International Conference Strutex. Faculty of Textile Engineering, Technical University of Liberec, 2006, IBSN 80-7372-135-X
2. Svecova J.: Influence of sandwich structure of military clothing on physiological comfort, New approaches to securing state security, Brno, University of Defence, 2016, ISBN 978-80-7231-455-3
3. Svecova J.: Innovations of special functional clothing for the army, Diploma Thesis, Technical University of Liberec, Department of Clothing, Liberec, 2014
4. Nagy L., Koldinska M., Havelka A., Jandova S.: The methodology for evaluation and predicting of clothing comfort for functional apparel, Industria textila, 2017 (In press)
5. Havelka A., Kus Z., Nagy L.: Possibilities of testing and evaluation of functional membrane textiles, Fibres and Textiles 23(4), 2016, pp. 42-46, ISSN: 1335-0617
6. CSN EN 60721-2-1. Classification of environmental conditions Part 2-1: Environmental conditions appearing in nature - Temperature and Humidity, Praha: Czech Office for Standards, Metrology and Testing, 2014, p. 12
7. ČSN EN ISO 5084 (800844). Textiles - Determination of thickness of textiles and textile product, Praha: Czech Office for Standards, Metrology and Testing, 1999. p. 16
8. EN ISO 11092. Textiles - Physiological effects - Measurement of thermal and water-vapour resistance under steady-state conditions (sweating guarded-hotplate test), 2014
9. ASTM F 1868. Standard Test Method for Thermal and Evaporative Resistance of Clothing Materials Using a Sweating Hot Plate, 2014

CONDUCTIVE PATHS AND INFLUENCE OF THEIR INTERCONNECTION ON TRANMISSION OF ELECTRIC SIGNAL IN SMART CLOTHING

Ján Barabáš[1], Ľudmila Balogová[2], Michal Gála[1] and Branko Babušiak[1]

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

Abstract: *Smart clothing containing electroconductive fibres, integrated into construction of textile material, are an alternative for continuous long-term monitoring of human biomedical signals. Operational elements located in the smart clothing are interconnected by conductive paths enabling transmission of data gained via textile sensors to a control and communication unit from where they are transferred to mobile or PC using wireless technology. Method of interconnection of the conductive paths with operational elements of the clothing depends mainly on character of materials used (electroconductive fibre – metal/plastic/textile material). Emphasis is placed on establishment of a stable connection with required transmission characteristics. The paper present results of measuring transmission characteristics of the conductive paths, embroidered with electroconductive thread on a non-conductive textile material, terminated with metal press fasteners. Electrical resistance of the conductive paths for the whole uninterrupted conductive path length, specific segments (right and left) of the conductive path with the metal press fastener and the both segments connected with the metal press fastener was evaluated. Transmission characteristics of harmonic signal (sin) and non-harmonic rectangular signal for frequency ranging from 1 Hz up to 300 kHz with input voltage of 1 V and 3 V were evaluated on a solid joint made by closure of the metal press fasteners. Results of the measurement confirmed trouble-free transmission of the harmonic and non-harmonic signal using proposed conductive paths and satisfactory quality of the output signal without any deformations.*

Keywords: *smart clothing, electroconductive sewing thread, conductive path, metal press fasteners, electric resistance, harmonic signal, non-harmonic signal*

1 INTRODUCTION

Monitoring of human physiological signals using intelligent clothing is based on a concept of so-called Body Sensor Networks (BNS) with an emphasis placed on sensing systems, autonomous primary data processing, miniaturization and last but not least also on reliable interconnection of specific BNS components [1-4]. The sensors have analog outputs, representing physiological parameters, from which a picture about health condition of a patient is established. Conductive paths (Wired Body Area Network) or wireless interconnections (Wireless Body Area Network) are used in the system for power supply, signal transmission to the sensors and data transmission to a data bus. Analog data are converted to digital form in the data bus and they are transmitted to a local central unit e.g. smartphone (PDA). They can be further wirelessly transmitted from the local central unit e.g. to a healthcare system (Remote System) [5, 6].

Major task of the conductive paths is transmission of electrical biosignals, sensed from textile electrodes (e.g. ECG sensors [7, 8]), which are manifestation of electrical activity in a living organism. The biosignals are based on electrical properties of muscle and neural tissue. Electrocardiography (ECG), using electrodes placed on the human body, measures difference of voltage as manifestation of propagation of action potential in myocardium. The active electrodes act as sensors, detecting electrical signals, generated by the heart and conducted through the heart tissue. Electrocardiography (ECG) is a process of recording electrical activity of the heart in a form of electrocardiogram, i.e. recording time change of electrical potential caused by heart's electrical activity in a form of ECG curves [9].

Quality of the output electrical biosignals transmitted by means of conductive paths is influenced by properties of materials used to prepare the conductive paths, by way of incorporation of the conductive paths into the structure of textile material and by stability of interconnection of the conductive paths with functional components of the intelligent clothing. Basically, the conductive paths consist of electroconductive fibres made from 100% metal (e.g. copper, silver) or polymer containing conductive particles (e.g. carbon) and/or fibres with conductive surface treatment (core/shell structured bicomponent fibres – e.g.

polyamide/silver). A possibility how to create conductive paths is embroidering electrical circuit on a textile substrate with an electroconductive sewing thread incorporating electroconductive fibres, enabling electrical signal transmission. This embroidering technology substitutes an uncomfortable system of cables common on traditional ECG monitoring methods. Special attention should be given to the method of interconnection of the conductive paths with functional components of the clothing. Emphasis should be placed on establishment of a stable interconnection with required transmission characteristics. A necessary condition is to ensure resistance of the connection to mechanical stress and propose an appropriate configuration responding to the required application.

Quality of the output biosignal can be characterized and evaluated by transmission characteristics such as e.g. harmonic and square signal for specific heart rate at particular input voltage. Periodic, indefinite, cyclic signals serving as a medium for information transfer are involved. Graphical evaluation of the transmission characteristics is a way how to confirm functionality of the electrical circuit in a form of conductive paths and biosignal transmission.

2 EXPERIMENTAL

Technology of conductive paths prepared from electroconductive sewing thread with metal accessories attached at the end of the conductive path for stable interconnection of the conductive paths and functional components of the intelligent clothing is described in the experimental part. Besides, method for measurement of transmission characteristics of the conductive paths used for evaluation of quality of the output signal is described as well.

2.1 Materials

The conductive paths were prepared from electroconductive sewing thread containing Elitex®, commercially available conductive multifilament fibre, using embroidering technology. Core of the Elitex® conductive fibre is polyamide covered by a thin layer of pure silver. Electrical resistance of the sewing thread was on a level of cca 17 Ω/m.

The embroidering technology was used to achieve flexible interconnection of the functional modules/components of the electronic circuit. The conductive path consisted of a series of stitches created by interlocking upper and bottom electroconductive sewing thread. Each conductive path consisted of two independent segments (right and left segment) with a length of 10 cm. A system of metal textile accessories was proposed to connect two segments into one conductive path. Respective part of the metal textile accessories (metal button and/or metal snap fastener) was attached at one end of each segment. Strong bond and electrical contact was established by interlocking the conductive segments. A conductive path unbroken by metal accessories with a length of 20 cm was prepared as well. It was used to evaluate influence of interconnection of the conductive paths (fibres) with metal accessories on transmission characteristics of the electrical signal. Preparation of the conductive paths is described in Table 1 and photodocumentation of the conductive paths is shown in Figure 1a-1d.

Table 1 Characteristics of the prepared conductive paths

Designation of the conductive path	Description of preparation of the conductive path
VC1	Conductive path with a length of 20 cm
VC2	Conductive path consists of two independent segments of conductive paths with a length of 10 cm. At one end of the conductive path of each segment there is a conductive area with dimensions of 0.5 x 0.5 cm, created by irregular stitching with conductive sewing thread, to which respective part of a metal button was attached mechanically by riveting. The other end of the conductive path of each segment is finished by free end of the electroconductive sewing thread. A strong bond and interconnection of the both segments to one conductive path is established by interlocking the both parts of the metal button
VC3	Conductive path consists of two independent segments of conductive paths with a length of 10 cm. At one end of the conductive path of each segment there is respective part of a metal snap fastener (spring socket and stud) sewn by free end of the electroconductive sewing thread used to prepare the conductive path. The other end of each segment is finished by free end of the electroconductive sewing thread. A strong bond and interconnection of the both segments to one conductive path is established by interlocking the both parts of the metal snap fastener
VC4	Conductive path consists of two independent segments of conductive paths with a length of 10 cm. At one end of the conductive path of each segment there is a conductive area with dimensions of 0.5 x 0.5 cm, created by manual stitching with conductive sewing thread, on which respective part of metal snap fastener (spring socket and stud) was sewn. The other end of conductive part of each segment is finished by free end of the electroconductive sewing thread. A strong bond and interconnection of the both segments to one conductive path is established by interlocking the both parts of the metal snap fastener

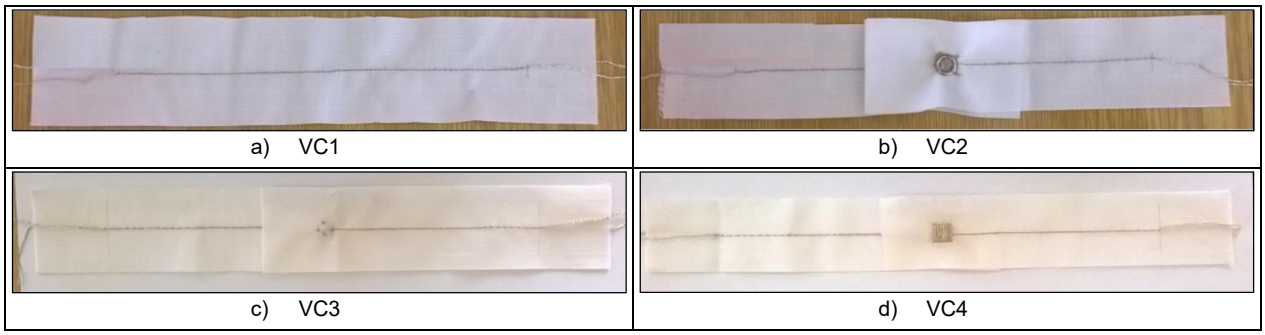


Figure 1 Conductive paths

Electrical resistance and transmission characteristics were evaluated on samples prepared this way.

2.2 Measurements and evaluation methodology

The transmission characteristics of the conductive threads and interconnection of left and right segments (sample VC2, VC3 and VC4) were evaluated by measuring the electrical resistance [Ω] and quality of signal transmission (amplitude measurements and visual inspection of the wave form).

The first phase included a simple evaluation of the electrical resistance measured using the Agilent 34404A laboratory precision multimeter from defined points of measurement. The average value from three measurements was calculated and is listed in the corresponding table of results - left segment, right segment and interconnected segments, from which we calculated the resistance of the snap fastener interconnection itself. Sample VC1 only includes the total impedance of the electro conductive thread since no snap fastener interconnection is present.

The second phase included the testing of harmonic signal transmission. The harmonic signal was generated using the Rigol DG4162 signal generator within the 1Hz to 300 kHz range, with a peak-to-peak amplitude of 1 V and transmitted over the electro conductive threads.

The third phase of measurements included the testing of square signal transmission - to mimic the 3 V transistor-transistor logic (TTL) used in subsequent application of the electro conductive threads in our intelligent clothing prototype. Square signal with frequencies from 1 Hz to 300 kHz was evaluated and transmitted over the electro conductive threads.

For phase 2 and phase 3 we evaluated the amplitude of the transmitted signal and also visually inspected the waveforms - comparing the original and transmitted signal using the KEYSIGHT MSO-X 3012A oscilloscope.

3 RESULTS AND DISCUSSION

Phase one results are listed in Tables 2 - 4. They include the measured impedance of individual left and right segments (VC2, VC3, VC4), the total impedance of both connected segments and the calculated impedance of the snap fastener interconnection..

Table 2 Measured impedance values for VC2 - mechanically pressed snap fastener

	Meas. n.1	Meas. n.2	Meas. n.3	Average	Snap fastener
Left segment impedance	8.1 Ω	8.0 Ω	8.3 Ω	**8.1 Ω**	-
Right segment impedance	7.0 Ω	7.3 Ω	7.1 Ω	**7.1 Ω**	-
Total impedance	24.2 Ω	23.8 Ω	22.5 Ω	**23.5 Ω**	**8.3 Ω**

Table 3 Measured impedance values for VC3 – 4 point sewed snap fastener

	Meas. n.1	Meas. n.2	Meas. n.3	Average	Snap fastener
Left segment impedance	3.6 Ω	3.5 Ω	3.6 Ω	**3.6 Ω**	-
Right segment impedance	3.7 Ω	3.8 Ω	3.4 Ω	**3.6 Ω**	-
Total impedance	8.2 Ω	9.1 Ω	8.1 Ω	**8.5 Ω**	**1.3 Ω**

Table 4 Measured impedance values for VC4 – area sewed under snap fastener

	Meas. n.1	*Meas. n.2*	*Meas. n.3*	*Average*	*Snap fastener*
Left segment impedance	5.5 Ω	5.7 Ω	6.1 Ω	**5.8 Ω**	-
Right segment impedance	12.0 Ω	11.8 Ω	12.3 Ω	**12.0 Ω**	-
Total impedance	18.1 Ω	19.6 Ω	19.8 Ω	**19.2 Ω**	**1.4 Ω**

The lowest impedance was obtained from VC3 wherein the snap fastener was sewed in 4 positions (see Figure 1c) - thus we opted to use this method of connecting the electro conductive threads with snap fasteners in all future designs instead of mechanical pressing method (Figure 1b, VC2). The additional area created under the snap fastener by sewing the electro conductive thread also increased the impedance of the interconnection (Figure 1d, VC4) and significantly increased the impedance of the right segment

Phase two results have confirmed excellent transmission of the harmonic signal in all samples; see Figure 2 for amplitude plot results using VC1 and Figure 3 for amplitude plot results using VC2. The input waveform is transmitted undistorted with appropriate amplitude for all tested samples, regardless of the presence of the snap fastener interconnection.

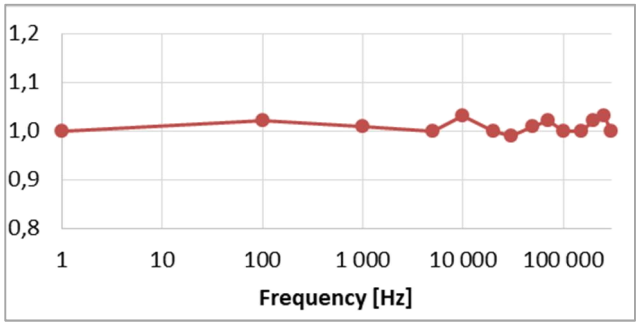


Figure 2 Transfer characteristic of textile without snap fastener (VC1) - sine wave - input amplitude 1V

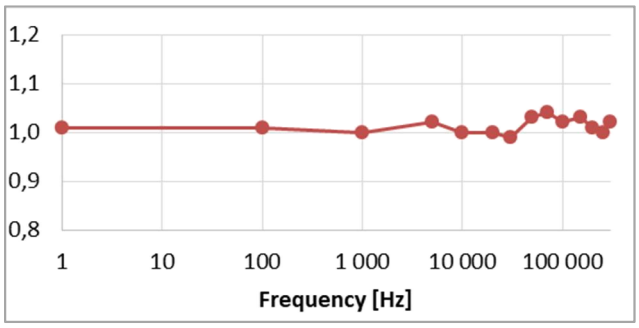


Figure 3 Transfer characteristic of textile with snap fastener (VC2) - sine wave - input amplitude 1V

Phase three results are more interesting. Due to the nature of the square signal a transient effect is visible at the rise and fall slopes of the waveform, especially for higher frequencies (beyond 20 kHz) – see Figure 4. However, the average amplitude is well within the expected TTL levels and the transmitted signal can be processed without any errors. We verified this by transmission of a real digital signal over the I^2C (Inter-Integrated Circuit) bus – see Figure 5. The TMP275 IC from Texas Instruments [10] was powered by a pair of electro conductive threads and the digital temperature output was transmitted using another pair. The PCB with the electric components (pictured left, disconnected for more detail) was connected with the electro conductive fibres using four snap fasteners, as was the receiving side connector (pictured right, connected).

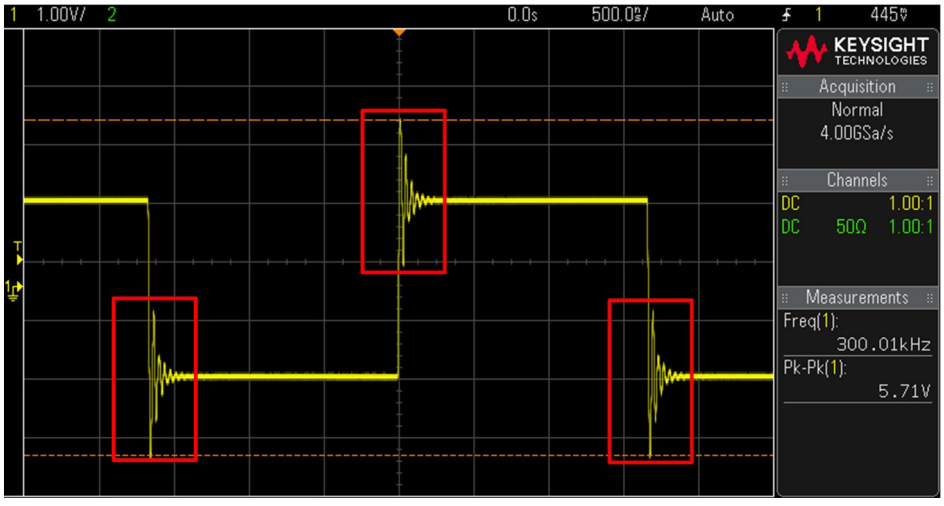


Figure 4 Visible transient effects beyond 20 kHz, rise and fall slopes of square signal, 3V TTL

Figure 5 Sample I^{2}C bus digital signal transmission – PCB with TMP275 IC, snap fasteners, electro conductive threads

Figures 6 and 7 show the average amplitudes of the transmitted square signal, confirming our above findings.

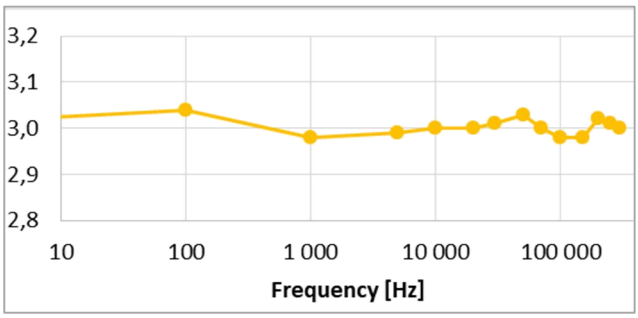


Figure 6 Transfer characteristic of textile without snap fastener (VC1) – square signal - input amplitude 3V

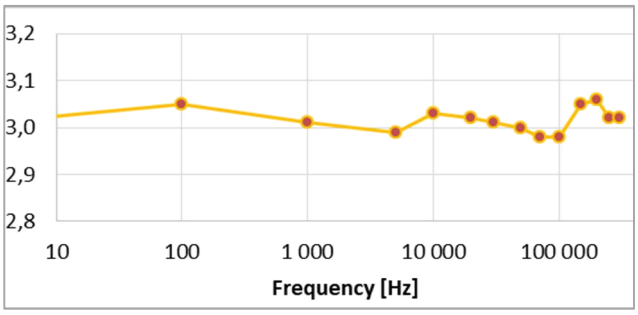


Figure 7 Transfer characteristic of textile with snap fastener (VC2) – square signal - input amplitude 3V

Similar transfer characteristics were obtained for VC3 and VC4 samples and are thus not pictured in this article.

4 CONCLUSION

Electro conductive threads are an important component of so-called intelligent textiles. Instead of using traditional wires which can be bulky and uncomfortable, all electrical connections are created using electro conductive threads which are sewn within the clothing itself. These are then used not only to power the necessary electronic components but also for signal harnessing and transmission thereof within the body signal network system.

Based on our results from phase 1 we can conclude that the interconnection of conductive threads using snap fasteners is possible and feasible. The lowest impedance was observed when the snap fasteners were sewed using the electro conductive thread in 4 locations. This method of attaching also lowered and equalized the right and left segment impedance values – especially when comparing samples VC3 and VC4. Additionally, phase 2 and phase 3 results have confirmed proper signal transmission over the electro conductive threads – both for harmonic and non-harmonic signals in a wide frequency range. The transient effects present in non-harmonic signal transmission do not influence signal quality when using 3V TTL logic as was verified by transferring a real-life digital signal over the I^{2}C bus.

The obtained results and methods have been further employed in the development of a wearable intelligent clothing prototype pictured in Figure 8 and will be subject to further testing of not only electrical but also mechanical properties in order to assure a functional unit.

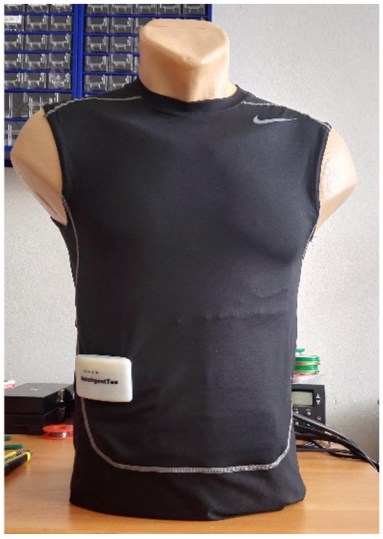


Figure 8 Developed intelligent clothing prototype with processing unit (white box) attached using snap fasteners connected by sewed electro conductive threads

ACKNOWLEDGEMENTS: *This work was supported by the Slovak Research and Development Agency on the base of Agreement No. APVV-14-0519.*

5 REFERENCES

1. Fuhrhop S., Lamparth S., Heuer S.: A textile integrated long-term ECG monitor with capacitively coupled electrodes, in: 2009 IEEE Biomed. Circuits Syst. Conf. BioCAS 2009, pp. 21-24, doi:10.1109/BIOCAS.2009.5372095
2. Chamadiya B., Mankodiya K., Wagner M., Hofmann U.G.: Textile-based, contactless ECG monitoring for non-ICU clinical settings, J. Ambient Intell. Humaniz. Comput., 2013, doi:10.1007/s12652-012- 0153-8
3. Singh R.K., Sarkar A., Anoop C.S.: A health monitoring system using multiple non-contact ECG sensors for automotive drivers, in: Conf. Rec. - IEEE Instrum. Meas. Technol. Conf., 2016, doi:10.1109/I2MTC.2016.7520539
4. Li H., Chen X., Cao L., Zhang C., Tang C., Li E., Feng X., Liang H.: Textile-based ECG acquisition system with capacitively coupled electrodes, Trans. Inst. Meas. Control., 2017, doi:10.1177/ 0142331215600254
5. Kang T., Merritt C., Karaguzel B., Wilson J., Pourdeyhimi B., Grant E., Nagle T.: Sensors on Textile Substrates for Home-Based Healthcare Monitoring, Proceedings of the 1st Distributed Diagnosis and Home Healthcare (D2H2) Conference Arlington, Virginia, USA, April 2-4, 2006, p. 5-7, ISBN 1-4244-0058-9
6. Aleksandrowicz A., Leonhardt S.: Wireless and Non-contact ECG Measurement System – the "Aachen SmartChair, Integr. Vlsi J., 2007, doi:10.14311/974
7. Lee J.S., Heo J., Lee W.K., Lim Y.G., Kim Y.H., Park K.S.: Flexible capacitive electrodes for minimizing motion artifacts in ambulatory electrocardiograms, Sensors (Switzerland), 2014, doi:10.3390/s140814732
8. Cerovic D.D., Dojcilovic J.R., Asanovic K.A., Mihajlidi T.A.: Dielectric investigation of some woven fabrics, J. Appl. Phys., 2009, doi:10.1063/1.3236511
9. Baum O.V., Voloshin V.I.; Popov L.A.: Biophysical models of the heart electrical activity, Biofyzika 51(6), 2006, pp. 1069-1086, ISSN: 0006-3029
10. Datasheet - TMP275 ±0.5°C Temperature Sensor With I2C and SMBus Interface, available online at http://www.ti.com/lit/ds/symlink/tmp275.pdf

THE THERMAL AND POROUS PROPERTIES OF PROTECTIVE RUBBER BOOTS

Marcela Kolinova[1], Martina Syrovatkova[1], Petra Komarkova[2] and Rudolf Tresnak[2]

[1]*The Institute for Nanomaterials, Advanced Technology and Innovation, Technical University of Liberec, Czech Republic*
[2]*Department of Clothing, Technical University of Liberec, Czech Republic*
marcela.kolinova@tul.cz, martina.syrovatkova@tul.cz, petra.komarkova@tul.cz, rudolf.tresnak@tul.cz

Abstract: *Utilization of the space warp knitted fabric and their combination with different non-textile materials increases in many areas of life nowadays. These materials are highly porous with excellent thermal properties. This paper presents an experimental investigation on the thermal behaviour and porosity of the sandwich structures defined for the production of protective rubber boots. The coefficient of the thermal conductivity was measured by the heat flow meter and togmeter. The porosity was detected by the using non-destructive method by the microtomography. The paper also describes the influence of porosity on the thermal conductivity of the sandwich structures defined for the production of protective boots. The results show significant effect of sandwich structure porosity on their thermal conductivity. Finally the paper describes the sandwich structures by the using special software for analysis the porosity of structures, their connectivity and the pores size distribution inside structures. The results of this study indicate that the sandwich structure containing 3D knit show better thermal properties.*

Keywords: *thermal conductivity, porosity, pores size distribution, protective rubber boots, space warp knitted fabric.*

1 INTRODUCTION

It is well know that the porosity is important parameter for thermal properties. Thermal properties of the specific footwear have influence on the choice of material for their construction. Generally, low thermal conductivity of material is characterized by beneficial thermal properties [1]. The insulation characteristics of the specific footwear depend on the structure, material thickness, number of layers, humidity of the environment, etc. For this special protective footwear are required good porous and thermal properties. During summer, the thermal conductivity of materials should be low to resist heat transfer from outside to inside and in winter it is reverse (to protect heat transfer from inside to out). The porosity of the fabric is a key parameter for evaluating the permeability of the material. Air permeability is important factor influences the comfort of a textile product and is actually a function of the porosity of the material [4]. There are several methods to determine the porosity of the material [2]. One of the latest methods is the detection of this parameter using X-ray microtomography. There is a non-destructive analysis of any textile and non-textile structure. There are many methods and devices for measurement of thermal insulating properties of fabrics [3]. They differ in principle and applicability. For each device we have to evaluate the influences of various factors (different sample sizes, dissimilar pressure for testing samples, different types of sensors, measurement errors, etc.). For detecting the porosity of the textile structures exist methods (image analysis, bubble sort, ...) which are different methodology and applicability [10].

2 EXPERIMENTAL

2.1 Materials

In the present study four sandwich structures defined for the production of protective rubber boots are used for testing (Table 1). Material thickness measurement was performed as per ČSN EN ISO 5084.

Table 1 The tested materials and their characteristics

Sample No.	Fiber composition							Thickness [mm]	Mass per unit area [g/m^2]
	rubber	*3D knitted*	*PU foam*	*brush. velour*	*adhez. layer*	*rubber foam*	*tricot*		
C1	✓	✓	✓	✓	-	-	-	8.79	2680
C2	✓	✓	✓	✓	-	-	-	10.72	2660
C3	✓	-	-	-	✓	✓	✓	7.20	3640
C4	✓	✓	-	✓	✓	✓	-	9.98	3690

2.2 Methods

The paper shows 3D analysis of the sandwich structures. The resolution is porosity, connectivity, pore size distribution and 3D visualization of the samples. This study indicates experimental investigation of the effect of porosity on the thermal properties which are most frequently evaluated by the coefficient of thermal conductivity. Material properties were measured according to standards - EN ISO 5084 (800844) Textiles - Determination of thickness of textiles and textile products and EN ISO 12127 (800849) Textiles - Determination of mass per unit area using small samples. Thermal and porous properties of sandwich structures were experimentally verified by heat flow meter (Instrument was designed according to ASTM C518-04 - Standard Test Method for Steady - State Thermal Transmission Properties by Means of the Heat flow Meter Apparatus. Resulting values of thermal conductivity are calculated in accordance with ASTM C1045-01 - Standard Practise for Calculating Thermal Transmission Properties Under Steady - State Conditions.), togmeter (according to ISO 5085 - Determination of thermal resistance - Part 1: Low thermal resistance, Part 2: High thermal resistance) and microtomography (according to producer´s standards are not standardized). Finally an attempt has been made in this study to find the correlation between thermal conductivity and porous characteristics of the test samples.

Coefficient of the thermal conductivity

The measurement of the ability of a material to transfer heat [5]. Given two surfaces on either side of the material with a temperature difference between them, the thermal conductivity is the heat energy transported per unit time and per unit surface area, divided by the temperature difference. It is measured in watts per degree Kelvin [3].

The instruments to measure coefficient of thermal conductivity

The general principle of the heat flow meter instruments is based on one dimensional Fourier law. If a flat sample is placed between two flat isothermal plates maintained at two different temperatures, and a uniform one-dimensional temperature field has been stabilized, the temperature field in the sample should be uniform within all the sample's volume [4]. The temperature gradient can be determined by measurements of the difference between temperatures of the hot and cold plates and thickness of the sample. The lower plate was set at 35°C and the upper plate been continuously adjusted to temperatures -20, -10, 0, 10 and 20°C.

The instrument to measure thermal resistance

The principle of the device is that, so conductors in series with respect to the direction of heat flow, the ratio of the temperature drop across the conductors is equal to the ratio of their thermal resistance. Thus, if the temperature drop across a material of known thermal resistance and that across a test specimen in series with it are measured, the thermal resistance of the test specimen can be calculated. The specimen is tested in the horizontal plane [5]. The instrument is equipped temperature sensors. The heating element is controlled by a digital temperature controller. The device is placed in the casing where is controlled air flow. The samples of a circle are inserted on one plate of the unit or between the two plates of the device. Then turn on heating element and temperatures are read in each of the three thermoelectric points after steady state.

Porosity, connectivity and pores distribution

Microtomography can be used to visualization the internal structure of the materials by non-destructive way [8, 9]. There is important 2D or 3D analysis to obtain quantitative parameters of scanned dataset. Special software performs a picture analysis on selected pixels (white pixels = object and black pixels = pores). Connectivity determines which pixels are connected to other pixels (2D)/voxels (3D), it characterized mass and pores. A precondition for such an analysis is different X-ray absorption material components [8].

The microtomography to 3D analysis of the structures

Microtomography scans the object in the form of 2D images, which can be converted with the help of special reconstruction software to 3D object. The resolution of the device is up to 0.5 micron, the maximum size of a tested material 70 mm in diameter and in length [6].

3 RESULTS AND DISCUSSION

3.1 Measurements of thermal conductivity λ by using heat flow meter

The influence of temperature of the upper plate device on the coefficient of thermal conductivity of the sandwich materials is shown in Figure 1. There is evident that the coefficient of thermal conductivity increases with increasing temperature of the upper plate unit from the Figure 1. All tested sandwich structure exhibit very acceptable thermal insulation properties for different temperature gradients. The graph shows the average value (5 measurements). The coefficient of variation has a very low mutual variety. The curve of sample C3 shows different dependence than other structures. This sample consists from rubber foam and does not contain spacer warp knitted fabric.

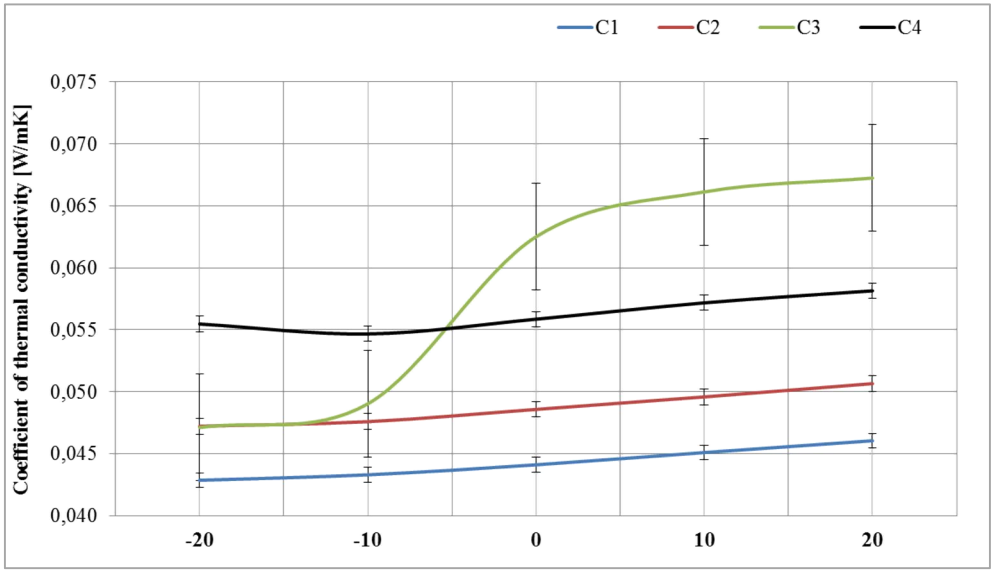


Figure 1 The influence of temperature on the coefficient of the thermal conductivity

3.2 Measurements of thermal resistance by using togmeter

There was used method of measuring single-plate. The sample remained uncovered and after steady state temperatures were read in each of the three thermoelectric points. The result of measurement is shown in Figure 2.

The measurement the coefficient of thermal conductivity by this device shows a low value of this parameter. As in the previous experiment, the thermal insulating properties of the sandwich structures defined for the production of protective boots are very favourable. The sample C3 has higher coefficient of thermal conductivity. The graph shows the average value (5 measurements). The coefficient of variation has a very low mutual variety.

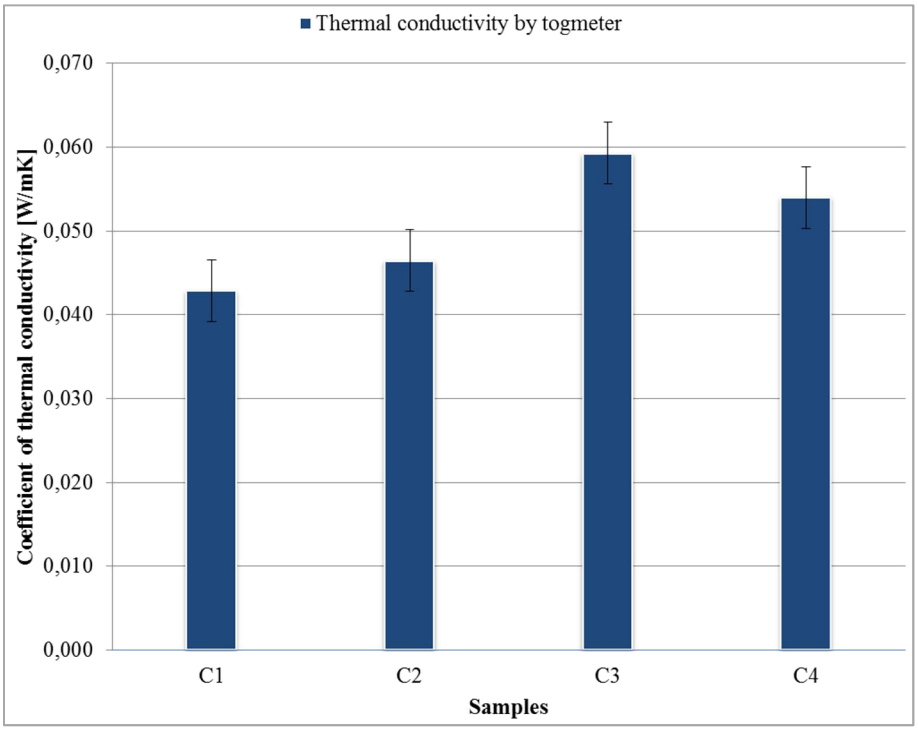


Figure 2 The measurement of coefficient of the thermal conductivity by togmeter

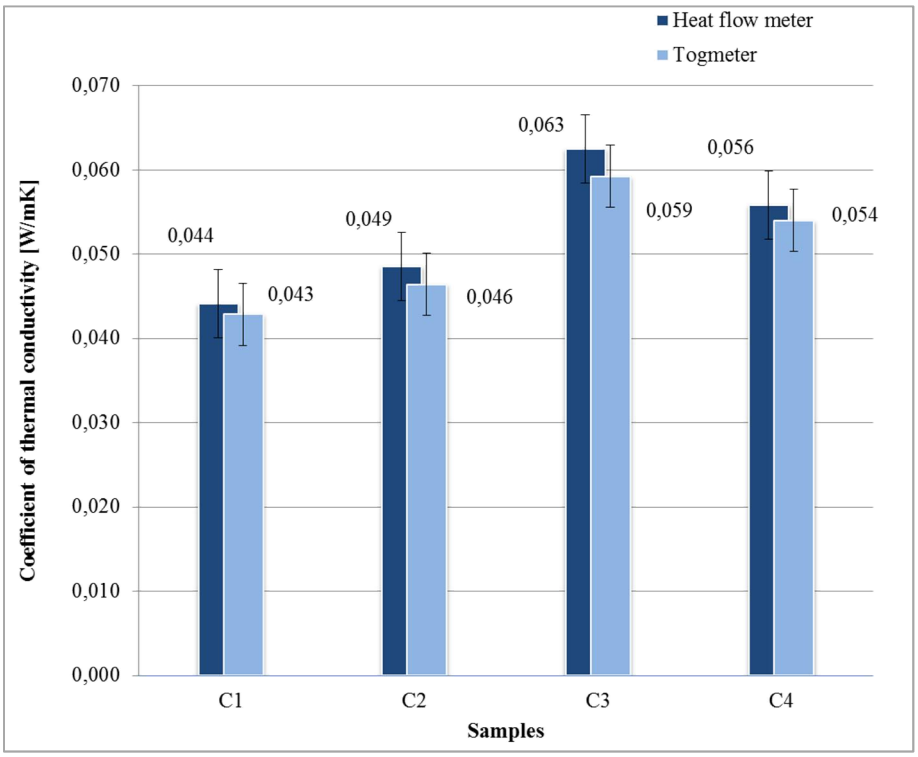


Figure 3 The comparison of results of coefficient of the thermal conductivity

3.3 The comparison of results of coefficient of thermal conductivity by two units

The comparison of measurement results of coefficient the thermal conductivity for sandwich structure by using two devices is shown in Figure 3.

The values obtained of the two devices are equivalent and the percent deviation is very small.

3.4 Analysis of sandwich structures using microtomography

Sandwich structures were scanned by microtomography with the same scanning parameters (Table 2).

Table 2 Scanning parameters

Source Voltage [kV]	50
Source Current [µA]	200
Image Pixel size [µm]	4
Exposure [ms]	531
Rotation Step [deg]	0.2
Scan duration [min]	53

The obtained datasets were reconstructed and then were made visualization of these structures (Figure 4). Finally the 3D analysis of samples was performed using specific software (Table 3).

Table 3 The results of 3D analysis by using CT-microtomography

Characteristics of sandwich structures	**C1**	**C2**	**C3**	**C4**
Total VOI volume [mm^3]	121	168	93	130
Total porosity [%]	77	86	61	61
Connectivity	99 921	73 568	291 874	399 903

Note: The total porosity of the each samples corresponds to the total VOI volume of the test material shown in table.

3.5 The influence of the porosity on the thermal properties of sandwich structures

Also, pore size distribution was analyzed for each sample. The pore size was distributed at the following ranges: 0 – 0.21 mm, 0.22 – 0.40 mm, 0.41 – 0.60 mm, 0.61 – 0.80 mm, 0.81 – 1.00 mm and 1.00 – 1.44 mm. Percent volume in range for each material is shown in Figure 6.

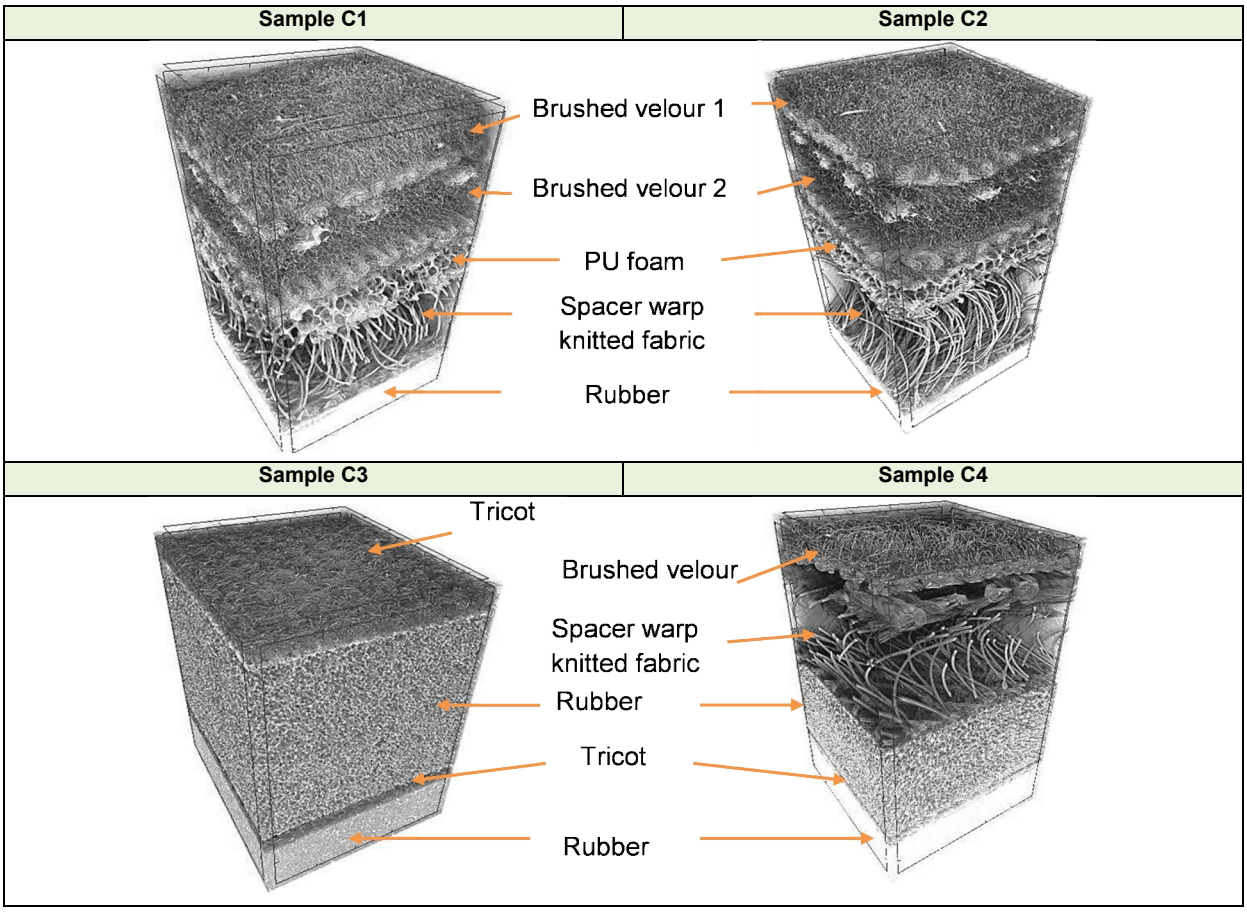


Figure 4 The visualization of sandwich structures by specific software CTVox

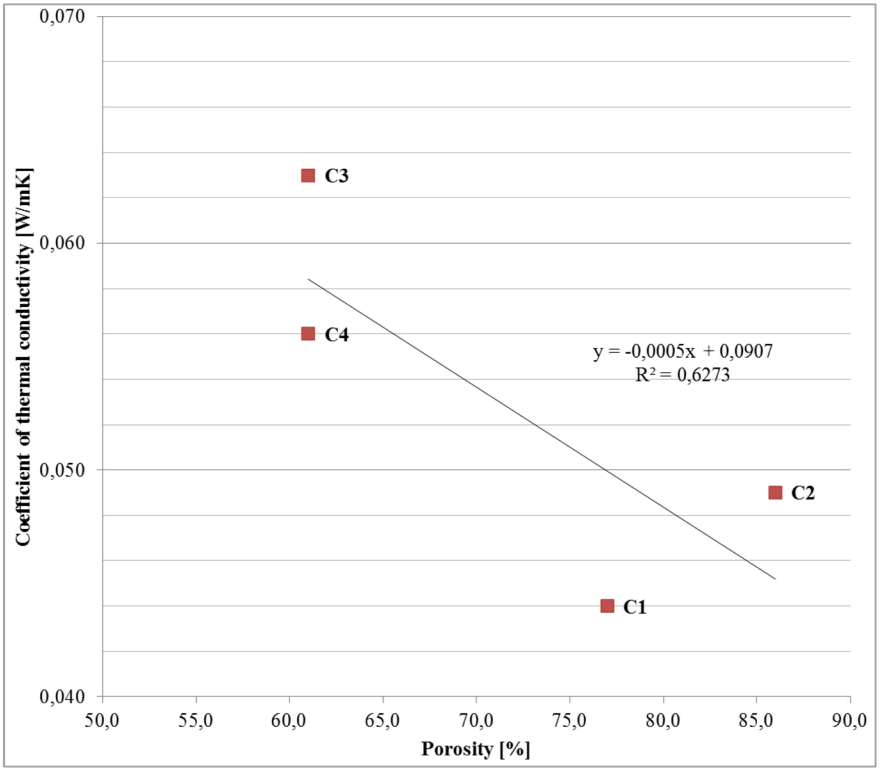


Figure 5 The influence porosity on the coefficient of thermal conductivity

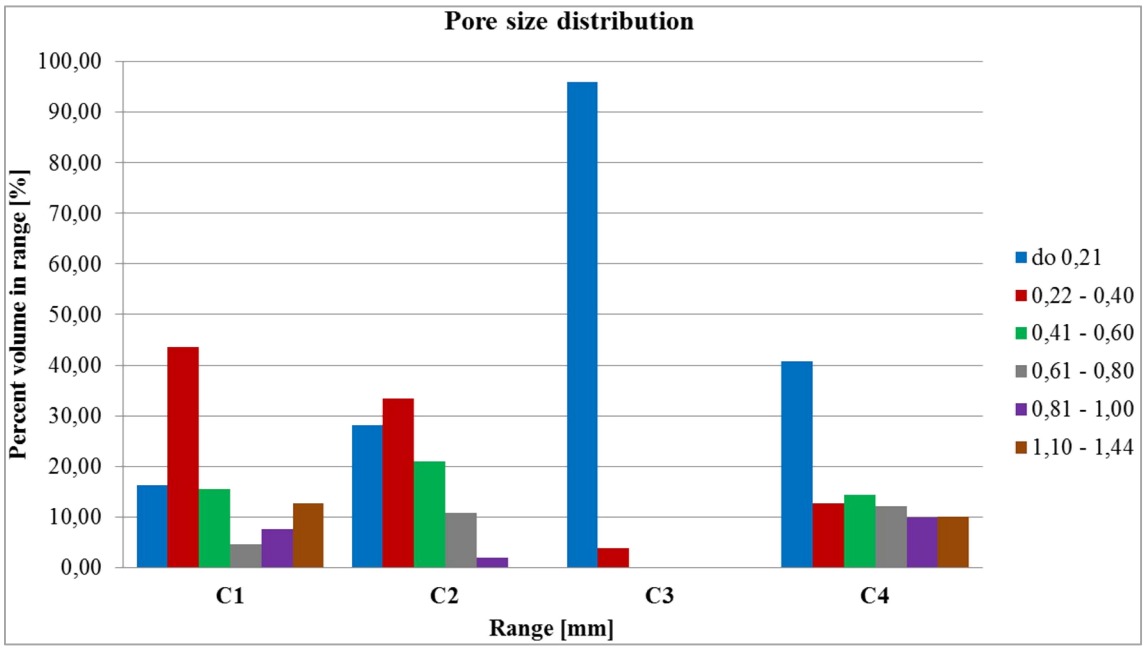


Figure 6 Percent volume in range of each tested sample

4 CONCLUSION

In this paper were tested thermal insulating and porous properties of the sandwich structures defined for production of the protective footwear (Table 4). The coefficient of thermal conductivity was tested by two devices including a comparison of the measurement results. Porous properties were investigated by X-ray non-destructive analysis including pore size distribution for the studied samples.

Table 4 Detected values of tested samples

Samples	Coefficient of thermal conductivity [W/mK]	Connectivity	Porosity [%]
C1	0.044	99 921	77
C2	0.049	73 568	86
C3	0.063	291 874	61
C4	0.056	3 993	61

1. By testing of the coefficient thermal conductivity by the heat flow meter was found that a sandwich structure containing a spacer warp knitted fabric (especially the samples C1 and C2) show better thermal insulation properties i.e. lower coefficient of thermal conductivity. Compared to that the sandwich with predominant component of foam rubber present worse thermal insulation properties (C3). Samples C1 and C2 have identical composition and they differ only in the material thickness. It causes the differential coefficient of thermal conductivity. Sample C4 is a structure similar to the sample C3 containing also a thin layer of the spacer warp knitted fabric.
2. The results of experimental measurement of the coefficient thermal conductivity by the togmeter showed a very similar measured value as in the point 1. Comparison of these results of the coefficient of thermal conductivity by the two devices is comparable though the methodology is different for each device.
3. The spacer warp knitted fabrics have big amount of air in the pores and therefore the coefficient of thermal conductivity of sandwich structures containing spacer warp knitted fabric decreases. Samples C1 and C2 due to the content of these spacer warp knitted fabric have higher porosity. It indicates good permeability and it leads to improved thermal insulation properties. Conversely connectivity of these structures is increased in materials without the 3D knitted (samples C3 and C4). The pores size distribution for tested sandwich structures is follows:
   - Sample C3 contains about 96% pores in range to 0.21 mm. Other samples contain less - C1 (16%), C2 (28%) and C4 (41%).
   - In the range from 0.22 – 0.40 mm, the sample C1 contains 44%, sample C2 34% and C4 contains 13% of pores. Sample C3 contain these pores size only 4%.
   - In the biggest pores size in the range 1.10 – 1.44 are included samples C1 (about 10%). Samples C2 a C3 does not content these pores.

The sandwich structures defined for the production of specific protective footwear are good insulators with high-porous characteristics especially

containing spacer warp knitted fabric. Their wide use is also applied in the production of specific protective footwear and it contributes to increase the thermal insulating and porous properties of the whole sandwich structure. Further research will be focused on quality rubber and subjective testing of heat-insulating properties. Comfort is important and depends on the individual feeling of the user.

ACKNOWLEDGEMENT: *The research was supported by the project LO1201 through the financial support of the Ministry of Education, Youth and Sports in the framework of the targeted support of the "National Programme for Sustainability I" and the OPR&DI project "Centre for Nanomaterials, Advanced Technologies and Innovation" registration number CZ.1.05/2.1.00/01.0005.*

5 REFERENCES

1. Veerakumar A., Mishra R., Militky J., Novak J.: Thermo-acoustic Behavior of 3D Knitted Spacer Fabrics, Fiber and Polymers 16(11), 2015, pp. 2467-2476
2. Wiener J., Glombikova V., Komarkova P., Kolinova M.: Optimization of quality and speed scaning of fabrics structure by computed microtomography systems, Proceedings of 14th AUTEX World Textile Conference 14, Uludag University, 2014
3. Matusiak M., Kowalczyk S.: Thermal-Insulation Properties of Multilayer Textile Packages, Autex Research Journal 14(4), 2014, pp. 299-307
4. Instruments Manual Heat Flow Meter, LaserComp, Inc., USA, 2009
5. Instruments Manual Togmeter, SDL Atlas, England, 2003
6. Instruction manual compact X-ray micro CT, Belgium, 2007
7. The user´s guide CT-Analyser, Belgium, 2013
8. Dias T., Delkumburewatte G.B.: Changing porosity of knitted structures by changing tightness, Fibers and Polymers 9(1), 2008, pp. 76-79
9. Du N., Fan J., Wu A.: Optimum Porosity of Fibrous Porous Materials for Thermal Insulation, Fibers and Polymers 9(1), 2008, pp. 27-33
10. Glombikova V., Komarkova P., Havelka A., Kolinova M.: Approach to evaluation of car seats fabrics performance, Industria Textila, under review

EXPERIMENTAL RESEARCHES ON DETERMINATION OF RELIABILITY INDEXES OF HEAT-PROTECTIVE MATERIALS

A.I. Rubanka, N.V. Ostapenko, M.M. Rubanka, O.V. Kolosnichenko and K.L. Pashkevich

Faculty of Design, Kyiv National University of Technologies and Design,
Nemirovich-Danchenko str. 2, 01011 Kyiv, Ukraine
allarubanka@gmail.com

Abstract: *The article presents the results of the experimental researches on determination of dependency of the breaking stress and the elongation at the moment of abruption on the number of washing cycles and the temperature for heat-resistant textile materials. Results, obtained after the experiments, provided the opportunity to predict the behavior of the selected materials, depending on the operating loads.*

Keywords: *heat-resistant materials, breaking stress, elongation at the moment of abruption, washing.*

1 INTRODUCTION

Manufacturing of modern ergonomic and reliable protective clothing primarily depends on the materials used. The range of modern heat-resistant textile materials is quite wide. Nowadays they are distinguished by raw materials composition, type of processing, interweaving and so on. Natural fabrics are used preferably, but the share of synthetic and mixed fabrics increases annually.

Among the natural fabrics cotton is used most often for making emergency-rescue clothing. Also linen is well known, which is used mainly in manufacturing of suits for welders in lower economic segment of the market. The main reason for the rejection from linen is its high surface density and rigidity, so its use in working conditions is ergonomically inadvisable because of the dynamic discrepancy of the clothes. The advantage of the synthetic fabrics for manufacturing of heat-resistant clothing is their durability. Reduced hygienic characteristics can be considered as a main disadvantage.

We analyzed the existing market materials and proposed their classification based on the method of provision of heat resistance (Figure 1). So, we can underline several ways of heat resistance provision, namely:

- application of substances on the fabric, which break up at burning with bleeding of incombustible gases (impregnation of fabrics);
- formation of incombustible film (membrane) on the fabric that protects the fiber from the contact with air during the combustion (fabric covering);
- chemical transformation of functional groups of fibers to increase the stability of macromolecular chains to thermal splitting (heat-resistant fibers);
- combination of two or more of the abovementioned methods [1].

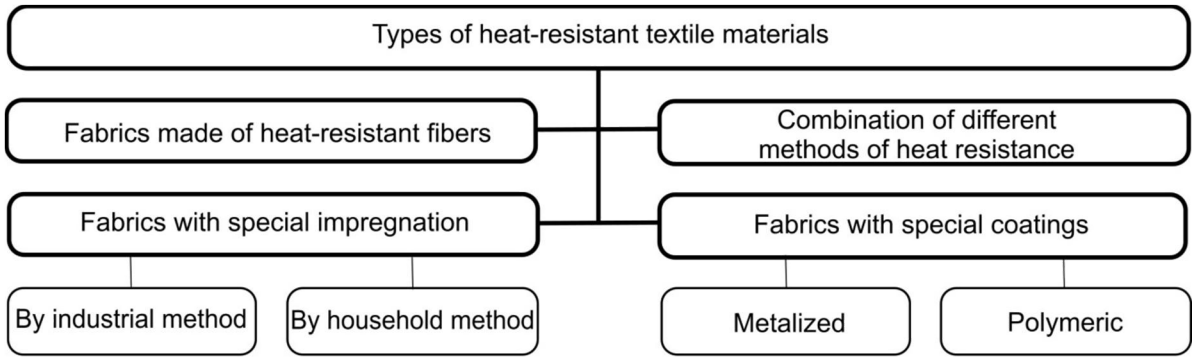


Figure 1 Types of heat-resistant materials by means of provision of heat resistance

Among the fabrics with special processing the Proban® technology is the most popular. It is fireproof chemical processing, developed in the 1950s, by which fabrics and knitted cotton or mixed with cotton fabrics are impregnated at the final stages of their production. Proban is a polymer chemical substance with a low molecular weight used for impregnation of fabrics. The fabric is dried in an environment with specified moisture content, then in the high concentration of gaseous ammonia, is oxidized by hydrogen peroxide, washed, dried and soften again by polyethylene fabric softener. The heaviness of the fabric ignition is achieved through the inert polymer, which is located in fiber and isn`t washed out from the fabric during the washing. When heating, fire retardant (antipyrene) breaks down to form acids in the fabric and catalyzes the formation of carbon. Carbon prevents the oxidation of potassium. That is, when the fabric, processed by the Proban, is exposed to the flame, the localized area is formed, which acts as an insulating layer. So, Proban provides comfortable, reliable and economically efficient solution for the fire safety at the workplace. Fabric with Proban does not “support” the combustion and smolder processes, does not affect the original properties of cotton and does not washed away during the washings and dry cleanings (up to 50 cycles).

Famous Pyrovatex is a fire-resistant material with processing, which is applied on the cotton fabric or on the fabric containing synthetic fibers in the amount no more than 25%. The attention is on keeping fabric soft and breathable while keeping a high level of protection after several washing cycles. Pyrovatex is a chemical product that contains organic compounds of phosphorus. Cotton fabrics are processed with this substance on a molecular level. Fireproof properties remain stable after repeated washing or dry cleaning in case if all recommendations on care are the subject to compliance. Under the action of the flame “carbonic scaffold” of dehydrated cellulose is produced, which stops the flame spreading and its penetration into the fabric. Thus there is no risk of melting and after removal of flame source the fabric does not burn or smolder. The relative simplicity of creation of such a fabric makes it one of the most economical heat-protective solutions. Unlike the Proban technology, Pyrovatex is not washed off from the fabric that does not limit the time of its use.

Nomex fabric is a synthetic polyamide, developed in the early 1960s by DuPont Company. Nomex fiber is the aramid polymer (class of heat-resistant fibers), which has a chemical added aromatic base that has a man-made chemical formula that provides the fiber with additional rigidity and strength. This combination of the unique elements creates a fiber with high thermal, chemical and radiation resistance and is used for environments with a high level of risk. Nomex can be manufactured in the form of fiber or sheet, which further increases its use. Suits, helmets, gloves, pads, underwear etc. are made from the Nomex fibers [2].

The question about the change of characteristics specified by the manufacturer as a result of operating loads remains poorly known. Such operating loads for heat-resistant clothing primarily include the impact of the increased temperature. Also these clothes are the subjects to washing from time to time, which could affect negatively on their protective properties. That is why we conducted the experimental researches on determination of dependency of the breaking stress and the elongation at the moment of abruption on the temperature of the heat chamber and the number of washing cycles. The temperature of the heat chamber varied from 0 to 150°C. The full washing cycle was made using standard detergents at the temperature 60±5°C.

2 EXPERIMENT PLANNING

A number of experimental researches of heat-resistant textile materials were made in an accredited analytical and experimental testing laboratory “Textiles – TEST” of KNUTD with the aim of determination and prediction of reliability indexes. As the object of the experimental researches, the following fabrics of foreign production with different ways of heat resistance provision were selected, namely:

- suiting fabric Nomex BV-120 (100% metaaramid Nomex fibers) with a surface density of 265 g/m^2, production of “Ten Cate Protect”, The Netherlands;
- suiting fabric XB 9340 (75% cotton, 25% Kevlar, Proban impregnation, anti-static) with a surface density of 340 g/m^2, production of “Ten Cate Protect”, The Netherlands;
- suiting fabric FlameStat Lite (100% cotton, Proban impregnation, anti-static) with a surface density of 250 g/m^2, production of “Carrington”, The United Kingdom;
- suiting fabric RigChief (100% cotton, Pyrovatex impregnation, anti-static) with a surface density of 370 g/m^2, production of “Daletec”, Norway.

During the study of the processes and systems with two factors the plan of regular hexagon type was chosen as a rational one, namely noncomposite rototable plan of second order [3], which provides for 10 tests, six of which are performed at levels of factors, indicated at the tops of hexagon, and four tests - at levels of factors that correspond to the center of the plan. The advantage of the chosen plan is that for the factor x_1 it requires the use of five levels (+1; +0.5; 0; -0.5; -1), and for the factor x_2 - just the use of three levels (+0.866; 0; -0.866). The matrix of the plan presented in the Table 1.

Table 1 The matrix of experiment planning

No. of experiment	x_0	x_1	x_2	x_1x_2	x_{12}	x_{22}	y
1	+1	+1	0	0	+1	0	y_1
2	+1	-1	0	0	+1	0	y_2
3	+1	+0.5	+0.866	+0.433	+0.25	+0.75	y_3
4	+1	+0.5	-0.866	-0.433	+0.25	+0.75	y_4
5	+1	-0.5	+0.866	-0.433	+0.25	+0.75	y_5
6	+1	-0.5	-0.866	+0.433	+0.25	+0.75	y_6
7	+1	0	0	0	0	0	y_7
8	+1	0	0	0	0	0	y_8
9	+1	0	0	0	0	0	y_9
10	+1	0	0	0	0	0	y_{10}

Table 2 The values of the factors at levels of variation

Name of the factor	No. of experiment									
	1	2	3	4	5	6	7	8	9	10
Number of washings *n*	12	0	9	9	3	3	6	6	6	6
Temperature of the heat chamber *t* [C]	75.0	75.0	139.95	10.05	139.95	10.05	75.0	75.0	75.0	75.0

In order to ensure the reliability of the obtained results, during the realization of the experiment plan in every experiment and during the test of reproducibility of the process by Cochran criterion it was found that the number of repeats (duplications) of every experiment should be not less than six.

The values of the factors at appropriate levels of variation according to the matrix of experiment planning are presented in the Table 2.

3 RESULTS AND DISCUSSION

It was determined the regression dependencies of breaking stress P [N] in warp → Y_1 and in weft → Y_2, elongation at the moment of abruption L [mm] in warp → Y_3 and in weft → Y_4, on the number of washings n → X_1 and on the temperature of the heat chamber t [°C] → X_2.

For two factors the equation of regression will be the following one:

$$y = b_0 + b_1x_1 + b_2x_2 + b_{12}x_1x_2 + b_{11}x_1^2 + b_{22}x_2^2 \quad (1)$$

Coefficients of equation (1) were obtained using the below formulas:

$$b_0 = \frac{1}{4}\sum_{u=1}^{4} y_{0u}\ ; \quad b_1 = \frac{1}{3}\sum_{j=1}^{10} x_{1j}y_j\ ;$$

$$b_2 = \frac{1}{3}\sum_{j=1}^{10} x_{2j}y_j\ ; \quad b_{12} = \frac{4}{3}\sum_{j=1}^{10} x_{1j}x_{2j}y_j \quad (2)$$

$$b_{11} = \frac{3}{4}\sum_{u=1}^{4} x_1^{\,2}y_j + \frac{1}{12}\sum_{j=1}^{10} x_2^{\,2}y_j + \frac{1}{4}\sum_{j=1}^{10} y_j$$

$$b_{22} = \frac{3}{4}\sum_{u=1}^{4} x_2^{\,2}y_j + \frac{1}{12}\sum_{j=1}^{10} x_1^{\,2}y_j + \frac{1}{4}\sum_{j=1}^{10} y_j$$

where y_{0u} - the value of the response function in the *u-th* experiment at the center of the plan; x_{1j}, x_{2j} – coded values of the factors in the *j-th* experiment; y_j – the value of the response function in the *j-th* experiment.

The obtained values of the regression coefficients are presented in the Tables 3 - 6.

As a result of the check it was found that for the equations of regression coefficients are insignificant; such coefficients are marked with gray in Tables 3 - 6.

Using the obtained equation of regression (1) the graphic dependencies were built, which are presented on the Figures 2 - 17.

Table 3 Coefficients of the equation of regression, obtained as a result of data processing after tests of suiting fabrics Nomex BV-120

Coefficient	Breaking stress *P* [N]		Elongation at the moment of abruption *L* [mm]	
	in warp	in weft	in warp	in weft
b_0	1670.0	1465.0	44.5	41.0
b_1	-10.5	-3.150	0.525	1.042
b_2	31.465	46.793	-0.488	0.038
b_{12}	0.577	-0.520	-1.576	-2.327
b_{11}	-12.525	-1.022	4.999	2.899
b_{22}	7.613	22.438	2.444	1.644

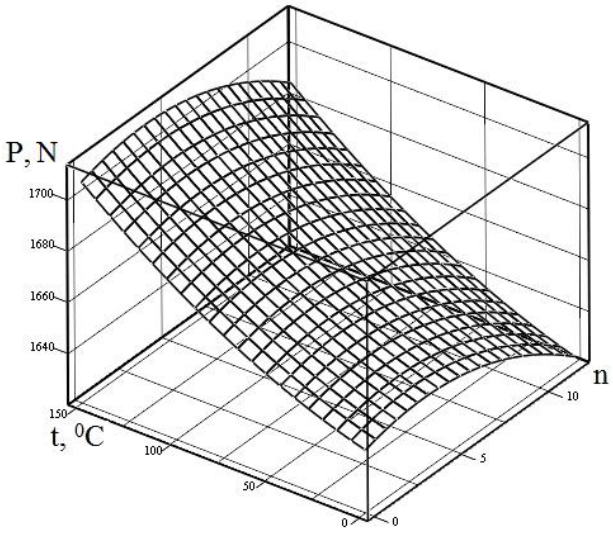


Figure 2 The diagram of dependency of the breaking stress *P* for the Nomex BV-120 material in warp on the number of washings *n* and on the temperature of the heat chamber *t*

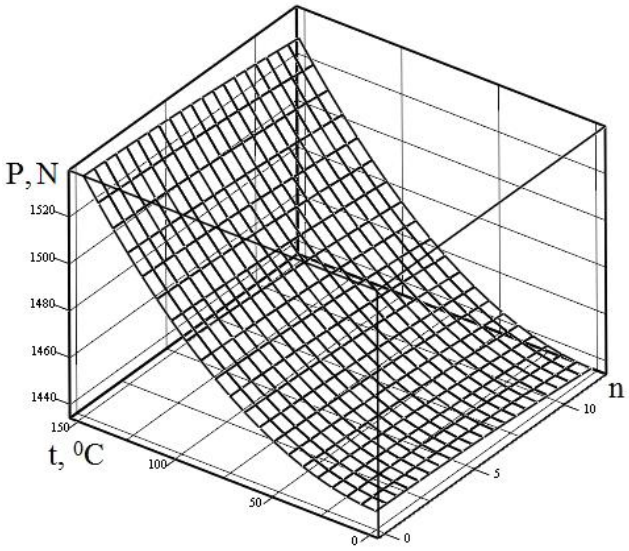


Figure 3 The diagram of dependency of the breaking stress *P* for the Nomex BV-120 material in weft on the number of washings *n* and on the temperature of the heat chamber *t*

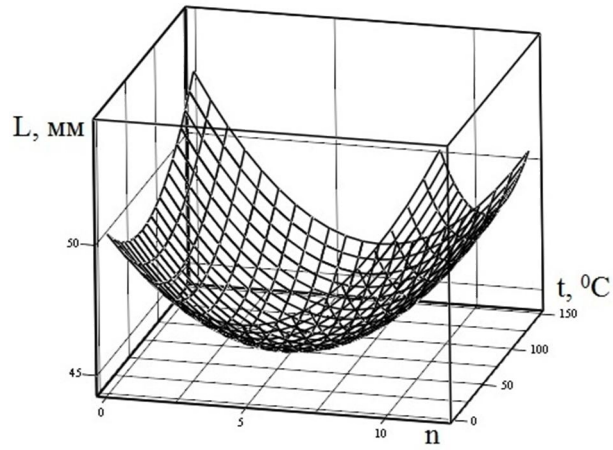


Figure 4 The diagram of dependency of the elongation at the moment of abruption *L* for the Nomex BV-120 material in warp on the number of washings *n* and on the temperature of the heat chamber *t*

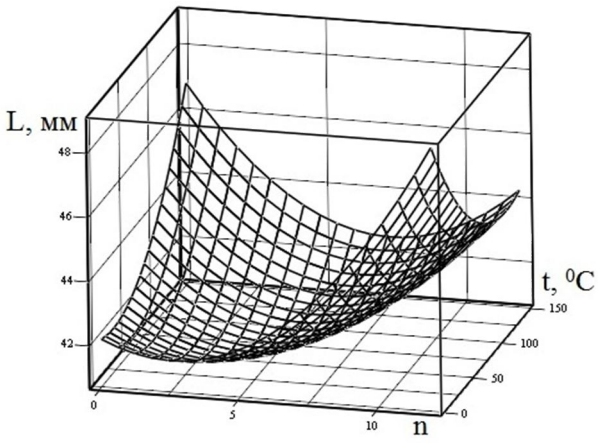


Figure 5 The diagram of dependency of the elongation at the moment of abruption *L* for the Nomex BV-120 material in weft on the number of washings *n* and on the temperature of the heat chamber *t*

Table 4 Coefficients of the equation of regression, obtained as a result of data processing after tests of suiting fabrics XB 9340

Coefficient	Breaking stress *P* [N]		Elongation at the moment of abruption *L* [mm]	
	in warp	in weft	in warp	in weft
b_0	1360.0	1732.5	8.5	14.5
b_1	-46.083	-42.25	0.290	-0.867
b_2	-2.627	11.633	-1.340	-1.201
b_{12}	-26.269	17.262	0.727	3.002
b_{11}	122.229	42.226	2.70	4.10
b_{22}	27.231	-141.133	5.152	5.564

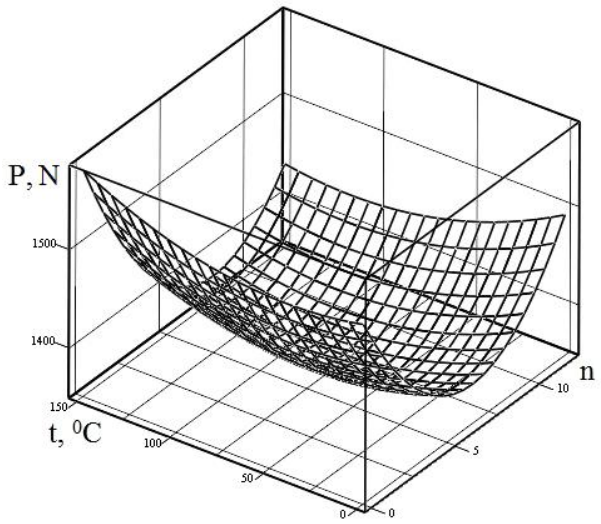


Figure 6 The diagram of dependency of the breaking stress *P* for the XB 9340 material in warp on the number of washings *n* and on the temperature of the heat chamber *t*

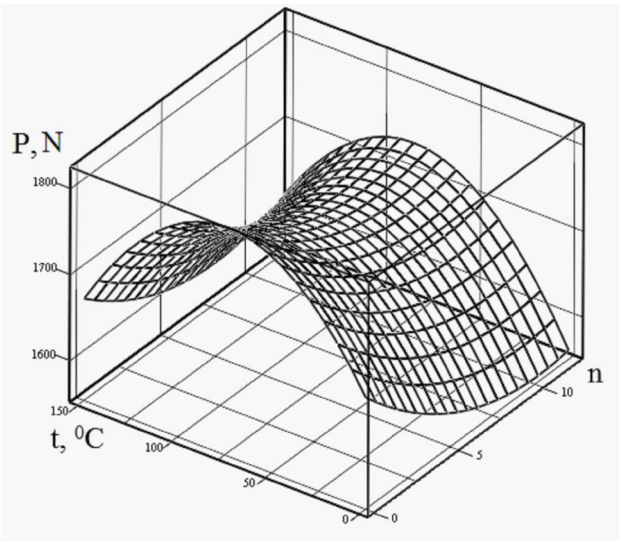


Figure 7 The diagram of dependency of the breaking stress *P* for the XB 9340 material in weft on the number of washings *n* and on the temperature of the heat chamber *t*

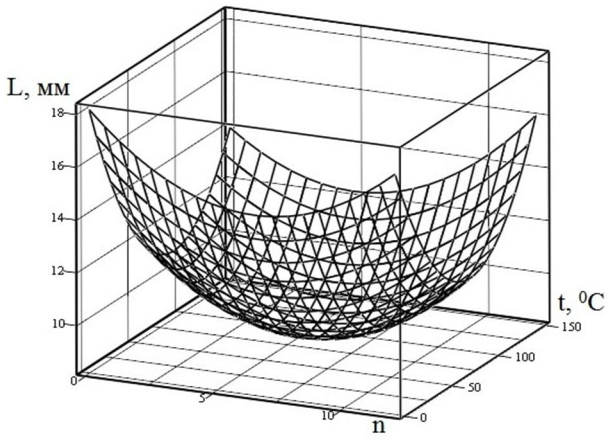


Figure 8 The diagram of dependency of the elongation at the moment of abruption *L* for the XB 9340 material in warp on the number of washings *n* and on the temperature of the heat chamber *t*

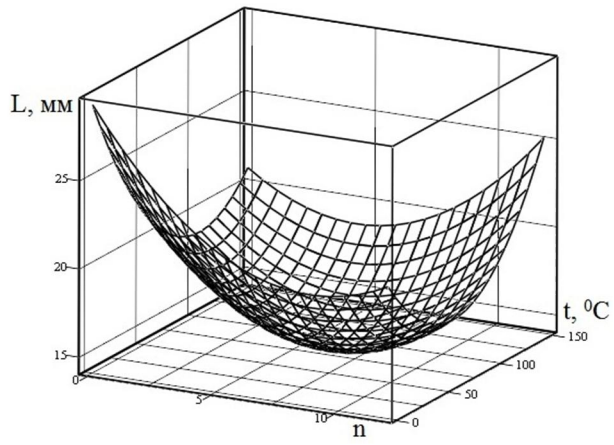


Figure 9 The diagram of dependency of the elongation at the moment of abruption *L* for the XB 9340 material in weft on the number of washings *n* and on the temperature of the heat chamber *t*

Table 5 Coefficients of the equation of regression, obtained as a result of data processing after tests of suiting fabrics FlameStat Lite

Coefficient	Breaking stress *P* [N]		Elongation at the moment of abruption *L* [mm]	
	in warp	in weft	in warp	in weft
b_0	1350.0	630.0	10.0	10.5
b_1	-3.333	11.50	0.565	-0.467
b_2	-30.021	-7.505	-1.602	-0.548
b_{12}	33.024	33.023	1.403	0.30
b_{11}	30.980	-13.759	3.550	1.850
b_{22}	30.151	-59.493	5.218	2.375

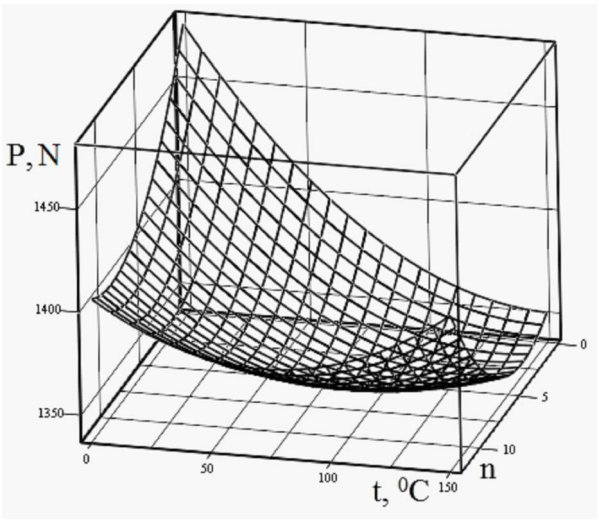


Figure 10 The diagram of dependency of the breaking stress *P* for the FlameStat Lite material in warp on the number of washings *n* and on the temperature of the heat chamber *t*

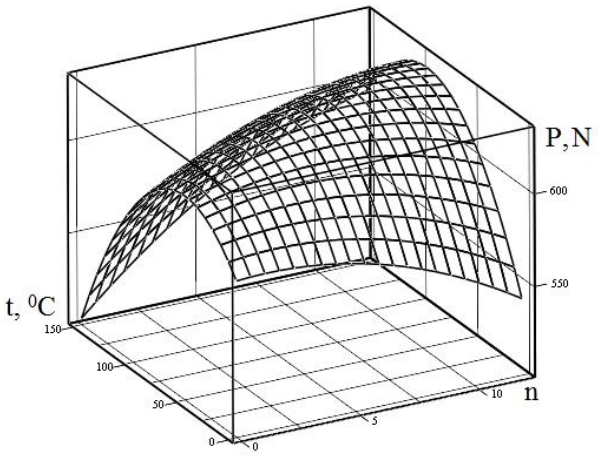


Figure 11 The diagram of dependency of the breaking stress *P* for the FlameStat Lite material in weft on the number of washings *n* and on the temperature of the heat chamber *t*

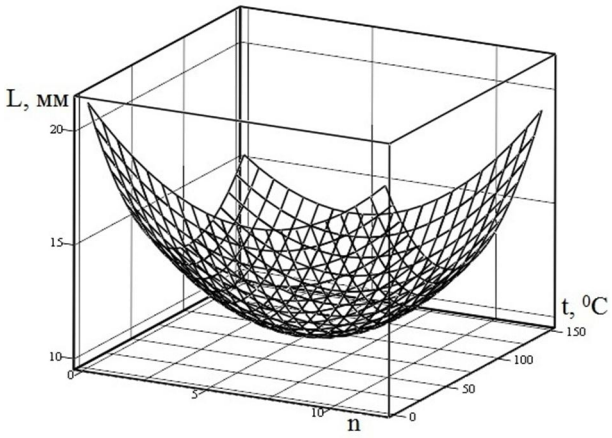


Figure 12 The diagram of dependency of the elongation at the moment of abruption *L* for the FlameStat Lite material in warp on the number of washings *n* and on the temperature of the heat chamber *t*

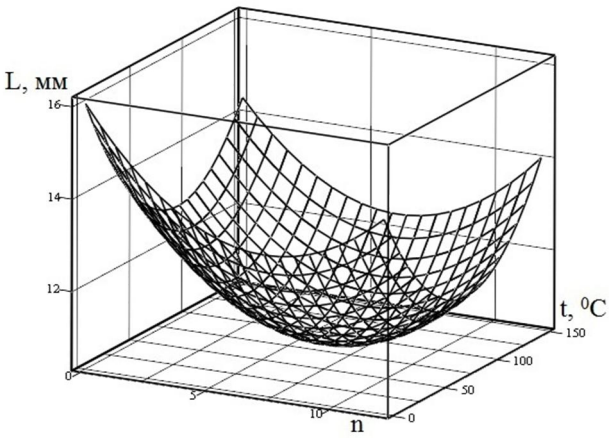


Figure 13 The diagram of dependency of the elongation at the moment of abruption *L* for the FlameStat Lite material in weft on the number of washings *n* and on the temperature of the heat chamber *t*

Table 6 Coefficients of the equation of regression, obtained as a result of data processing after tests of suiting fabrics RigChief

Coefficient	Breaking stress *P* [N]		Elongation at the moment of abruption *L* [mm]	
	in warp	in weft	in warp	in weft
b_0	1320.0	797.5	10.5	16.0
b_1	-19.783	37.417	0.90	-0.20
b_2	-39.403	-61.168	-1.501	-1.201
b_{12}	9.757	113.330	0.60	1.201
b_{11}	-16.019	-4.261	2.650	4.20
b_{22}	0.060	-66.515	5.115	6.730

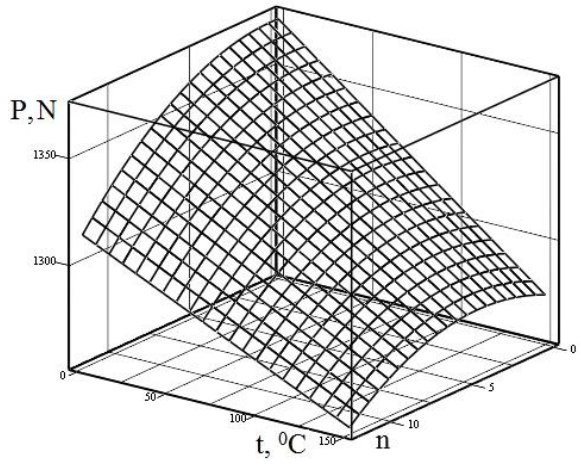


Figure 14 The diagram of dependency of the breaking stress *P* for the RigChief material in warp on the number of washings *n* and on the temperature of the heat chamber *t*

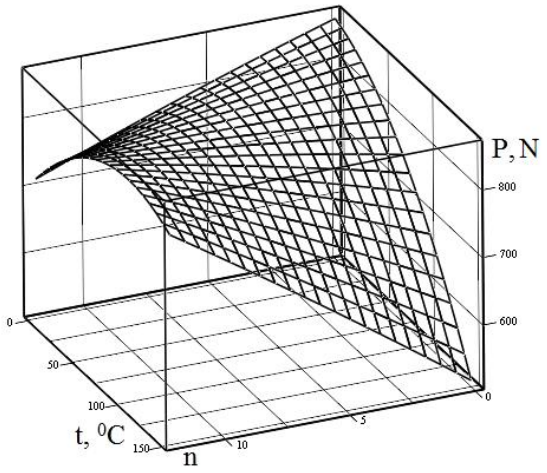


Figure 15 The diagram of dependency of the breaking stress *P* for the RigChief material in weft on the number of washings *n* and on the temperature of the heat chamber *t*

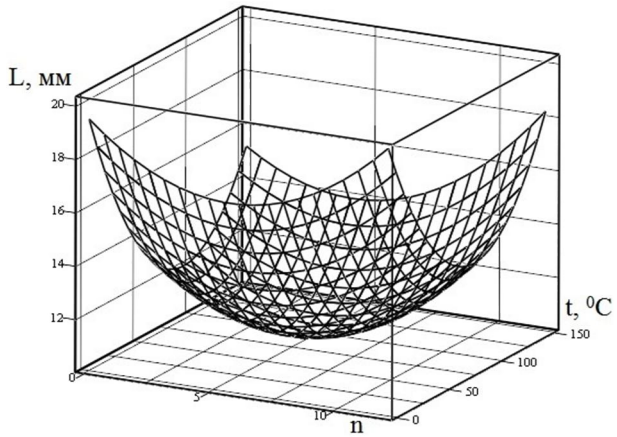


Figure 16 The diagram of dependency of the elongation at the moment of abruption *L* for the RigChief material in warp on the number of washings *n* and on the temperature of the heat chamber *t*

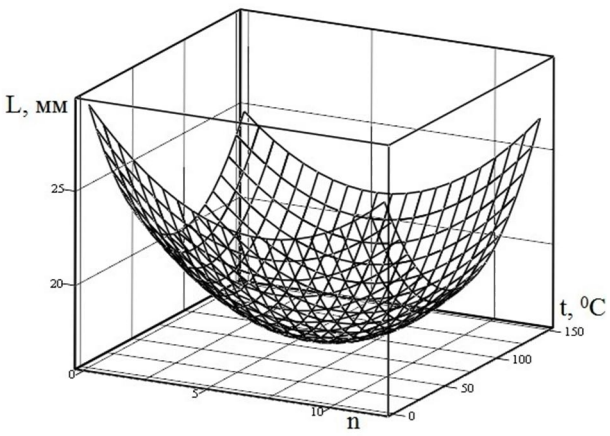


Figure 17 The diagram of dependency of the elongation at the moment of abruption *L* for the RigChief material in weft on the number of washings *n* and on the temperature of the heat chamber *t*

The significance of the factors was tested using the Student criterion and the adequacy of equations of regression during the experiment – using the Fisher criterion [4].

The insignificant coefficient b_2 of the equation of regression, obtained as a result of data processing after tests of suiting fabrics Nomex BV-120 in weft, since its absolute value is less than the value of the confidence interval, that is, $b_2 = 0.038 < \Delta b_i = 0.4652$. Also, the insignificant coefficient b_{22} of the equation of regression, obtained as a result of data processing after tests of suiting fabrics RigChief in warp, since $b_{22} = 0.060 < \Delta b_i = 0.5442$. Estimated value of the Fischer criterion F_{rozr} of the obtained test model of suiting fabrics Nomex BV-120 in warp – 3.1762, in weft - 3.1134; suiting fabrics XB 9340 in warp - 3.0263, in weft - 3.1074; suiting fabrics FlameStat Lite in warp - 2.9874, in weft - 2.9713; suiting fabrics RigChief in warp - 3.2571, in weft - 3.2144. Table value of Fisher's criterion F_{tabl} is 4.03. Since $F_{rozr} < F_{tabl}$ has no reason to reject the hypothesis of the adequacy of models.

Some graphic dependencies show that breaking stress (Figures 6, 7, 11) and elongation at the moment of abruption (Figures 4, 8, 9, 12, 13, 16, 17) have pronounced extreme character because of the number of washings and the temperature of the heat chamber. We can talk about the existence of optimal number of washings and temperature of the heat chamber.

The limits of variation of the factors of full-scale experiment are technologically grounded because they cover a wide range of operational characteristics of heat-resistant textile materials.

Results of the obtained graphical dependencies provide us with opportunity to make a conclusion about the existence of points that correspond to the rational choice of parameters, which can be found by the way of determination of the function extremum, differentiating the equation of regression (1) for each of the varied factors.

4 CONCLUSIONS

As a result of the experimental researches, the dependencies of changes in reliability indexes were determined. Experimentally obtained equations of regression provide with the opportunity to predict the behavior of the materials as a result of operating loads, such as the breaking stress and the elongation at the moment of abruption on the number of washings and the temperature of the heat chamber.

Experiments proved that selected materials change their properties after 12 washing cycles within acceptable limits. Conducted experimental researches on determination of dependencies of changes in the breaking stress and the elongation at the moment of abruption after the wet processing (washings) allow to state that all selected materials can be used in manufacturing of protective clothing for rescue operations. It was found that that material Nomex BV-120 met all the requirements the best.

5 REFERENCES

1. Ostapenko N.V., Kolosnichenko M.V., Lutsker T.V., Kolosnichenko O.V., Rubanka A.I.: Dyzain-proektuvannia vyrobiv spetsialnoho pryznachennia [Design-projecting of products with special purpose], Kyiv: Kyiv National University of Technologies and Design, 2016 (in Ukrainian)
2. Specialistworkclothing. Available at: https://specialistworkclothing.wordpress.com, (accessed 15 May 2017)
3. Spiridonov A.A.: Planirovanie eksperimenta pri issledovanii tekhnologicheskikh protsessov [Experimental planning during the examination of technologic processes], Moscow: Mashinostroenie, 1981 (in Russian)
4. Vinarskiy M.S., Lure M.V.: Planirovanie eksperimenta v tekhnologicheskikh issledovaniyakh [Experimental planning in technological researches], Moscow: Tekhnika, 1975 (in Russian)
5. Ostapenko N.V., Lutsker T.V., Rubanka A.I., Kolosnichenko O.V.: Uzahalnena systematyzatsiia vyrobiv spetsialnoho pryznachennia [Generalized systematization of the products with special purposes], Theory and practice of design, Technical aesthetics 10, 2016, pp. 122-143
6. Horislavets I.V., Rubanka A.I., Yevtushyk O.V., Ostapenko N.V.: Rozrobka vymoh do spetsialnoho odiahu dlia riatuvalnykiv [Development of requirements to the specials clothing for rescues], Bulletin of the Kyiv National University of Technologies and Design 92(6), 2015, pp. 222-226
7. 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. 3-8
8. 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
9. 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
10. Rubanka A.I., Ostapenko N.V., Rubanka M.M., Kolosnichenko O.V.: Determination of linear dimensions changes in heat-resistant textile materials, Nauka i studia 161(24-7), 2016, pp. 52-57
11. Horrocks A., Price D.: Fire retardant materials, Cambridge: Woodhead Publishing, 2001
12. Alongi J., Bosco F., Carosio F., Di Blasio A., Malucelli G.: A new era for flame retardant materials? Materials today 17(4), May 2014, pp. 152-153

SYNTHESIS OF METALS NANO-PARTICLES IN THE POROUS STRUCTURE OF TEXTILES FOR UV-SHIELDING

Viktoriia Vlasenko[1], Petro Smertenko[2], Sergij Bereznenko[1], Svitlana Arabuli[1] and Valentyna Kucherenko[1]

[1]Kyiv National University of Technologies and Design, N.-Danchenko srt. 2, 01011 Kyiv, Ukraine
[2]V.E. Lashkaryov Institute of Semiconductor Physics, NAS of Ukraine, 41 pr. Nauki, 03028, Kyiv, Ukraine
vlasenko@ekma.com.ua, petrosmertenko@gmail.com

Abstract: *The up-to-date numerous clinical and physiological studies show that ultraviolet radiation (UVR) has a negative impact on human organisms and provoke the dangerous diseases, such as cardiovascular, allergic, blood diseases, skin cancer, decreasing of immunity and so on. Nowadays the task of human protection against UVR has become very important and very urgent. That is why the development of new and effective methods and means for the human organism protection against UVR to acceptable levels persists to be one of the pressing challenges for people society and for researchers. Just the textiles and textile articles with especial protective properties may play the significant role in decision of this task. The aim of our work is investigation and elaboration of new reliable effective and rather simple method of textile modification with nano-metal particle. We propose to use the method of hydrometallurgy, namely, using textile impregnation in solution of soluble metal salts with following reduction of metal-ions in textile structure. We have done our work with Cu-sulfate solution and following Cu-ions reduction in porous structure of polyester textile and on surface of each fiber. The proposed method is simple, accessible and effective (cheap and accessible reagents, processing is possible on the equipment for dyeing); may be used for porous substrates of any chemical nature. It may be realized for soluble metal-salts.*

Keywords: *UV-shielding; textile modification; using of water soluble metal-compound.*

1 INTRODUCTION

The up-to-date numerous clinical and physiological studies show that UVR has a very negative impact on human organisms and provoke the different dangerous diseases (cardiovascular, allergic, blood diseases, skin cancer etc.). Also it may cause genetic changes, decreasing of immunity and so on [1-5]. So, nowadays the task of human protection against UVR is very important and urgent. That is why the development of modern effective methods and means for the human organism protection against UVR to acceptable level is one of the very pressing tasks for people society and for researchers. Just the especial protective textiles and textile articles are playing a significant role in decision of this task. The textiles used must be modified by suitable methods to have the sufficient protective properties against UV radiation. They must be conductive and have especially specific construction. Some methods are well known to provide UV-shielding by using of textile materials [6-9].

Treatment with UV absorbers, able to convert electronic excitation energy into thermal energy, acting as radical scavengers and singlet oxygen quenchers. To be effective UV absorbers have to absorb throughout the spectrum, to remain stable against UV radiation and to dissipate the absorbed energy to avoid degradation or loss in color. The main UV absorbers for modification of textile products are derivatives of o-hydroxy benzophenones, o-hydroxy phenyl triazines, o-hydroxy phenyl hydrazines and thus are rather toxic substances [10, 11]. It is known also combinations of UV absorbers with antioxidants and inorganic pigments (for example, with titanium dioxide, zinc oxide and ceramic materials) [12-14]. Metal oxide nano particles of TiO_2, ZnO and Fe_3O_4 that included into fibers structure or using for textiles as finishing agents have not sufficient effect on UV rays absorption; used in large quantities impair the textile properties and act as photocatalysts and degrade textiles. They are rather toxic for humans even if they are incorporated into fibers.

Dyeing with different types of dyes or pigments that absorb in UV range is increasing the Ultraviolet Protection Factor (UPF) of textiles [15]. The main problem in this case is that only darker colors (black, navy, dark red) absorb UVR much more strongly than the light pastel colors in general. But for the summer the pastel colors of fabrics are preferred. Moreover, the UPF could be low, if dark colors are applied on loosely textile structures. All these factors must be taken into account during elaboration of new processes of textiles modification.

The aim of our work is the investigation of the new, rather simple method of textile nano-modification. The proposed method involves the use of soluble metal salts. This method consists in impregnating of textile material in a solution of the soluble metal salt (in our work Cu-sulphate), followed by the reduction of metal ions in the structure and on the surface of the textile material. Technique and technology modification by this method can be carried out on modern equipment for dyeing and finishing.

2 EXPERIMENTAL PART

2.1 Setting the task

It is known that the processes of modification of textiles by nano-sized metal particles are time-consuming and expensive. At the same time, using the methods of hydrometallurgy, involving the reduction of metal ions in salt solutions, metal particles could be produced. So, it is possible to produce nano-metal-modified textiles by treating them in solutions of metal salts and reduction reaction of metal ions in textile structure. This technique can be used to obtain metals nano-particles from soluble salts metals of the first group, some salts of the second group metals (chlorides, bromides, iodides, nitrates and some others). This process is known as “hydrometallurgy” [16].

In our opinion, this technique can be used not only for textile materials, but also for any porous bodies. It is important that the chemical nature of the textiles and other materials in this case has not matter.

2.2 Samples preparation

Modification of the polyethylene terephthalate (PET) textile material with Cu nano-sized particles was carried out directly in the $CuSO_4$ solution. The essence of this method consists in textile sample impregnating in a solution of $CuSO_4$, followed by the chemical recovery of copper ions in the textile structure and on the surface of textile. As reducing agents polyhydric alcohols, carbohydrates, ascorbic acid, etc. may be used.

Copper sulphate was dissolved in glucose solution at a temperature of 30-50°C. The textile sample was impregnated in this solution and was constantly mixed. After a certain time the sample was immerse in glucose reducing solution, to complete the copper sulphate reduction process.

Transactions copper ions recovery process with using of glucose to copper nano-powder is carried out in air and atmospheric pressure. To maintain the pH between 8-9 sodium hydroxide was added gradually (in 5, 15, 25, 40 minutes).

The sequence of stages of copper ion recovery process in glucose solution may be represented by the scheme:

$$CuSO_4 + (C_6H_{12}O_6 + NaOH) \rightarrow Cu_2O$$

$$Cu_2O + NaOH \rightarrow Cu$$

Under these conditions the reduction of copper oxide Cu_2O to copper Cu was ended after 60-70 minutes. Then the textile samples were dried in air without pressing.

2.3 Investigation technique

Optical microscopy shows that impregnation of textile materials in a metal salt solution with subsequent reduction of metal ions provides the formation of metal nanoparticles in the structure of the textile material and on its surface (see Figure 1). We can see Cu particles on fiber sized about 100 nm.

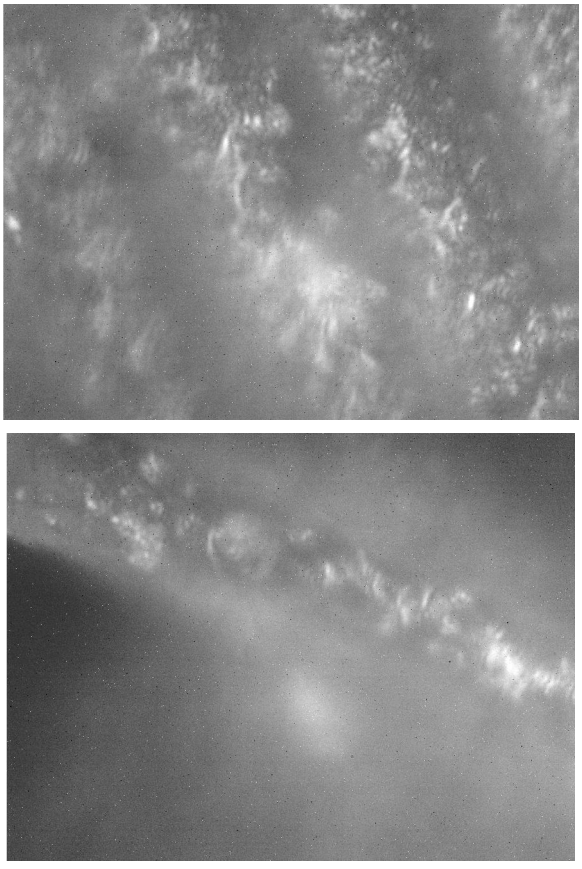


Figure 1 Optical image of cotton fabric bleached, modified by Cu: a) fabric; b) separate fiber

Testing the efficiency of copper nanoparticles coated materials for UV-light absorption was carried out in the Test-Laboratory of our University on the device FADOMETR mark LE-1 (model KT7035). The source of UV radiation is arc Xenon Lamp OSRAM XENON SHORT ARC DISPLAY/OPTIC LAMP XBO® XTREME LIFE; filter - a triangular prism, in the middle of which there is an arc Xenon Lamp. The radiation intensity is measured by the UV-Radiometer “Tenzor-71”.

Table 1 The degree of ultraviolet light absorption by Cu modified textile at wavelengths A (315-400 nm) and B (315-280 nm)

№ specimen	Characteristics of the sample	Power light, [W/m^2] (range A)		The degree of absorption in the range A [%]	Power light [W/m^2] (range B)		The degree of absorption in the range B [%]
		before sample	*behind sample*		*before sample*	*behind sample*	
1.1	PET fabric unmodified	51.1	4.2	91.8	8.9	0.5	94.4
1.2	PET fabric modified by Cu		0.2	99.6		0.3	96.6
2.1	Cotton fabric unmodified	51.1	7.5	85.3	8.9	5.1	42.7
2.2	Cotton fabric modified by Cu		3.4	93.3		0.7	92.1

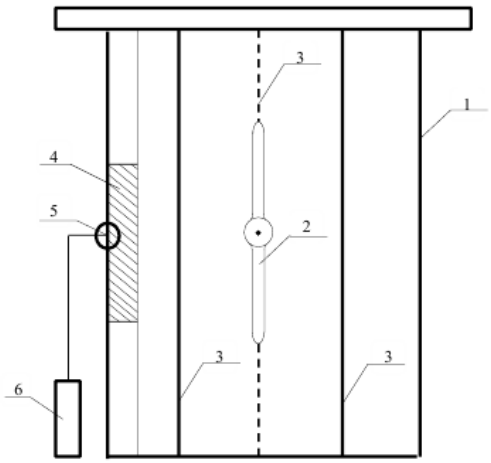


Figure 2 Scheme of FADOMETR: 1 - frame for placing of textile samples; 2 - arc Xenon Lamp type; 3 - triangular prism - filter in which a Xenon Lamp is placed; 4 - sample of textile material; 5 - UV-radiometer "Tensor-71"; 6 - the electronic block with the screen of the UV-radiometer

3 RESULTS OF RESEARCH

The results of UV-light absorption testing are summarized in Table 1. As we can see the modification by nano Cu-particles enhanced the protection properties both in A and in B range of UVR.

4 CONCLUSION

It was investigated the new method of nano-metal textile modification by impregnation in the metal-salt solution and subsequent reduction of metal ions in structure and on surface of textile material (by the example of a solution of Cu-salt).

This technique, in principle, can be used to obtain metals nano-particles from soluble salts metals of the first group; some salts of the second group metals (chlorides, bromides, iodides, nitrates) and some others.

The proposed method is simple, accessible and effective (cheap and accessible reagents, processing is possible on the equipment for dyeing); may be used for porous substrates of any chemical nature.

UV-shielding by using of textile materials modification by nano Cu-particles with using of $CuSo_4$ solution enhanced the protection properties both in A and in B range of UVR.

***ACKNOWLEDGEMENT**: This work was carried out with the support of the Ukraine Ministry of Science and Education.*

5 REFERENCES

1. Hart P.H., Gorman S.: Exposure to UV Wavelengths in Sunlight Suppresses Immunity. To What Extent is UV-induced Vitamin D_3 the Mediator Responsible?, Clin Biochem rev. 34(1), 2013, pp. 3-13, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3626364
2. Holick M.F.: Biological Effects of Sunlight, Ultraviolet Radiation, Visible Light, Infrared Radiation and Vitamin D for Health, Anticancer Research 36(3), 2016, pp. 1345-1356; http://ar.iiarjournals.org/content/36/3/1345.full
3. Juzeniene A., Brekke P., Dahlback A., Andersson-Engels S., Reichrath J., Moan K., Holick M.F., Grant W.B., Moan J.: Solar radiation and human healt, Reports on Progress in Physics 74(6), 2011, 066701, 56pp, doi:10.1088
4. Mikkelsen S.H., Lassen C., Warming M.: Survey and health assessment of UV filters, Survey of chemical substances in consumer products 142, 2015, pp. 81-113
5. Zaets V.N., Karpov P.A., Smertenko P.S., Blume Ya.B.: Molecular mechanisms of the repair of UV-induced damages of plant DNA, Cytology and Genetics 40(5), 2006, pp. 40-68
6. Wilson C.A., Bevin N.K., Laing R.M., Niven B.E.: Solar protection – Effect of selected fabric and use characteristics on ultraviolet transmission, Textile Research Journal 78, 2008, pp. 95-104
7. Singh M.K., Singh A.: Ultraviolet protection by fabric engineering, Journal of Textiles 16, 2013, doi:10.1155/2013/579129
8. Wai-yin Wong, Jimmy Kwok-Cheong Lam, Chi-Wai Kan, Ron Postle: Influence of reactive dyes on ultraviolet protection of cotton knitted fabrics with

different fabric constructions, Textile research journal 86(5), 2016 pp. 512-532

9. Vlasenko V.I., Smertenko P.S., Arabuli S.I., Bereznenko S.M., Kucherenko V.I., Dumitresku YU.: Rozrobka tekstylnykh kompozytsiynykh materialiv dlya zasobiv zakhystu vid elektromahnitnoho vyprominyuvannya, *SHCHORICHNA NAUKOVA KONFERENTSIYA "Intelektualnyy potentsial XXI veka*, 2016, pp.15-22
10. Herzog B., Quass K., Schmidt E., Müller S., Luther H.: Physical properties of organic particulate UV absorbers used in sunscreens II. UV-attenuating efficiency as function of particle size, J Colloid Interface Sci 276(2), 2004, pp. 354-63
11. Mahltig B., Rauch K., Dieckmann U., Nitsche R., Fritz T.: Optimized UV protecting coatings by combination of organic and inorganic UV absorbers, Available online: https://www.researchgate.net/publication/222047797_Optimized_UV_protecting_coatings_by_combination_of_organic_and_inorganic_UV_absorbers
12. Thien Vuong Nguyen, Phi Hung Dao, Khanh Linh Duong, Quoc Hoan Duong, Quoc Trung Vu, Anh Hiep Nguyen, Van Phuc Mac, Trong Lu Le: Effect of R-TiO_2 and ZnO nanoparticles on the UV-shielding efficiency of water-borne acrylic coating, Progress in Organic Coatings 110, 2017, pp.114-121
13. Stamatakis et al.: Optimum Particle Size of Titanium Dioxide and Zinc Oxide for Attenuation of Ultraviolet Radiation, J Coating Tech 62(789), 1990, p. 95
14. Zhang H., Zhu G.Q.: One-step hydrothermal synthesis of magnetic Fe_3O_4 nanoparticles immobilized on polyamide fabric, Applied Surface Science 258, 2012, pp. 4952-4959
15. Gürses A. et al.: 2 Dyes and Pigments: Their Structure and Properties, Springer Briefs in Green Chemistry for Sustainability, pp. 13-29, DOI 10.1007/978-3-319-33892-7_2
16. K Smit D.S.: Hydrometallurgy, Chapter 2, 2001, pp. 4-32, https://www.scribd.com/document/328031834/Smit-Ds-Chapter-2

DEVELOPMENT OF THE METHOD OF SCALING PATTERNS AND VIRTUAL GARMENTS FORMS

Oksana Zakharkevich and Svetlana Kuleshova

Khmelnitsky national university, Department of Technology and Design of Garments
Institytska str. 11, 29016 Khmelnitskyi, Ukraine
zbir_vukladach@ukr.net; kuleshova_lana@ukr.net

Abstract: *In the paper a method of non-uniform scaling was applied to scale separate horizontal sections of the virtual mannequin and to scale garments patterns of the bodice blocks. A connection between features of the garments forms and eases was determined as regressions between body measurements, amount of ease and scale factors. It was proposed to calculate the scale factors by using values of eases, which were obtained with formulas based on measured projection parameters by using specified conditional units. It allows recreating and studying any form of garment with its geometrical symbol only. Several algorithms of calculating the scale factors in different processes of design and study of virtual garments forms were the basis for the computer program "Scale factor". "Shape scale" is the part of the program which includes all cases of the scale factors calculation for the 3D-scaling. "Pattern scale" is the part that is recommended for different processes of 2D garment design. User can choose the method of the calculation according to the available input data.*

Keywords: *non-uniform scaling, virtual model, scale factor, amount of ease, patterns.*

1 INTRODUCTION

Nowadays the garment industry is quickly becoming a high-tech industry, which uses 2D and 3D CAD tools. If designers use 2D CAD tools, they often need the instructions for the basic blocks. Instructions are given for a wide range of basic garments (for example, in [1] author represents women's outerwear, in [2] and [3] women's and men's garments designs were described). The instructions must be used in every given circumstances in order to obtain the garment blocks with different values of eases. Furthermore, even if designers use pattern design system (PSD), it takes relatively a long time nonetheless. That is why many researchers try to find new methods to obtain the garments blocks and make it faster with the same level of quality.

Method of silhouette transformation of the garment's parts was proposed in [4]. Transformation of the base design of the skirt into the base design of trousers that was described in [5] is the logical extension of the method of silhouette transformation. Both methods are similar to the grading process. A method of grading patterns by scaling was advanced in [6]. Hence, that provides the ability to accomplish the silhouette transformation of the garment parts by scaling their patterns.

Some of the PSD have specific tools to scale patterns (for example, PSD "Julivi" has a tool "Scale", and another PSD "Gracia" has a tool "Stretch", which is corresponded to the scale process). However, these tools are supposed to be used only for making experimental garments samples or for taking into account the fabric properties. At present there is no enough knowledge about the scaling process in garment industry, especially about a determination the scale factors in specific design situation.

Besides that, scaling is one of many methods that are used in order to obtain a virtual garment. Group of authors proposed to apply a uniform scaling to scale separate horizontal sections of the virtual mannequin [7]. However, a garment form is not the same as the human body form. Flat bodice blocks mostly take into account this fact by using different eases for the different garment parts. Obviously, a ratio of values of the eases in scaled garment form must be the same as in the flat bodice blocks, which were obtained by classic instructions. Probably it could be achieved by non-uniform scaling with a separate scale factor for each axis direction. Such method was proposed in [8] where non-uniform scaling was applied to scaling the horizontal sections of the virtual mannequin. Authors described the regression relationships between body measurements, amount of ease (on bust line, waistline, and hipline) and the scale factors. The regressions ensure that the ratio of different parts of eases in the virtual garment form will be the same as in a standard form of the real garment. Therefore, they can be used to calculate the scale factors in order to create the virtual form of the garment.

The main purpose of current work is to develop a computer program for calculating the scale factors to be used in processes of apparel design. In order

to achieve such a goal we need to obtain detailed information about determining the scale factor for each axis direction in any possible case of 2D and 3D garment design.

2 SCALING PATTERNS OF BODICE BLOCKS

2.1 *Determination of scaling center for the experiment*

Usually the scaling is performed with basic point that called a center of scaling. Until now, we have no information about scale factors for each axis direction in the case of scaling patterns of bodice blocks. Therefore if the scale factors are different for both directions of the same axis then the location of the scaling center must be clearly defined.

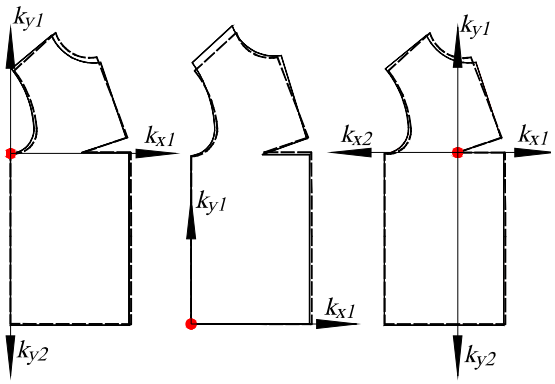


Figure 1 Variants of scaling with various scaling centers

The center of scaling was determined as the result of the follows operations. Few separate cases of scaling the bodice blocks of women's garments were performed with various centers of scaling (Figure 1).

Constructions of the woman's suit jacket and coat were designed within two pattern design systems: "Gracia" and "Julivi". Constructions were designed for the same body size and with the same instructions of the design that were described in [3]. For the suit jacket an amount of ease on the bust line is a minimal value of the recommended range in the selected instruction, and for the coat the amount of ease is a maximal value. Coordinates of constructive points were measured with PDS options. The scale factors were obtained for each axis as a ratio of coordinates of the corresponding points (Table 1).

According to the data in the Table 1 Fisher test confirmed that any of constructive points could be used as a center of scaling. However, as a result of visual observations of the scaled constructions on the Figure 1 the point on the top of the side line was selected as recommended center of scaling. The areas of the garments parts, which were designed by various instructions, and the areas of the scaled garments parts were compared (Table 2).

The analysis confirmed that non-uniform scaling with the selected center of scaling could be used to obtain the bodice blocks of various garments types.

Table 1 Scale factors and Fisher test results

Parameter		Scaling center					
		top of the side line		bottom of the side line		center of the dart	
name	symbol	*coat → suit jacket*	*suit jacket → coat*	*coat → suit jacket*	*suit jacket → coat*	*coat → suit jacket*	*suit jacket → coat*
Scale factors	k_{x1}	0.934	1.071	0.934	1.071	0.956	1.046
	k_{x2}	–	–	–	–	0.906	1.111
	k_{y1}	0.912	1.098	0.995	1.005	0.907	1.105
	k_{y2}	1.020	0.980	–	–	1.021	0.969
Unexplained variance	D_X	0.132	0.099	0.091	0.099	0.099	0.140
	D_Y	0.225	0.275	0.746	0.579	0.216	0.301
Explained variance	Da_X	0.141	0.206	0.101	0.206	0.110	0.237
	Da_Y	0.227	0.284	0.748	0.589	0.218	0.309
Fisher test (experimental)	F_X	1.069	2.077	1.099	2.077	1.106	1.692
	F_Y	1.011	1.031	1.003	1.016	1.011	1.026
Fisher test	F_t	3.020	3.020	3.020	3.020	3.020	3.020

Table 2 Comparing the areas of the garments parts

Parameter	Areas of the garment parts [cm^2]			
	suit jacket		coat	
	front	*back*	*front*	*back*
draft in "Julivi"	1513.84	1638.05	1631.33	1739.45
draft in "Gracia"	1508.22	1639.80	1615.08	1761.18
average value for drafts in PSD	1511.03	1638.93	1623.21	1750.31
scaled construction	1500.44	1653.54	1623.54	1717.39
difference	10.59	14.61	0.33	32.92
relative difference [%]	0.70	0.89	0.02	1.88

2.2 Experimental part

Theoretical scale factors for the scaling patterns were obtained by mathematical model of calculating scale factors. Each scale factor is an average value of the results of division the length between two points of the garment block by the length between the same points of the basic block of other garment type. The lengths were computed according to the instructions which have been proposed by few different authors (Figure 2). Thus, the list includes three instructions: I – described in [2], II – described in [1], and III – in [3]. The lengths depend on the body measurements, on the eases, and on features of the selected instructions.

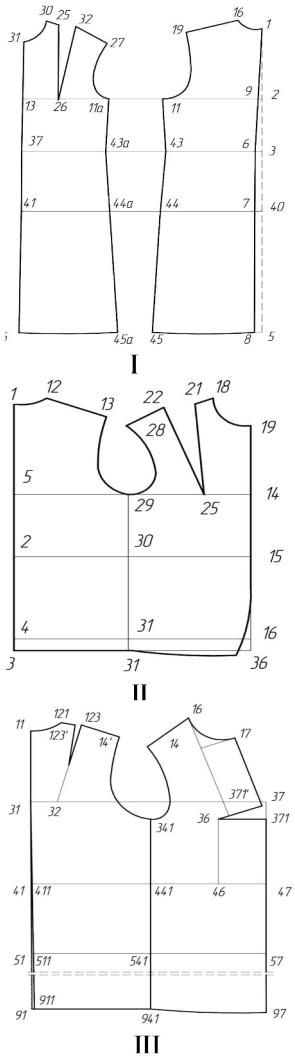


Figure 2 Bodice blocks for the research

Each instruction includes different number of the constructive points, different names of points, and different graphic methods. Thus, coordinates of each constructive point can be calculated by few various formulas accordingly to each instruction. In order to be able to compare the coordinates the same points in the various constructions were named identically (Table 3).

Table 3 Corresponding constructive points in various instructions

Part of bodice blocks	Point	Point in the instruction		
		I	*II*	*III*
Front	1f	31	19	17
	2f	13	14	371
	3f	37	15	47
	4f	47	16	57
	5f	44a	31	541
	6f	43a	30	441
	7f	11a	29	341
	8f	27	28	14
	9f	32	22	-
	10f	26	25	36
	11f	25	21	-
	12f	30	18	16
Back	1b	1	1	11
	2b	9	5	31
	3b	6	2	41
	4b	7	4	51
	5b	44	31	541
	6b	43	30	441
	7b	11	29	341
	8b	19	13	14”
	9b	16	12	121

Thus, the formulas of the calculation the coordinates were obtained for each point in the Table 3. For example, for the point 2f the formulas are follows:

$$X_{2fI} = 0.5\,(S_{gIII} - S_{gII} + S_{gI} - B - F + P_g - P_f + 0.9) \quad (1)$$

where X_{2fI} – abscissa of the constructive point 2f, computed according to [1]; S_{gIII}, B, F, S_{gI}, S_{gII} – measurements of the body [cm]; P_g, P_f – amount of eases [cm].

$$X_{2fII} = 0.25(O_{gII} + 10.25 - B + F + 0.25Wa) \quad (2)$$

where X_{2fII} – abscissa of the constructive point 2f, computed according to [2]; O_{gII}, B, F – measurements of the body [cm]; Wa – width of the armhole [cm].

$$X_{2fIII} = -0.24(T_{57} + P_{35}) + 0.5(T_{45} + T_{15} - 1.2 - T_{14}) + P_{37} - a_{17} \quad (3)$$

where X_{2fIII} – abscissa of the constructive point 2f, calculated according to [3]; T_{57}, T_{45}, T_{15}, T_{14} – measurements of the body [cm]; P_{35}, P_{37} – amount of eases [cm]; a_{17} – constant.

Each scale factor is average value of the results of division the coordinates of the corresponded points, which were calculated by the same formulas but with the different amount of eases. The scale factors were calculated according to the plan of the experiment (Table 4).

The results of calculation were used as a basis to obtain the regression relationships between the body measurements, amount of ease and the scale factors for the patterns scaling (Table 5).

Similar experiments were conducted for the bodice blocks of the four woman’s garments types (a suit jacket, a jacket, a coat, and a raincoat) taking into account all possible directions of scaling between them.

Table 4 The main characteristics of the experiment

Characteristic	Height H [cm]	Bust B [cm]	Hips Hs [cm]	Amount of ease on the bust line E [cm]	
				garment 1	*garment 2*
middle	161	92	100	7.9	9.2
range	15	4	4	1.4	1.6
maximal	176	96	104	7.2	8.4
minimal	146	88	96	8.6	10.0

Table 5 Results of regression analysis

Direction of scaling	Scale factor	Formula	R^2
suit jacket → coat	k_{xf}	$1.477–0.02E_{BJ}+0.022\ E_{BC} –0.0015B$	0.892
	k_{y1}	$1.267–0.01(0.138H–0.1\ B +0.1Hs)$	0.608
	k_{xb}	$1.007–0.023\ E_{BJ} +0.021\ E_{BC}$	0.998
coat → suit jacket	k_{xf}	$0.961+0.021\ E_{BJ} –0.019\ E_{BC}$	0.988
	k_{y1}	$0.826+0.01(0,118H–0.044Hs)$	0.770
	k_{xb}	$0.995+0.018\ E_{BJ} –0.015\ E_{BC}$	0.977

where E_{BJ} (E_{BC}) – amount of eases on the bust line for the suit jacket (coat) [cm].

Table 6 Comparing the areas of bodice blocks

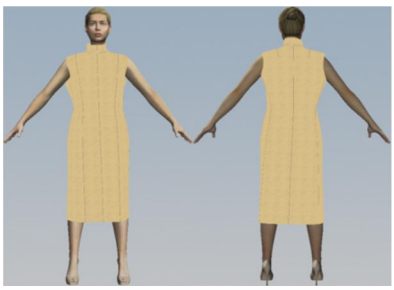
Initial garment type	Areas of the garment parts [cm^2]				Differences [%]			
	suit jacket	*raincoat*	*coat*	*jacket*	*suit jacket*	*raincoat*	*coat*	*jacket*
–	3219	3342	3352	3875	–	–	–	–
coat	3138	3356	–	3777	-2.50	0.42	–	-2.54
suit jacket	–	3392	3606	3848	–	1.50	7.57	-0.71
raincoat	3087	–	3337	3778	-4.10	–	-0.47	-2.51
jacket	3379	3572	3427	–	4.99	6.88	2.23	–

2.3 Results and discussion

The areas of bodice blocks of various garments types were measured with tools of PSD "Julivi" (Table 6). The differences in areas between blocks that were scaled and that were designed with standard instructions mostly lie in the range from 0 to 5%. Scaling directions "suit jacket-coat" and "jacket-raincoat" are characterized with differences that excess 5% mark that recommended in garment industry. Such bodice blocks need minor improvement with tools of 2D garment design in order to achieve a high level of fitting quality.

In order to evaluate fitting quality of garments that obtained with scaling method, virtual garments were designed (Figure 3). Ten experts evaluated parameters of fitting quality (the scale from 0 to 5) that were described in [9]. Complex indexes for the virtual garments samples are shown in the Table 7.

Complex indexes of fitting quality of virtual garments samples are no lower than four that confirms the possible application of developed method into garment design and manufacturing. The pair "raincoat-coat" gets the lowest values of complex indexes of fitting quality while the differences in areas of the garment parts for this pair are minimal (Table 6). Thus, the patterns, which are obtained by scaling, provide the same level of fitting quality as constructed ones and the lowest value of complex index is not due to the scaling.



bodice blocks obtained by scaling method

bodice blocks obtained by instructions [3]

Figure 3 Virtual garment samples (fragment)

Table 7 Complex indexes of fitting quality

Initial garment type	Q			
	suit jacket	*raincoat*	*coat*	*jacket*
coat	4.632	4.469	–	4.725
suit jacket	–	4.879	4.721	4.731
raincoat	4.650	–	4.407	4.577
jacket	4.812	4.521	4.787	–

Although the fitting quality of garments samples corresponds to a high level, no one of them gets the highest mark. That is because the amount of eases, which is one of the main factors for scale factor calculating, is considered only at the bust line. Furthermore, it is impossible to take into account the amounts of eases at other constructive lines such as hips and waist simultaneously with described one.

That is why in order to achieve desired level of fitting quality, the bodice blocks of garments samples must be scaled as it was described above and after that, the bodice blocks are to be improved by simple moving the constructive points on the hips and waist level. In such a way, the garment silhouette will correspond to the garment type, which is must be designed, with required level of accuracy.

Thus, the scaling of the bodice blocks might be used in apparel design when designer has previously developed patterns of one of above-mentioned garments.

3 SCALING BASED ON PROJECTIONS PARAMETERS OF GARMENT SHAPE

All described calculations could be used as a basis for the scaling when information about values of eases is available. However, in some cases there is no such information. For example, we have only a sketch or geometrical image of the garment's shape. The shapes of different garments were analyzed in [10]. Geometrical images of the garments shapes were represented on the female figure. It is possible to measure only projections parameters of the shapes (as it shown on the Figure 4). The values of the projections parameters for different garment shapes are represented in the Table 8.

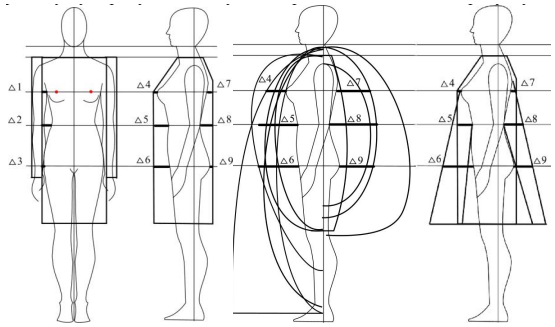


Figure 4 Projections parameters of the garments shapes

Projections parameters were measured on geometrical images of the garments shapes on the female figure (height 170 cm, bust 88 cm, hips 92 cm). According to [11] this female figure is harmonious. Thus, values of the projections parameters can be computed for any other female figure by using the specific ratio coefficient and conditional units.

Table 8 Projections parameters values

Shape	Parameter	Value	
		cm	*conditional units*
Shape 1 (Rectangle)	Δ_1	0.25	0.11
	Δ_2	5.53	2.47
	Δ_3	0÷0.14	0÷0.06
	Δ_4	0÷0.18	0÷0.08
	Δ_5	0.78	0.35
	Δ_6	0.88	0.39
	Δ_7	0.18	0.08
	Δ_8	0.63	0.28
	Δ_9	0÷0.11	0÷0.05
Shape 2 (Trapezium)	Δ_1	0÷0.85	0÷0.38
	Δ_2	0÷1.27	0÷0.57
	Δ_3	0.19÷1.09	0.08÷0.49
	Δ_4	0÷0.14	0÷0.06
	Δ_5	0÷1.12	0÷0.50
	Δ_6	0.27÷1.76	0.12÷0.79
	Δ_7	0÷0.20	0÷0.09
	Δ_8	0÷1.67	0÷0.75
	Δ_9	0.11÷1.04	0.05÷0.46
Shape 3 (Ellipse)	Δ_1	0.13÷2.46	0.06÷1.10
	Δ_2	0.73÷3.48	0.33÷1.55
	Δ_3	0.33÷3.35	0.15÷1.50
	Δ_4	0.00÷1.14	0.00÷0.51
	Δ_5	1.05÷2.25	0.47÷1.00
	Δ_6	1.19÷2.37	0.53÷1.06
	Δ_7	0.20÷1.91	0.09÷0.85
	Δ_8	0.94÷2.78	0.42÷1.24
	Δ_9	0.36÷2.00	0.16÷0.89

where Δ_1, Δ_2… Δ_9 are projection parameters (Figure 2)

If there is a need to study features of the garment forms, which are represented by their geometrical images, information about relationship between the projections parameters and the eases is mandatory. In [12] author proposed to calculate amount of ease by formulas, which we have transformed according to our purpose (taking into account the ratio coefficient for the specific body shape):

$$E_B = -1.004 + 0.013T_1(0.976\Delta_4 + 0.214\Delta_1 - 0.008\Delta_7) \quad (4)$$

$$E_W = -4.14 - 0.013T_1(0.1\Delta_5 + 0.82\Delta_2 - 0.12\Delta_8) \quad (5)$$

$$E_{HS} = 10.84 + 0.013T_1(0.06\Delta_6 - 0.66\Delta_3 + 0.1\Delta_9) \quad (6)$$

where E_B (E_W, E_{HS}) – amount of ease on bust line (waistline, hipline), [cm];

Δ_1, Δ_2… Δ_9 – projection parameters of the garment's silhouette, conditional units;

T_1 – figure height, [cm].

Projection parameters of the garment's silhouette supposed to be measured or selected from the Table 8 (as it shown on the Figure 4) using conditional units. Thus, the scale factors can be calculated by use values of eases, which were obtained with (4)-(6) and measured (or selected) projection parameters. Therefore it would be possible to recreate and study garment form even if only its image is available.

4 DEVELOPING THE COMPUTER PROGRAM

All design processes in garment industry are characterized by rapid technology development that has to be maintained by using the appropriate software. That is why obtained information was used to develop a computer program for scale factors calculating. Computer program "Scale factor" includes several simple algorithms. Each of them could be called from the main window by clicking on the appropriate button (Figure 5).

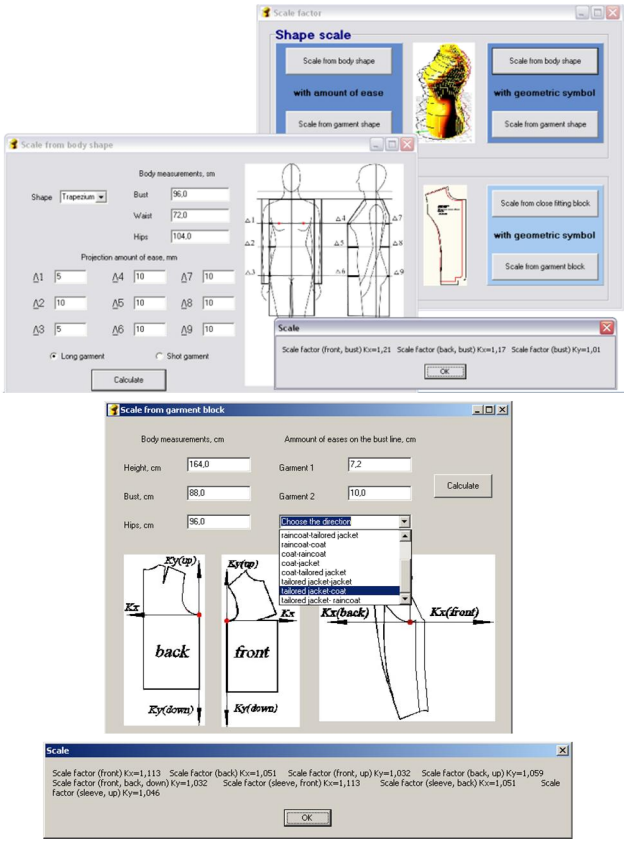


Figure 5 Computer program "Scale factor": examples of usage

"Shape scale" is a part of the program, which includes all cases of the scale factors calculation for the 3D-scaling. The text of the program units includes regression relationships between the body measurements, the amount of ease (on the bust line, waistline, and hipline) and the scale factors. The regressions were described in previously published work [8]. The formulas must be applied in a case when garment form is obtained by scaling the horizontal sections of virtual human body form. If there is no virtual human body form and there is a garment form, then the scale factors must be obtained as a ratio of two scale factors: the first one is using in scaling process from body form to garment form, that is designed, and the second one is using in scaling process from body to actual garment.

"Pattern scale is the part that is recommended for the different processes of 2D garment design. Program units of this part include results of the current research. Both parts include two panels: "with amount of ease" and "with geometric symbol".

Thus, user can choose the method of the calculation according to the available input data. A click on each button calls the next window. Clicking on the button "Calculate" begins the computing process. User gets the output data as a sequence of message boxes.

5 CONCLUSION

The main result of the work is that it gives further progress in study of adaptations of the blocks or previous patterns by using the pattern design system. Thus, the scaling method for designing patterns and developed computer program could be useful in a case of the rapid change in production of women's outerwear.

Computer program "Scale factor" can be also used in study of garment shape features and its transformation within time span. Besides that, it would be possible to research relationship between the body measurements and proportional characteristics of the form to achieve garment aesthetic quality.

6 REFERENCES

1. Aldrich W.: Metric pattern cutting for women's wear (5th Ed.), Wiley-Blackwell, 2008
2. Characteristics of the design method M. Myuller & Son. Retrieved from: http://wellconstruction.ru/konstr2/harakteristika-metodiki-konstruirovaniya-m-myuller-i-syin
3. Kudriavtseva N.V., Krasniuk L.V.: Practical work in designing women's and men's clothing by the unified method of designing clothes of CMEA, Study guide, Khmelnitsky: XNU, 2012
4. Slavinska A.L.: Basis of a modular clothes design, Monography, Khmelnitsky: XNU, 2007
5. Vovk Y.V., Slavinska A.L.: Working out unification of transformation type of the base design of the female skirt in the base design of trousers, Proceedings of higher education institutions, Textile industry Technology 6(354), 2014, pp. 84-89
6. Masalova V.A., Melikov E.Kh., Shil'dt E.V.: RU Patent No. 2264145, Russian Federation: Russian Patent and Trademark Office, 2005, Retrieved from: http://www.freepatent.ru/images/patents/205/2264145/patent-2264145.pdf
7. 3Dfashion – 3D technology in the design of clothing, Retrieved from: http://www.3dfashion.biz
8. Zakharkevich O.V., Hrechana M.V.: Method of constructing a virtual model of the woman's garments by scaling, Interuniversity collection "Scientific notes" Vol. 34, 2011, pp. 95-100
9. Koblyakova E.B., Ivleva G.S.: Designing clothes with CAD elements: study guide. Moscow: Light Industry press, 1988

10. Kuleshova S.G.: Database design of graphic fashion images in XX-XXI centuries, Herald of Khmelnytskyi national university, Technical science Vol. 3, 2013, pp. 148-153
11. Sirotenko O.P.: Improvement of the method of harmonizing of the structural and compositional decisions of the women's light clothing, unpublished
12. Strunevich E.Yu.: Developing of the method of transformation the sketch to construction in the process of automated designing women's clothing, unpublished

TEXTILE MATERIALS MANUFACTURING FEATURES WITH THE USE OF ANTIMICROBIAL ADDITIVES

Olga Zhdanova, Sergey Bereznenko, Natalia Bereznenko and Dmitriy Novak

Kyiv National University of Technologies and Design, Nemyrovych-Danchenko St. 2, 01011 Kyiv, Ukraine
novak.knutd@gmail.com

Abstract: *We investigated the influence of modifiers on the processes of manufacturing of polypropylene (PP), polyethylene (PE) and polyoxymethylene (POM) yarns. We studied their influence on the physical-mechanical and microbiological properties concerning the most widespread pathogens of diseases. Shown the effect of modified yarns on the energy-information state of organs and systems of human organs and variational possibilities of creation of preventive health-giving materials on their basis were studied.*

Keywords: *modifiers, yarns, antimicrobial properties, pathogenic microflora, energy state of organs.*

1 INTRODUCTION

Some global trends prove that one of the long-range issues of the present time in the textile industry is the issue of new raw materials, textiles and clothing with due regard to the specific usage conditions. Especially it concerns professional clothes for extreme life conditions (critically ill and infected patients, hospital workers, athletes, etc.). In recent years so-called "smart materials" which contain modified natural fibers (flax, hemp, etc.) have been used extensively [1, 2]. They have a set of unique properties (low surface resistance, protection against ultraviolet radiation, antiseptic and hygroscopic properties) with acceptable levels of formaldehyde migration, toxic substances and radionuclides content. It encourages the production of medical, health-based and children's clothes.

However, there is a necessity to eliminate high creasing of textile materials with an increased content of bast fibers (50-70%) by combining them with synthetic components, including antimicrobial additives (AMA) (silver nanoproducts (Ag), copper (Cu), iron (Fe) and others).

This "hybridization" of properties for bast and synthetic components creates favourable conditions for manufacturing of products for various purposes. The properties of these products comply with OEKO-TEX® 100 international standards.

2 LITERATURE DATA ANALYSIS AND ARTICULATION OF ISSUE

In the modern society, people are involuntarily experiencing a growing influence of various factors (energy flows of internal and external origin, non-ionizing radiation), some types of drugs, pathogenic organisms (fungi, viruses, bacteria, intracellular parasites) on the human body. Under their influence, our organisms can change immune responses, spread and develop previously unknown types of diseases. A physical factor, such as pathogenic microflora, plays a dominant role in the emergence and development of many types of diseases.

The recent studies show that in the production of clothes for medical purposes (MP), the following factors should be considered:

- ethical, technogenic and ecological factors of human life support [1];
- features of microflora and its location in the human body as well as on the skin surface [2-4];
- specifics of distribution areas of hyperhidrosis (sweating) as one of the reasons for the reproduction of pathogenic organisms and creation of professional, social and psychological human deadaptation [5];
- energy-information aspect of the interaction between elements of the "man-clothes-environment" system in which clothes play a barrier role in relation to pathogenic organisms [6, 7].

In this regard, the role of clothes as a factor for suppression of harmful microflora and stimulation of beneficial microflora, including the biocide effect, is increasing significantly [8].

Antimicrobial finishing of textiles and other materials provide several functions:

- inhibition of reproduction and growth for colonies of microorganisms of the external origin;
- prevention of odors caused by waste products of microorganisms and protection of textile materials from destruction.

On the other hand, clothing materials are the source of self-energy emissions and provide a barrier function connected with the reflection or absorption of waves from pathogenic microflora and human body. This effect is achieved by interference, diffraction and resonance wave radiation from pathogenic components of textile materials and human body [9].

But the lack of information database about the features of formation of antimicrobic properties for polymeric materials by means of modifiers injection in their structure, the impact of the molding abilities of polymers on the manufacturing of yarns with protective properties requires further research in this area.

3 PURPOSE AND METHODS OF THE STUDY

The study was aimed to identify the features of the processes for injection of the AMA polymers into the structure and on their basis formation of yarns, which determine their suitability for further use in the manufacturing of textile and knitting materials for various purposes.

To achieve this goal the following tasks were done:

- to make initial selection of polymeric materials and determine the conditions of their injection into the structure of AMA;
- to examine the conditions of the fibers formation process for modified complex yarns and define the parameters of their formation on the existing equipment;
- to implement a comprehensive evaluation of antimicrobic, physical-mechanical properties of primary and composite yarns and define the area of their use;
- to identify the effectiveness of experimental samples influence on the functional state of organs and systems of the human body.

4 MATERIALS AND METHODS FOR THE INVESTIGATION OF IMPACT OF THE MODIFIES ON THE YARN FORMATION PROCESSES AND THEIR PROPERTIES

4.1 Materials and equipment that were used in the experiment

Impregnation of the yarns was carried out by completely placing of each sample in a solution of the antibacterial preparation, the impregnation time was 20 minutes, and the temperature of the solution was 20-24°C. After impregnation, the samples of the material were removed from the solution of the antibacterial preparation and dried in a suspended state without direct exposure of sunlight until dryness at temperature 22-26°C.

The following polymers were used in the study: polypropylene (PP) of A7 grade, polyethylene (PE) of 2112 grade, polyoxymethylene (POM), antimicrobial additives (AMA) - substituted diphenyl ether, suspensions and pastes based on Ag, Cu, Fe nanoparticles, surfactant active agent - polyethylene glycol (PEG 115). Production of complex yarns of PP and POM with AMA and nanocomposites was developed under laboratory technical regulations on the existing experimental equipment (laboratory extruder MSHG-00, machine for yarn formation MFGP, bench for drawing-out of yarn VSTV).

4.2 Methods to identify the features of sample properties

The research of physical-mechanical properties was carried out according to the current ISO and antimicrobial properties by death rates of the test plants and colony-forming organisms reduction (*S.aureus, E.coli, Calbicans, Candida*) (study carried out in cooperation with the State Research Institute «RESURS» and State Institution «Institute of Epidemiology and Infectious Diseases named after L. Gromashevsky» of the Academy of Medical Sciences of Ukraine, standard ASTM E 2149).

Energy-information assessment of nanomodified materials impact was performed on a software-based diagnostic system (HSDS) «Intera-Dia Cor», which is listed in the register of medical equipment in Ukraine No. 3227/2004 from 30.10.2009. According to the techniques used in the work [10], the indicators of energy stability, instability and coefficient of comfortability (CC) [11] were defined by the formula:

$$K_K = \frac{(K_C - K_H)}{K_C} \cdot 100\% \quad (1)$$

where K_c is total number of testing organs, K_H is the number of organs with negative changes.

5 RESULTS OF THE INVESTIGATION OF THE INDICATORS OF MODIFIED YARN SAMPLES PROPERTIES

The physical-mechanical properties prepared according to the technical specifications samples of polyfilamentous yarns modified by AMA and suspensions of Ag, Cu, and Fe nanoparticles (S/Z twist - 250/200, temperature of thermofixing for PE - 100°C, POM - 140°C). AMA were injected in the yarns in the formation process. The researched results showed that the preparation of yarns by AMA do not degrade the physical-mechanical properties (Table 1 and Table 2).

The minimum level of AMA (0.1 - 0.5%) used in the yarn structure, which effectively influences on microflora and does not reduce physical-mechanical properties, was investigated. Considering these data, the production of modified polypropylene yarns in different disperse environments was made (Table 2).

The data from Tables 1 and 2 show the possibilities for using POM and PP-based yarns in the practice of making clothes for medical purposes. With the simultaneous use of the modifiers of Ag, Cu and Fe nanocomponents in the different dispersed environments (pasta, alcohol, water).

Table 1 Physical-mechanical properties of yarns

Yarn No.	Type of yarn	Multiplicity of extension	The linear density [tex]	Breaking indicators		Tests in knot	
				Load [cN]	*Elongation [%]*	*Load [cN]*	*Elongation [%]*
1	POM	8.5	29.5	1836.0	12.1	884.0	5.5
2	POM + AMA	8.3	39.2	2009.0	14.7	961.5	7.0
3	PE	5.8	31.3	1568.0	24.6	1188.0	13.1
4	PE + AMA	5.3	33.3	1458.0	25.2	1196.0	15.1
5	PE	7.2	22.1	708.0	31.6	592.0	10.1
6	PE + AMA	5.0	33.2	520.0	15.6	515.0	15

Table 2 Physical-mechanical properties of nanomodified yarn

Yarn No.	The composition of the yarn	Disperse environment	Multiplicity of extension	The linear density [tex]	Breaking load [cN]	Relative breaking load [cN/tex]	Breaking elongation [%]
1	PP (original)	—	5.4	31.2	1122.0	36.0	20.6
	PEG 115 + Ag						
2	PP + 0.5%	paste	5.3	32.3	1066.0	33.7	28.3
3	PP + 1.0%	paste	5.3	31.1	1165.6	37.5	24.9
4	PP + 1.0%	alcohol	5.4	30.2	1161.2	38.4	18.1
	PEG 115 + Cu						
5	PP + 0.5%	paste	5.3	30.9	1132.8	36.7	20.5
6	PP + 1.0%	paste	5.3	32.0	1206.8	37.7	20.3
	PEG 115 + Ag + Cu						
7	PP + 0.5%	alcohol	5.3	32.6	1127.0	34.6	25.6
8	PP + 1.0%	alcohol	5.3	31.1	1134.4	36.5	19.2
	PEG 115 + Fe						
9	PP + 0.5%	water	4.3	45.5	1046.8	23.0	36.1
10	PP + 1.0%	water	5.4	32.6	1162.8	35.7	23.8

Microbiological studies have shown that yarns have prolonged antimicrobial properties concerning the test-cultures of *S.aureus, E.coli and Candida* (Table 3).

Efficiency of modified yarns in relation to the test cultures of *S.aureus* in terms of colony-forming organisms is also confirmed by the values of delay zones (3-5 mm) and exposure reduction (about 90% in 30 min.).

The results of additional studies show that yarns based on PP+AMA and POM+AMA are appropriate to use as the lower yarn lock-stitch and stitch. The sterilization of seams made with the use of such threads is not worse than the yarn of Coats-grail type that is used in the manufacturing of clothes.

Taking into account the positive test results of polyfilament yarns, the production of combined yarns with the use of cotton, linen and hemp components in their structure was made (Table 4).

Table 3 Antimicrobial properties of fibrous materials samples

The composition of fibrous material	Reduce of the test-cultures [%]					
	E.coli		*S.aureus*		*Candida*	
	Time of research [hours]					
	6	24	6	24	6	24
POM + 0.5% of AMA	58.4	61.4	40.0	53.4	76.9	89.0
PP + 0.5% of AMA	–	99.0	–	99.5	60.1	69.5

Table 4 Physical-mechanical properties of combined yarns

Yarn No	Type of yarn	The linear density [tex]	Temperature of thermofixation [°C]	Breaking indicators		Tests in knot	
				Load [cN]	Elongation [%]	Load [cN]	Elongation [%]
1	Cotton yarn + (POM + AMA)	84.5	140	1451.5	6.1	1435.6	6.0
2	Cotton yarn + (PP + AMA)	54.7	140	1877.2	5.1	1858.4	5.3
		77.2	140	1120.4	4.2	1257.2	4.5
		82.9	140	1422.4	5.5	1450.4	5.3
3	Mixed flaxen yarn + (POM + AMA)	82.5	110	1137.2	5.7	1152.0	5.7
4	Mixed flaxen yarn + (PP + AMA)	54.4	110	1877.2	5.4	1858.4	5.3
		81.0	110	1181.6	5.2	1017.5	4.9
		83.0	110	1309.6	6.0	1331.2	5.5
5	Mixed hemp yarn + (POM + AMD)	139.8	110	2853.2	12.2	2375.6	9.7

Considering that thermoplastic polymers usually contain various modifiers (plasticizers, stabilizers, antistatic agents, fungicides, etc.), they are injected into polymers in small amounts to improve their technological and operational properties. The studies have shown that the content of AMA more than 1.0% by weight is impractical and can cause the degradation processes of yarn formation and drawing-out. Therefore, in further studies, the quantitative indices of AMA were limited to 0.5-1.0% by weight, and the minimal suppressing concentration of AMA with *S.aureus* cultures and *Candida* fungi at the level of 0.05-0.1% by weight was confirmed by diffusion test in agar and by the method of serial dilution in Saburo broth. Moreover, the data presented in Table 1 show that PE yarns have 2 - 4 times less breaking load in comparison with PP and POM yarns, so their use in textile and knitwear sector may be limited, they can be used in the structure of knitted gasket materials as adhesive components [12], which is solving the problem of packing for clothing details by means of the thermal zone and provides protection from microbial environment, especially in the areas of increased sweating. In addition, this material provides the required level of shape stability. The second feature of the formation of the AMA yarn is their dependence on temperature thermofixation (for PE-based yarn it must not exceed 110°C). As for PP-based yarns, no significant changes in the breaking load and breaking elongation at the fixation of temperature from 20 to 140°C occur, which is evidently caused by relaxation processes in filaments on rigid packaging. However, it must be noted that the type of dispersion environment (Table 2) does not significantly affect the physical and mechanical properties of modified yarns and they can be used in garment, textile, hosiery industries and hospital practice as retention sutures. The studies have shown that it is possible to expand the range of application for such yarns by combining them with linen, hemp, and cotton components (Table 4). Firstly, the technology of the production of yarns from the short fibrous fractions of flax and hemp [13], developed at the University, makes it possible to use their inherent antimicrobial properties in medicine and the related areas. It is possible to create yarns with a wide range of total linear density, which defines the area of their wide application (fabric, knitted fabric, artificial fur, combined products) (Figure 1).

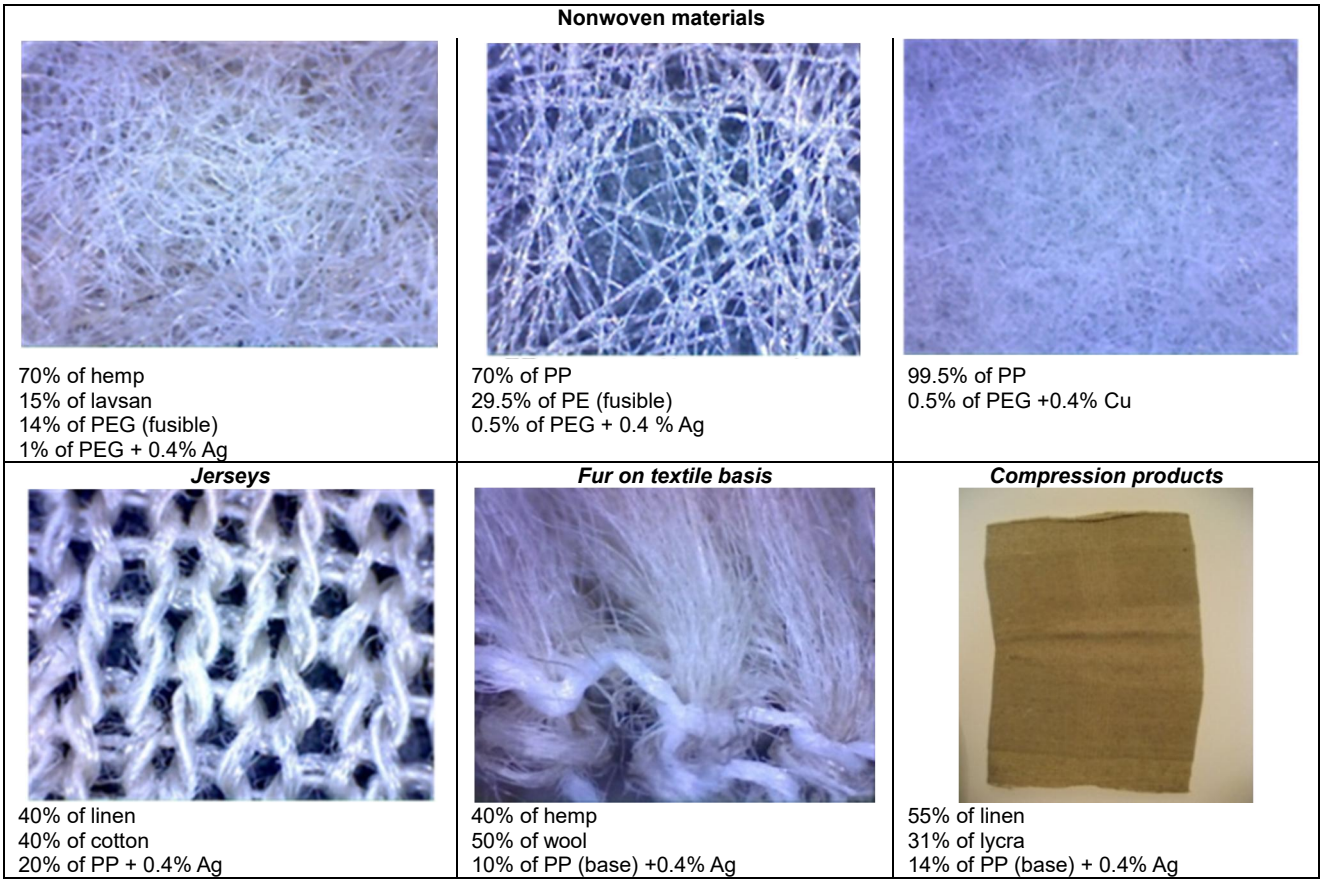


Figure 1 Nanomodified textile materials

The microbiological research showed that the abovementioned materials (Table 5) have sufficient antibacterial and fungicidal properties.

These data show a sustained impact of modifiers on pathogenic components. The effectiveness of such an action of modifiers was also confirmed in the processing of domestic assortment fabrics by impregnation and surface aerodynamic and spraying of Ag and Cu nanoparticles (zone growth retardation of *S.aureus* and *C.albicans* was 4-12 mm).

The positive research results open perspectives of this technology in the production of clothes for medical and recreational purposes directly in terms of garment production.

It is also possible to expand the range of properties of nanomodified materials due to the inclusion of current-conducting components in their structure [14].

Testing of the created materials was performed at the "Intera-Dia Cor" complex. They found a positive influence of the nanomodification materials on the functional state of organs and systems of human organs. It was proved by the testing data of nanomodified cotton fabric with a drug based on Ag particles (Figure 2).

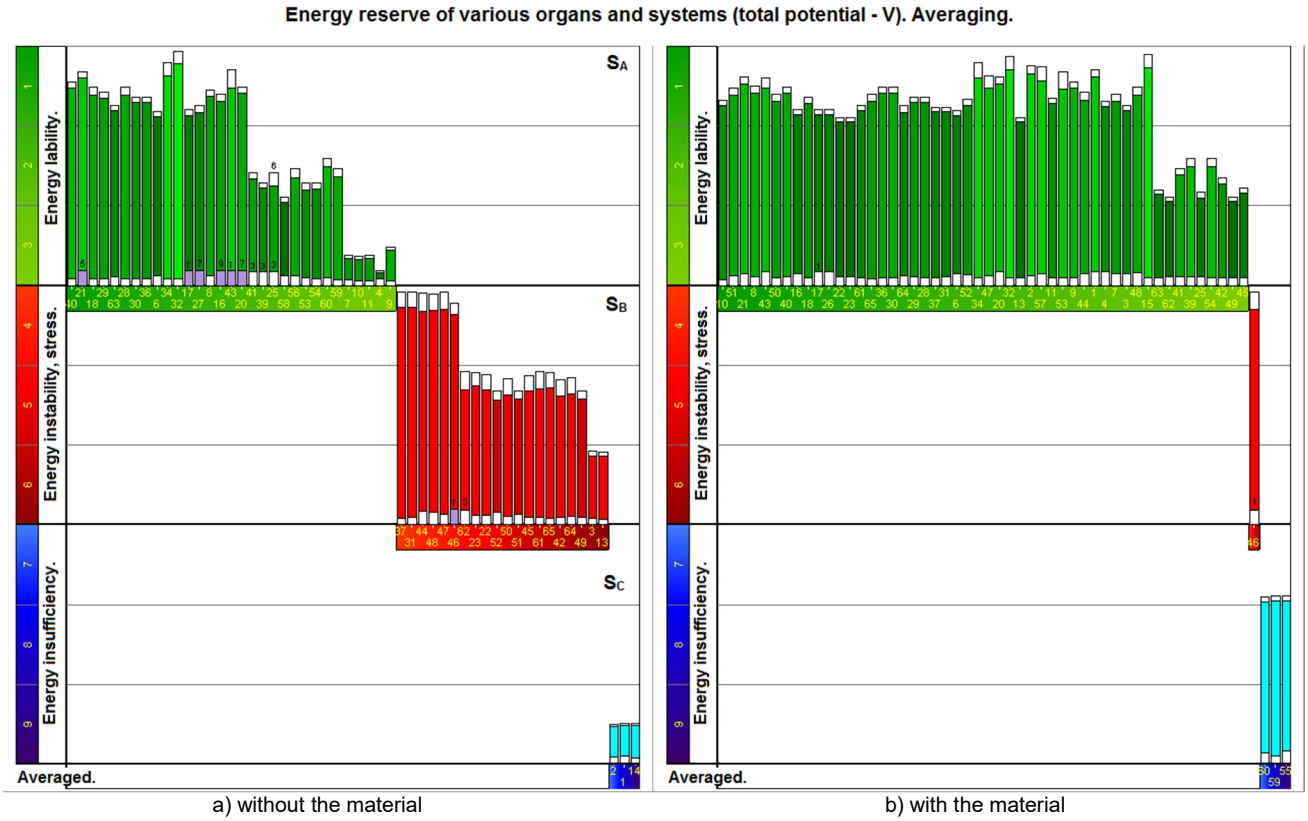
As it can be seen from the diagrams above, using nanomodified materials the indicators of the stable state can be increased significantly, due to the transition of 19 organs from an unstable to a stable state.

In addition, the individual approach to the choice of textile materials for clothes of health and preventive purposes was set. This is confirmed by the level of comfort that was within 51.4-97.4% for the 4 tested persons.

Table 5 Indicators of antibacterial and fungicidal properties of textile materials

Commodity composition	The inhibition zone [mm]	Quantity of microorganisms during the exposure											
		S.aureus				*E.coli*				*C.albicans*			
		Time of research [hours]											
		1	3	6	24	1	3	6	24	1	3	6	24
Cotton *	3	1	3	6	24	1	3	6	24	1	3	6	24
Linseed (Jersey)	3-4	133	1	0	0	4200	2	0	0	HB	0	HB	0
Non-woven PP material	4-5	44	0	0	0	822	750	430	0	-	-	-	-

Note: *-modified by the method of spraying suspension based on PEG + 0.5% Ag



a) without the material b) with the material

Figure 2 The results of the diagnosis of the functional state of organs of the tested person: S_A - stable; S_B - unstable; S_C -insufficient.

6 CONCLUSION

The findings concerning the creation of materials and products for medical and preventive purposes were generalized. The technology for manufacturing of experimental yarn samples using polymeric materials modified by antimicrobic products (AMA, suspensions and pastes with a content of 0.5-1.0% Ag, Cu, Fe) was developed. Energy-information and antimicrobial properties of textile materials in relation to pathogenic microflora were determined. The experimental samples of fabrics, knitwear, non-woven materials using the most effective modifiers were established. The received data give the basis to estimate prospects of a wider use of innovative materials with the attached antimicrobial properties at the production of protective clothes for various purposes.

7 REFERENCES

1. Bereznenko N.P., Yantsalovsky A.I., Vlasenko V.I., Lishchuk V.I.: Ecological and ethical aspect of the creation and use of nanomodified textile materials in products with preventive and medical purpose, In: 5th National Congress on Bioethics, Kyiv, 23-25.09, 2013, p. 106
2. Lukichev N.L.: Electropunctural diagnostic, homeopathy, and the phenomenon of long-range, M., Mosgorpechat, 1990, p. 136
3. Bacterial map of the body [electronic resourse] – Mode of access: https://www.gazeta.ru/science/2009/05/30_a_3181566.shtml
4. Diseases of the scalp - dermatological, fungal, pustular, infectious [electronic resource] – Mode of access: http://momandkids.net.ua/xvoroby-mamy-i-tata/3269-zaxvoryvana-chkiry-golovy.html
5. Head sweating: causes and methods of dealing with it [electronic resource] – Mode of access: http://amlima.com/vagitnist/1558-pitlivist-golovi-prichini-i-metodi-borotbi-z-neju.html
6. Fedotkin I.M.: Notes on the theory of information-wave medicine, Kiev, Publisher "Himgest", 2003, p. 43
7. Bereznenko M.P., Fedotkin I.M. Yantsalovsky I.M., Bereznenko S.M.: The role of clothing as a factor in health nature, Bulletin of KNU No. 3, 2013, pp. 16-19
8. Bereznenko M., Pawłowa M., Bereznenko S., Wlasenko V., Kurlowa N.: Synthetic threads modified with metal nanopreparations, Towaroznawcze problemy jakosci, Polish journal of commodity science, Radom 3(28), 2011, pp. 20-125
9. Luchko L.G.: Multidimensional medicine. The system of self-healing, Moscow: ANO "Publishing house", 2001, p. 432
10. Patent No. 35944, IPC G01N33/36. A method of evaluating the comfort of textile materials, Lucshevska O.M., Yantsalovsky O.Y., Trojan O.M.; applicant and patent holder Khmelnitsky National University – No. 200805703; Appl. 30.04.08; Publ. 10.10.2008, Bulletin. No. 19, p. 4
11. Lucshevska O.M., Trojan O.M.: Development of comfort methodology of textile materials research, Bulletin of KNU No. 6, 2008, pp. 151-155
12. Makhinya T.O., Kotova G.M., Bereznenko M.P. Zubovich L.A., Romankevich O.V.: Knitted cushioning material, Patent for the invention YA from 21885 from 30.04.1998. Bull. No. 2.
13. Bereznenko M.P., Bereznenko S.M., Khokhlova I.Ja., Korostenko S.M.: Thread wrapping: the patent for the invention of YA 60720 from 16.05.2005, Bull. No. 5
14. Novak D., Budash Y., Bereznenko N.: Graphic modeling of conductive filler spatial distribution in polymer matrix, Vlakna a textil (Fibres and Textiles) 23(2), 2016, pp. 37-42

SYNTHESIS AND INVESTIGATION OF AGAR-AGAR GELS FILLED BY HALLOYSITE NANOTUBES FOR MEDICAL USE

N.P. Suprun[1], A.V. Brichka[2] and S.Ya. Brichka[1]

[1]*Kyiv National University of Technologies & Design, N.-Danchenko srt. 2, 01011 Kyiv, Ukraine*
[2]*Chuiko Institute of Surface Chemistry, NAS of Ukraine, General Naumov srt. 17, 03164 Kyiv, Ukraine*
suprun.knutd@ukr.net

Abstract: *Was received a series of agar-agar hydrogels filled with aluminosilicate nanotubes and investigated their morphology and physicochemical characteristics.*

Keywords: *halloysite nanotubes, gel, agar-agar, synthesis, wound dressing.*

1 INTRODUCTION

Gels are gelatinous bodies that consist of a three-dimensional polymer frame and liquid. They represent a wide range of various functional materials which take an intermediate position between liquids and solid bodies. Gels are sometimes remarkable for unique mechanical, optical and electrical properties that determine their wide application in industry and daily life. A structured system gives to gels mechanical properties of firm bodies: absence of flowability, ability to maintain a form, strength, ability for elastic deformation. Recently great attention is paid to biopolymer-based gels which differ from synthetic polymers in the absence of toxicity, biocompatibility with living systems, favorable biological decomposition and availability. Among biopolymers polysaccharides are most extensively used. Hydrogels based on natural components with "smart" properties are of considerable interest to researchers, since they are in demand in medicine as therapeutic transport systems for burn therapy, as sanitizing.

Nanocomposite hydrogels are novel macromolecular biomaterials, which are three-dimensional cross-linked polymer meshes filled with nanoparticles or nanomaterials such as flat clays and discrete inorganic nanoparticles. Such systems are used extensively for up-to-date biomedicine in the field of somatic tissues engineering, for creation of medicine delivery systems and also as biosensors [1-3]. Adding of fillers gives to gels excellent mechanical properties that help in its turn to overcome certain restrictions which usual polymer hydrogels have [4-6]. Nanomedicine uses possibilities and objects of nanotechnologies for diagnostics and treatment of diseases or for improvement of biological functions of organism. In nanomedical biotechnology nanocrystal materials, which halloysitic aluminosilicate nanotubes belong to, are basic. Chemical compounds of a tubular form provoke interest in experts owing to new possibilities of synthesis of materials with the properties distinct from lamellar and other morphological forms. By using of nanotubes with a certain diameter and length it is possible to control functional characteristics of a desirable end-product. Along with a big variety of synthetic nanotubes there are natural halloysite aluminosilicate nanotubes which are notable for high dispersity and uniformity of distribution as a filling agent in gels, respectively [7].

Halloysite nanotubes are material of natural origin and a commercial product obtained from halloysite. Halloysite is described by chemical formula $Al_2Si_2O_5(OH)_4nH_2O$, where n changes from 0 to 2, at this water located between the layers of the crystal firm body. Halloysite nanotubes are not subject to biodegradation and are biocompatible that predetermines extensive possibilities of their use in medicine, cosmetology, and veterinary science. Polymer hydrogels on the basis of natural components and halloysite nanotubes with “smart” properties provoke significant interest in researchers as they are required in medicine as therapeutic systems with transport, barrier, absorbing properties for wound healing at therapy of burn traumas, as sanitary moisture absorptive materials (blood, urine, sweat, etc.), [8-14].

We consider that a phenomenon of energetically strong adsorption of molecules on nanotubes that enables to slow down the release of functionally significant substances from the material can be used at development of nanofilled gel wound coverings of agar-agar/halloysite nanotubes type.

The purpose of the work is to receive and investigate a series of agar-agar hydrogels for definition of the influence of nano-sized filling agent on their physicochemical characteristics.

2 EXPERIMENTAL PART

Hydrogels have been synthesized as follows: to 20 ml of distilled water heated to 60-70°C was added 200 mg of agar-agar, then kept for 15 minutes for biopolymer swelling, and then in a water bath the final dissolution of agar-agar was done. After this to the obtained solution was added 1, 2 and 3 mg of halloysite nanotubes, respectively, distributing them by stirring in a whole volume of the obtained mixture. The obtained nanocomposite was kept in the refrigerator at 6°C during 30 min for hydrogel formation. The content of nanotubes in relation to agar-agar has made 0.5-1.5%. To estimate the quality of obtained materials the system of general organoleptic indices has been used, which include appearance, taste, smell, consistence, color.

The surface morphology of materials were examined by scanning electron microscopy MIRA3 LMU, Tescan with a resolution of ±1 nm and with an Oxford X-MAX 80 mm^2 energy dispersive spectroscopic chemical analysis system with an instrument uncertainty of ±1%. The IR spectra of the materials were measured at room temperature on an IR Affinity-1, Shimadzu spectrometer in the 4000-550 cm^{-1} region using an ATRV attachment with an instrument uncertainty of ±1 cm^{-1}.

3 RESULTS AND DISCUSSION

Images of samples of agar-agar gel synthesized according to the above technique are represented at Figure 1A. A yellow color is caused by significant (about 1 cm) thickness of gel samples, and increase of intensity is connected with the increase in content of halloysite nanotubes filling agent from 0.5 to 1.5%. By touch the strength of hydrogels grows along with the increase of halloysite concentration. At hydrogels drying, filling agent concentration and agglomeration occurs on certain sites (Figure 1B).

The electronic images of frozen gels indicate a developed surface (Figure 2). There are macropores that can serve as the places of adsorption, for example, of physiological fluid that is released from wounds [10]. At the same time, the active substances localized in the nanotubes of the gels are prolonged to be released to the damaged areas of the skin.

To confirm the presence and to determine the distribution of aluminosilicate nanotubes in agar-agar gels the chemical element analysis of chosen gel areas, which are indicated in the Figure 3, has been carried out. Lower image clearness of aluminosilicate nanotubes can obviously testify to the fact that they are coated with a polymer layer. The usual agar-agar composition contains carbohydrates (to 70%) with nitrogen and sulfur atoms protein compounds (1-2%) and significant number of calcium ions etc. So, basic agar elements are carbon, oxygen and calcium. When filling the gel with nanotubes in the energy-dispersive analysis spectra the signals of silicon and aluminum atoms as well as oxygen, in addition, shall appear.

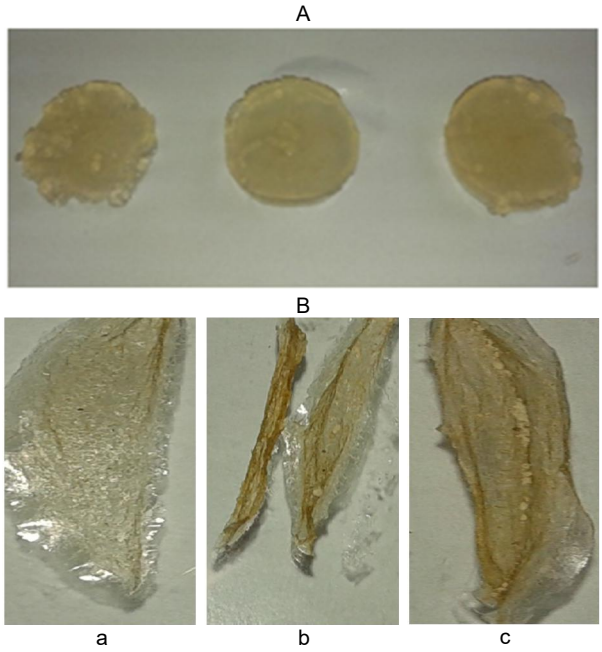


Figure 1 A **-** Optical photo of agar-agar hydrogels B - their dried samples, containing nanotubes: 0.5% (a), 1% (b) and 1.5% (c)

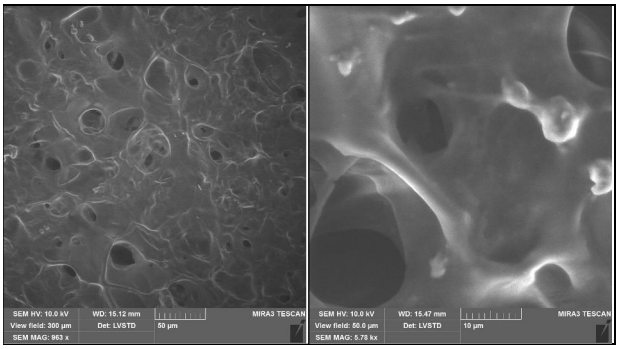


Figure 2 SEM images of frozen gels

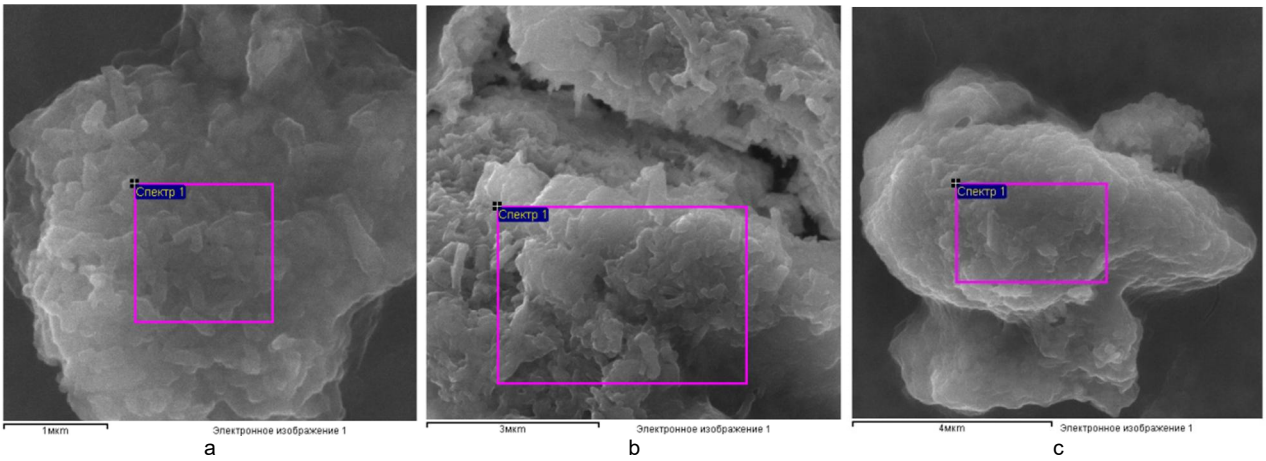


Figure 3 SEM images of dried gels containing nanotubes 0.5% (a), 1% (b), 1.5% (c) and the selected area for energy-dispersive chemical analysis

Quantitative composition of elements fixed in the spectra of filled hydrogels is given in Table 1. Significant carbon content in samples (25.85 - 37.31%) relates to agar-agar organic carbon. Silicon and aluminum elements correspond to halloysite nanotubes, and their ratio about 1:1 corresponds to stoichiometric ratio in halloysite [11].

Table 1 The results of the energy-dispersive chemical analysis of the dried gels in selected areas

Nanotube content [%]	Element content [%] at.					
	C	O	Si	Al	Ca	P
0.5	25.85	53.66	9.26	10.45	0.36	0.42
1	35.46	44.80	10.43	9.32	-	-
1.5	37.31	46.50	7.91	8.06	0.22	-

So, halloysite aluminosilicate nanotubes are distributed uniformly in the agar-agar hydrogel matrix. Oxygen is a part of organic component and aluminosilicate nanotubes, the structure of which form layers of silicon-oxygen tetrahedrons and aluminium hydroxide octahedrons. Revealed calcium and phosphorus may relate to gel former impurities and natural nanotubes.

IR spectroscopy is traditionally widely used for the study and characterization of complex natural heteropolysaccharides galactans particular group of agar-agar. In the IR spectra of freshly hydrogels (Figure 4) observed intense broad absorption bands of water and hydroxyl groups of components in the gel stretching vibration at 3700-3000 cm^{-1}. The presence of water is also evident intense band of deformation vibrations around 1740 cm^{-1}.

Skeleton fluctuations 1043.49 cm^{-1} and less intensive lower than 990 cm^{-1} are revealed. They relate to C-C and C-O polymer links. Divergences in peak maxima can obviously be related to error of samples preparation. Outlet nanotubes have absorption bands at … 907...52 cm^{-1}.

In our opinion, these bands have not been showed in IR spectra of composite hydrogels because of low content of nanotubes in hydrogels and possible nonuniform distribution of nanotubes on local sites in the gel mass. Indirect argument of the presence of aluminosilicate nanotubes with the increasing content in hydrogels is reduction in absorption band intensities with the increase in content of nanotubes.

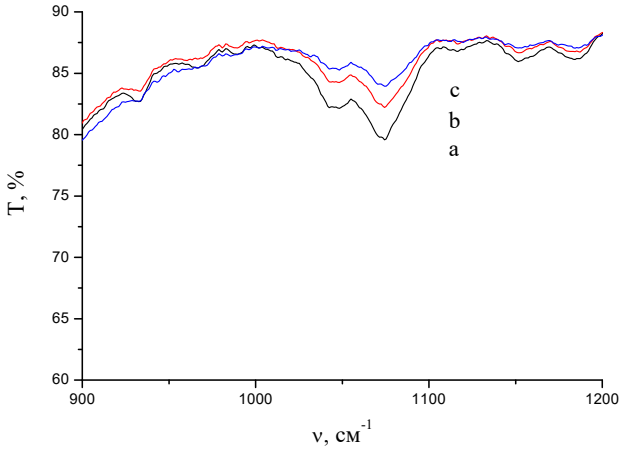


Figure 4 IR spectra of hydrogel sat 1200-900 cm^{-1} containing nanotubes 0.5 (a), 1 (b) and 1.5% (c)

4 CONCLUSION

Nanocomposite hydrogels on the basis of natural materials - agar-agar polysaccharide and halloysite aluminosilicate nanotubes have been synthesized. By organoleptic and physicochemical parameters gels are suitable for the use in biotechnology and medicine for creation of medical aseptic bandages, drain sorbents and wound dressing. Chemical analysis of nanocomposites corresponds to element content of gel components, in particular halloysitic nanotubes. Absorption bands of synthesized hydrogels are shown in IR spectra.

5 REFERENCES

1. Chang C.W., Spreeuwel A.V., Zhang C., Varghese S.: PEG/clay nanocomposite hydrogel: a mechanically robust tissue engineering scaffold, Soft Matter. 6(20), 2010, pp. 5157-5164
2. Satarkar N.S., Hilt J.Z.: Magnetic hydrogel nanocomposites for remote-controlled pulsatile drug release, J. Controlled Release130(3), 2008, pp.246-251
3. Gant R.M., Abraham A.A., Hou Y., Cummins B.M., Grunlan M.A.: Design of a self-cleaning thermoresponsive nanocomposite hydrogel membrane for implantable biosensors, Acta Biomater. 6, 2010, pp. 2903-2910
4. Martin J.E., Patil A.J., Butler M.F., Mann S.: Guest-molecule-directed assembly of meso structured nanocomposite polymer/organoclay hydrogels, Adv.Funct. Mater. 1(4), 2011, pp. 674-681
5. Xu K., et al: Polyampholytes superabsorbent nanocomposites with excellent gel strength, Compos. Sci. Technol. 67, 2007, pp.3480-3486
6. Haraguchi K, Takehisa T.: Nanocomposite hydrogels: a unique organic inorganic network structure with extraordinary mechanical, optical, and swelling/de-swelling properties, Adv. Mater. 14, 2002, pp.1120-1124
7. Brichka S.Ya.: Aluminosilicate nanotubes application, Material science of nanostructures 4, 2012, pp. 40-60
8. Cavallaro G, Gianguzza A, Lazzara G., Milioto S, Piazzese D. Alginate gel beads filled with halloysite nanotubes, Applied Clay Science, 72 2013, pp.132-137
9. Christine Shu Ching Chiewa, Phaik Eong Poh, Pooria Pasbakhsh, Beng Ti Tey, Hak Koon Yeoh, Eng Seng Chan: Physicochemical characterization of halloysite/alginate bionanocomposite hydrogel, Applied Clay Science 101, 2014, pp. 444–454
10. Jiaxing Tu, Zheng Cao, Yihan Jing Changjiang Fan a, Chao Zhang, Liqiong Liao, Lijian Li: Halloysite nanotube nanocomposite hydrogels with tunable mechanical properties and drug release behavior, Composites Science and Technology 85, 2013, pp.126-130
11. Lvov Y.M., Shchukin D.G., Möhwald H, Price R.R.: Halloysite clay nanotubes for controlled release of protective agents, ACS Nano 2, 2008, pp.814-820
12. Levis S.R., Deasy P.B.: Characterisation of halloysite for use as a microtubular drug delivery system, Int. J. Pharm. 243(1-2), 2002, pp.125-134
13. Brichka S.Ya.:Chemistry of halloysite and imogolite nanotubes, Kyiv, Ukraine: Publishing House "Kiy", 2016, 258 pp
14. Brichka S.Ya: Natural aluminosilicate nanotubes: structure and properties, Material science of nanostructures 2, 2009, pp. 40-53

THE INFLUENCE OF FLUORESCENT PIGMENT ON STRUCTURE AND MECHANICAL PROPERTIES OF MODIFIED PP AND PLA FIBRES

Z. Tomčíková[1], A. Ujhelyiová[2], P. Michlík[1], Š. Krivoš[1] and M. Hricová[2]

[1]Research Institute for Man-Made Fibres, a. s., Štúrova 2, 05921 Svit, Slovak Republic
[2] Institute of Natural and Synthetic Polymers, Faculty of Chemical and Food Technology, STU in Bratislava Radlinského 9, 81237 Bratislava, Slovak Republic,
tomcikova@vuchv.sk; anna.ujhelyiova@stuba.sk

Abstract: *The objective of this study was to prepare modified fibers from two types of polymer, polypropylene (PP) and polylactide (PLA). Fibers were modified by fluorescent pigment. Fluorescent pigments cause color change of material after illumination by UV light with a short time of luminescence decay. Their application into fibers can be served as one from solutions how to protect of original products. The influence of uniaxial deformation on the supermolecular structure and basic mechanical properties of modified fibres was investigated as well as colour performance of mentioned pigment in fibers under day light (D65) and after illumination with UV lamp. Supermolecular structure parameters as birefringence, sound velocity in fibres and crystallinity were studied and compared between PP and PLA modified fibres. Also, basic mechanical properties as fineness, Young´s modulus, tenacity at break and elongation at break of undrawn and drawn modified fibres prepared by discontinuous technological process were evaluated and compared. The obtained experimental results concerning supermolecular structure and mechanical characteristics of both types of modified fibres were compared with of their non-modified undrawn and drawn fibres prepared under the same technological conditions.*

Keywords: *modified PP fibres, modified PLA fibres, fluorescent pigment, structure, mechanical properties.*

1 INTRODUCTION

The market of the world textile industry in the year 2016 has exceeded the threshold of 100 million tons although the world fiber market has a continued slowing of growth in the 4th consecutive year. Man-made fibres (MMF) grew 2.0% while natural fibers remained unchanged. The main countries of manufactures fibres are China, India and the USA [1].

Polypropylene (PP) is one of the most widely used thermoplastic materials on petroleum base, because has good mechanical properties, easy processing and low price [2, 3]. It can be used in a wide variety of applications, for example: textiles, automotive components, packaging, stationery, plastic parts and reusable containers of various types, laboratory equipment and other [4-6]. The increasing concerns about our ecological system have results a lot of research activity in the area of bio-based plastics. At present, one of the most promising fully biodegradable polymers is polylactide (PLA) [7] which attract of various markets e.g. textile, packaging and automotive industries, as an eco-alternative to traditional petroleum-based commodity polymers. Although PLA exhibits high strength and stiffness, on the other side has the inherent brittleness [8-10].

In recent years much attention is focused on originality products protection [11, 12] because there are a huge number of counterfeits in all industry areas. It is practically impossible to distinguish original products from the fakes. One of the cost acceptable solutions is an application of fluorescent pigments which have short time of luminescence decay [13]. Fluorescent pigments belong to the group photoluminescent materials where the excitation is caused by light. Photoluminescent materials exist as organic and inorganic ones as solid materials and liquid as well [14, 15]. Fluorescence of individual samples can be detected by dint of fluorophores. Fluorophore is a compound capable to absorb light of certain wavelength and successively emits the light with longer wavelength.

The objective of this study was to prepare two types of fibers with the different polymer matrix (PP and PLA) modified by fluorescent pigment and to compare their properties. The undrawn and drawn modified fibres by discontinuous technological process were prepared. The influence of uniaxial deformation and pigment content on the supermolecular structure and basic mechanical properties was investigated and compared between two types modified fibers. Subsequently different colour performance of fluorescent pigment in fibers under day light (D65) and after illumination with UV

lamp was studied. Obtained results of both types of fibres modified with fluorescent pigment were compared with fibers without pigment content prepared under the same technological conditions.

2 EXPERIMENTAL AND METHODS

2.1 Materials

Isotactic polypropylene (PP) produced by Slovnaft (Slovakia) with MFI = 27.6 g/10 min (230°C/2.16 kg), Polylactide acid (PLA) produced by NatureWorks®LLC (USA) with MFI = 22.8 g/10 min (210°C/2.16 kg) and special organic fluorescent pigment of Radiant Color Company were used. PP masterbatch (pigment content of 2.0 wt.%, MFI = 20.9 g/10 min (230°C/2.16 kg), Filter index = 84 MPa.kg^{-1}) and PLA masterbatch (pigment content of 2.0 wt.%, MFI = 33.6 g/10 min (210°C/2.16 kg), Filter index < 50 MPa.kg^{-1}) developed by Research Institute for Man-Made Fibres, a. s. Svit were used during fibres preparation process.

2.2 Fibre preparation

The modified PP fibres with content of pigment 0.01; 0.05; 0.1; 0.15; 0.2 and 0.3% were prepared from mechanical mixture of PP granulated polymer and PP masterbatch using the classical discontinuous process of spinning and drawing. The laboratory discontinuous line has an extruder with diameter of D = 32.0 mm, with a discontinuous one-step drawing process. The constant processing conditions - spinning temperature of 220°C, spinning die plate of 2x25 holes with diameter of 0.3 mm, final spinning process speed of 1500 m.min^{-1}, the drawing ratio λ=2.0, the drawing temperature of 130°C and final drawing process speed of 100 m.min^{-1} were used.

The modified PLA fibres with the same content of pigment as polypropylene fibres were prepared from mechanical mixture of PLA granulated polymer and PLA masterbatch using the same process of spinning and drawing as had the above mentioned modified PP fibres. In this case the constant processing conditions - 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 ratio λ=2.0, the drawing temperature of 80°C and final drawing process speed of 100 m.min^{-1} were used.

2.3 Methods used

Fibre birefringence - total orientation of fibres

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

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

The sound velocity in fibres

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

Crystallinity of fibres

Crystallinity β represents the crystalline portion of fibres and may be evaluated using various methods. In this work, a Perkin Elmer DSC 4 device was used for the evaluation of the thermal properties of non-modified and modified PP and PLA fibres. The non-isothermal process of analysis was performed. All samples of PP fibres were heated in temperature range from 60 to 260°C and PLA fibres in temperature range from 60 to 200°C at a rate of 10°C.min^{-1} under a nitrogen flow. From melting endotherm of 1st heating of PP fibres the melting enthalpy (ΔHm) was determined. This value was used for the calculation of crystallinity β in PP fibres using Equation 2:

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

where $\Delta H_{m,0}$ = 198.11 kJ.kg^{-1} is the melting enthalpy of PP with the 100% crystallinity.

The crystallinity β of PLA fibres was calculated according to the following Equation 3 [16]:

$$\beta = \frac{\Delta H_m - \Delta H_c}{\Delta H_{m,0}} \cdot 100\% \quad (3)$$

where ΔH_m is the measured melting enthalpy of PLA fibres, ΔH_c 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}) [17].

Mechanical properties of fibres

The mechanical properties of non-modified and modified PP and PLA fibres using Instron 3343 equipment were measured in accordance with the STN EN ISO 2062:2010 and fineness was measured in accordance with the STN EN ISO 2060:1998.

3 RESULTS AND DISCUSSION

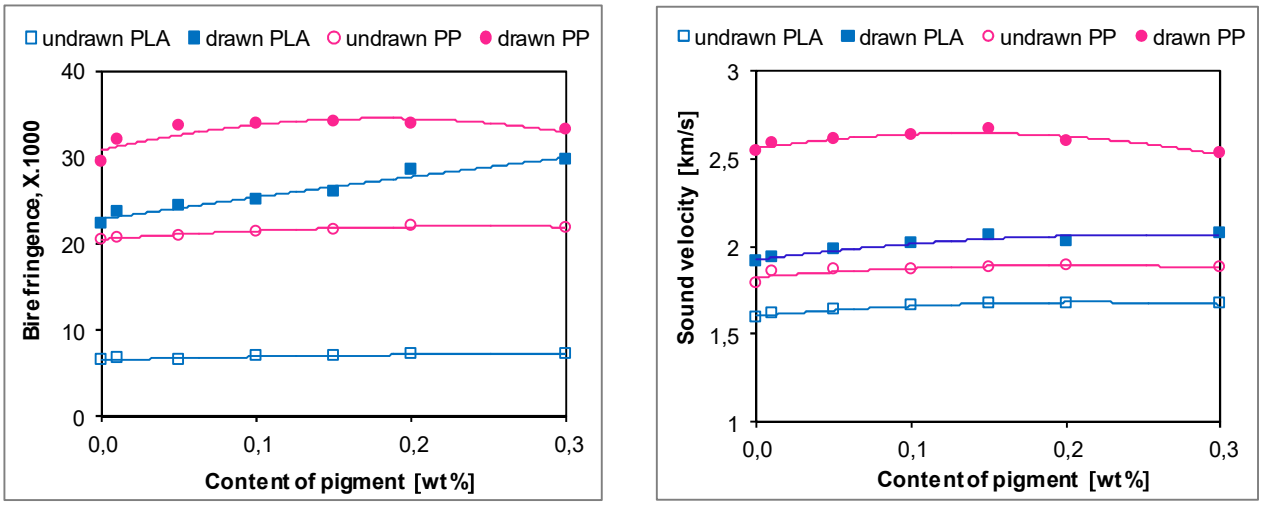
From the processes of spinning (spinning speed of 1500 m.min^{-1}) and drawing (drawing ratio λ = 2.0) of the studied modified systems of PP and PLA it follows that both systems (PP/fluorescent pigment and PLA/fluorescent pigment) are fibre forming and processes are stable in the whole range of concentration of fluorescent pigment (0.01 – 0.30 wt.%). The stability of these processes was comparable with spinning and drawing of non-modified PP and PLA fibres.

First, the supermolecular structure parameters of modified PP and PLA fibres were evaluated. The obtained results (Figures 1 and 2) show the effect of uniaxial deformation and various fluorescent pigment content on the supermolecular structure parameters of undrawn and drawn modified PP and PLA fibres.

Evaluation of supermolecular structure of undrawn fibres shows that PP fibres have a much more higher total average orientation of macromolecular chains (birefringence, Figure 1a) and a little bit higher orientation of macromolecular chains in surface areas (sound velocity, Figure 1b) in the spinning field at spinning speed of 1500 m.min^{-1} when compared to PLA fibres. At the same time, during the spinning, a higher crystallization of PLA matrix of undrawn fibres has been occurred in comparison with PP undrawn fibres (crystallinity, Figure 2). The influence of fluorescent pigment content on the orientation of macromolecular chains and crystallinity of PP and PLA matrices of undrawn modified fibres is insignificant. In the process of uniaxial deformation at drawing ratio λ=2.0, when compared to undrawn fibres, there is a significant increase both of the total average orientation of macromolecular chains in the direction of the fibre axis (birefringence) and of the orientation of macromolecular chains in surface areas (sound velocity), as well as to the increase of crystallinity for both PP and PLA drawn fibres.

The orientation of macromolecular chains in drawn PP fibres is higher than in PLA drawn fibres, and the crystallinity of PLA drawn fibres is significantly higher than the crystallinity of PP drawn fibres. Insignificant influence of fluorescent pigment content on orientation of macromolecular chains and crystallinity of PP drawn fibres was observed. In case of PLA drawn fibres the influence of increased fluorescent pigment content resulted in the increase of macromolecular chains total average orientation in the direction of fibre axis (Figure 1a) and slight decrease in their crystallinity (Figure 2). This can be the result of plasticizing effect of organic fluorescent pigment on PLA matrix in drawn fibre. It follows from the above that the process of uniaxial deformation has significant influence on the formation of supermolecular structure of the final form of drawn modified PP and PLA fibres. The influence of fluorescent pigment content in range 0.01 – 0.30 wt.% was not significant.

Secondly, the mechanical properties of modified PP and PLA fibres were evaluated. Figures 3 and 4 show the effect of uniaxial deformation and fluorescent pigment content on the basic mechanical properties of undrawn and drawn modified PP and PLA fibres.



a b

Figure 1 Dependence of birefringence (a) and sound velocity (b) of undrawn and drawn modified PP and PLA fibres on fluorescent pigment content

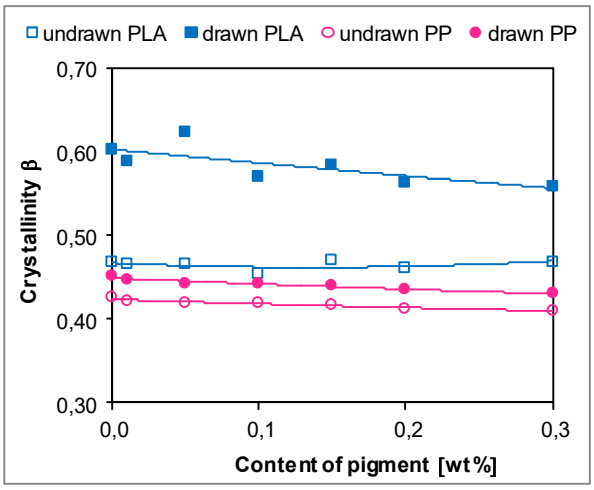


Figure 2 Dependence of crystallinity β of undrawn and drawn modified PP and PLA fibres on fluorescent pigment content

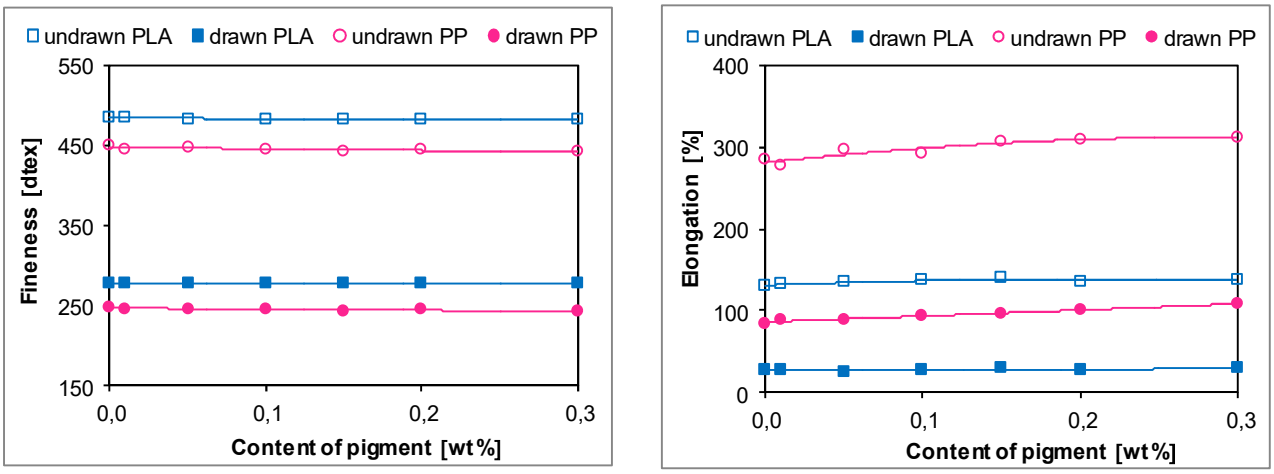
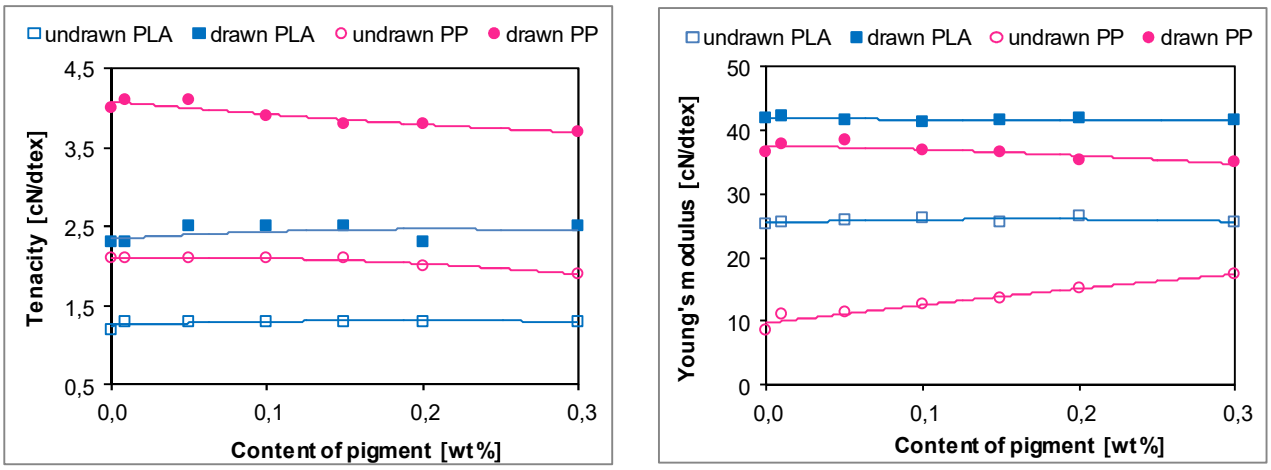


Figure 3 Dependence of fineness (a) and elongation at break (b) of undrawn and drawn modified PP and PLA fibres on fluorescent pigment content

It was found that the content of fluorescent pigment 0.01 – 0.30 wt.% in the fibre mass does not affect the fineness of undrawn and drawn modified PP and PLA fibres (Figure 3a). Different fineness of PP and PLA fibres result from different of density of PP and PLA fibres polymer matrix.

The defined parameters of supermolecular structure of undrawn and drawn modified PP and PLA fibres affected their mechanical properties. From the determined of mechanical properties of undrawn fibres prepared at a spinning speed of 1500 m.min^{-1} follows that the tenacity of PP fibres is higher (max 62%) in comparison with the tenacity of PLA fibres (Figure 4a). This is a result of the both much higher total average orientation of macromolecular chains (birefringence, Figure 1a) and higher orientation of macromolecular chains in surface areas (sound velocity, Figure 1b) of undrawn PP fibres in comparison with undrawn PLA fibres. At the same time, the Young's modulus of undrawn PLA fibres is significantly higher (Figure 4b) and elongation is significantly lower (Figure 3b) in comparison with undrawn PP fibres. This is related to higher crystallinity of undrawn PLA fibres compared to undrawn PP fibres (Figure 2). The effect of fluorescent pigment content of 0.01 – 0.30 wt.% on all evaluated mechanical properties of undrawn PP and PLA fibres is not significant as well as its effect on supermolecular structure of these fibres.

The process of uniaxial deformation at drawing ratio λ=2.0 significantly increases the tenacity (Figure 4a) and Young's modulus (Figure 4b) of drawn PP and PLA fibres in comparison with undrawn fibres. This results from substantial increased total average orientation of macromolecular chains in the direction of axis of drawn fibres (birefringence, Figure 1a), substantial increased orientation of macromolecular chains in surface areas of drawn fibres (sound velocity, Figure 1b), as well as increased crystallinity of drawn fibres (crystallinity, Figure 2).



a b

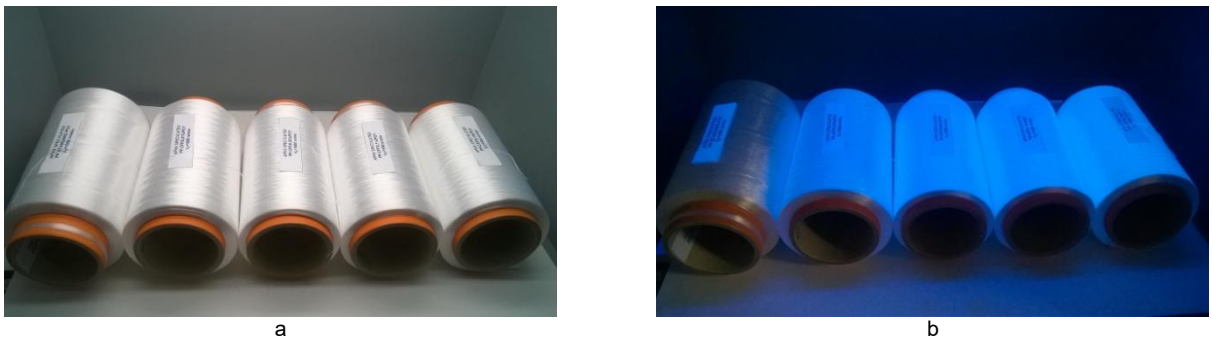
Figure 4 Dependence of tenacity at break (a) and Young's modulus (b) of undrawn and drawn modified PP and PLA fibres on fluorescent pigment content

At the same time, the tenacity of drawn PP fibres is prominently higher than the tenacity of drawn PLA fibres (Figure 4a). This results from significantly higher total average orientation of macromolecular chains (birefringence, Figure 1a) and higher orientation of macromolecular chains in surface areas (sound velocity, Figure 1b) of drawn PP fibres. The finally, the Young's modulus of drawn PLA fibres is higher (Figure 4b) and elongation is lower (Figure 3b) when compared to drawn PP fibres. It is affected by prominently higher crystallinity of drawn PLA fibres in comparison with drawn PP fibres (Figure 2). The significant influence of fluorescent pigment content of 0.01 – 0.30 wt.% on all evaluated mechanical properties was not proved, nor was its influence on supermolecular structure of drawn fibers.

The obtained values of the basic mechanical properties of undrawn and drawn modified PP and PLA fibres are in good correlation with determined values of their supermolecular structure parameters.

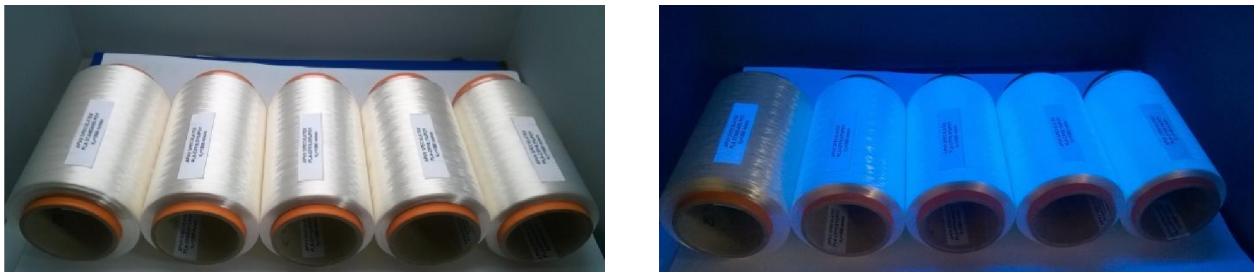
The last evaluated parameter was color performance of modified PP and PLA fibres investigated under UV lamp. Figures 5 and 6 show the effect of the fluorescent pigment content on color performance of modified PP and PLA fibres.

Figures 5a and 6a clearly show that under the daylight (D65) all prepared modified PP and PLA fibers are white. Under the UV lamp only non-modified PP and PLA standard fibres (Figure 5b and Figure 6b) are not shiny while the modified PP and PLA fibres with fluorescent pigment shine blue. The color intensity rises with increased content of fluorescent pigment in modified PP and PLA fibres. It can be seen that even the lowest pigment content 0.01 wt.% (samples 2 from left to right in figures 5b and 6b) of evaluated fluorescent pigment provides clearly visible color change under UV lamp.



a b

Figure 5 The influence of fluorescent pigment with content 0.01; 0.05, 0.10 and 0.30 wt.% on the color performance of modified PP fibres in comparison with non-modified PP fibre (on the left) under daylight D65 (a) and under UV lamp (b)



a b

Figure 6 The influence of fluorescent pigment with content 0.01; 0.05, 0.10 and 0.30 wt.% on the color performance of modified PLA fibres in comparison with non-modified PLA fibre (on the left) under daylight D65 (a) and under UV lamp (b)

4 CONCLUSION

Processes of spinning (spinning speed of 1500 $m.min^{-1}$) and drawing (drawing ratio λ = 2.0) of the studied systems - PP/fluorescent pigment and PLA/fluorescent pigment have showed that their stability is comparable with the stability of processes of non-modified PP and PLA fibres. The both systems were fibre forming and processes were stable in the whole concentration range of fluorescent pigment (0.01 – 0.30 wt.%). The technological conditions for stable spinning and drawing of modified PP and PLA fibres were found. The basic dependencies of the influence of uniaxial deformation and fluorescent pigment content on the supermolecular structure parameters, basic mechanical properties and color performance under UV lamp of modified PP and PLA fibres were evaluated.

It was found that in the spinning field there occurs a higher total orientation of macromolecular chains in PP matrix of modified fibres, which resulted in higher tenacity of undrawn PP fibres in comparison with undrawn PLA fibres. At the same time, higher crystallinity occurs in the PLA matrix of modified fibres, resulting in higher Young's modulus and lower elongation of undrawn PLA fibres in comparison with undrawn PP fibres. The influence of fluorescent pigment content on supermolecular structure and mechanical properties of undrawn PP and PLA fibres is not significant.

It was also found that the process of uniaxial deformation of undrawn fibres has significant influence on supermolecular structure and mechanical properties of the final form of drawn modified PP and PLA fibres. By drawing, a significant increase in total orientation of macromolecular chains in the direction of fibre axis and the increase in crystallinity of drawn PP and PLA fibres is achieved, while the tenacity of drawn PP fibres is significantly higher than the tenacity of drawn PLA fibres. This is influenced by significantly higher total orientation of macromolecular chains in the direction of fibre axis. At the same time, the Young's modulus of drawn PLA fibres is higher and the elongation is significantly lower when compared to drawn PP fibres, which is related to their significantly higher crystallinity than that of drawn PP fibres. The influence of the fluorescent pigment content on supermolecular structure and evaluated mechanical properties of drawn PP and PLA fibres was not significant.

An important result is also the finding that the color performance under UV light is visible even at lowest fluorescence pigment content (0.01 wt.%) in both modified PP and PLA fibres.

Based on the results obtained, it can be stated that the evaluated fluorescent pigment has no negative impact on technological stability of preparation of modified PP and PLA fibres; it does not significantly influence their supermolecular structure and mechanical properties, and is coloristically effective under UV lamp at even low concentrations. Therefore, it can be used as a tool for protection of original PP and PLA textile products.

ACKNOWLEDGEMENT: *This work was supported by the Slovak Research and Development Agency under the contract No. APVV-14-0175.*

5 REFERENCES

1. An.: Fiber production surpassed 100 million tons in 2016, Chemical Fibers International 67(2), 2017, p. 68
2. Gahleitner M., Paulik Ch.: Chapter 11 – Polypropylene and Other Polyolefins, In Book: Brydson's Plastics Materials (Eighth Edition), 2017, pp. 279-309, ISBN: 978-0-323-35824-8
3. Panaitescua D.M., Nicolaea C.A., Vulugaa Z., Vitelarub C., Sanporeanc C.G., Zahariad C.,Floreaa D., Vasilievicia G.: Cover image influence of hemp fibers with modified surface on polypropylene composites, Journal of Industrial and Engineering Chemistry 37, 2016, pp. 137-146
4. Manek V., Gudiyawar M.Y.: Thermal and flame-resistance behavior of polypropylene fabrics, Chemical Fibers Int. 65(3), 2015, pp. 177-179
5. Niebel V., Gloy Y.S., Gries T.: Polyolefin melt adhesion fibers and yarns and implementation into textile applications, Man-Made Fiber Year Book 2015, 65, 2015, pp. 47-48

6. Kazmi S.M.R., Jayaraman K., Das R.: Single-step manufacturing of curved polypropylene composites using a unique sheet consolidation method, Journal of Materials Processing Technology 237, 2016, pp. 96-112
7. Avérous L.: Polylactic Acid: Chapter 21 – Synthesis, Properties and Applications, In Book: Monomers, Polymers and Composites from Renewable Resources, 2008, pp. 433-450, ISBN: 978-0-08-045316-3
8. Liu H., Zhang J.: Research progress in toughening modification of poly(lactic acid), J. Polym. Sci., Part B – Polym. Phys. 49(15), 2011, pp. 1051-1083
9. Tan K.L., Lim S.K., CHan J.H., Low CH.Y.: Overview of poly(lactic acid) production with oil palm biomass as potentional feedstock, International Journal of Engineering and Applied Sciences 5(4), 2014, pp. 1-10
10. An: Improve transparency and performance of PLA, bioplastics Magazine 11(06), 2016, p. 31
11. Rossier R., Hersch R.D.: Hiding patterns with daylight fluorescent inks, 19th Color and Imaging Conference, 2011, pp. 223-228
12. Hersch R.D., Donzé P., Chosson S.: Color Images Visible under UV Light, ACM Trans. Graphics, Proc. ACM SIGGRAPH, 2007, 26(3), 75:1-75:9
13. Bamfield P.: Chromic phenomena, Technological Applications of colour chemistry, The Royal Society of Chemistry, Cambrige, 2001
14. Jarraya N.A., Khemakhem K., Turki-Guermazi H., Abid S., Saffon N., Fery-Forgues S.: Solid-state fluorescence properties of small iminocoumarin derivatives and their analogues in the coumarin series, Dyes and Pigments 132, 2016, pp. 177-184
15. Davidson M.V. (1998, July 20) Fluorescence microscopy, Retrieved 12, February 2009, from Molecular Expressions Optical Microscopy, Primer: http://microscope.fsu.edu/primer/techniques/fluorescene/fluorhome.html
16. Drieskens M., Peeters R., Mullens J., Franco D., Lemstra P.J., Hristova-Bogaerds D.G.: Structure Versus Properties Relationship of Poly(lactic acid). I. Effect of Crystallinity on Barrier Properties, J. Polym. Sci. Part B – Polym. Phys. 47(22), 2009, pp. 2247-2258
17. Cayuela D., Montero L.A., Manich A.M.: 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

MECHANISM OF LIQUID WATER TRANSPORT IN FABRICS; A REVIEW

Musaddaq Azeem[1], Amal Boughattas[2], Jakub Wiener[1] and Antonin Havelka[1]

[1]*Technical University of Liberec, Faculty of Textile Engineering, Studentska 1402/2, 461 17, Liberec 1, Czech Republic*
[2]*Monastir University, National School of Engineers, Department of Textile Engineering*
Avenue Ibn Eljazzar-5019 Monastir-TUNISIA
musaddaqazeem@yahoo.com

Abstract: *Liquid water transportation through textiles plays an important role in comfort properties. Transport mechanism takes place from liquid's first behavior when get in touch with fabric to last behavior when evaporated to atmosphere. Wetting phenomena has been carried out by liquid and air interface with textile materials. Basically wetting is physical interaction of fabric with liquid, air and their surface energies results into wicking. Wicking is unconstrained liquid movement, driven by capillarities. Capillarity deals with the penetration ability of liquid into fine pores of fibre to travel along its walls. Wetting, wicking and capillarity are influential parameters to relate the fluid transport in textile fibrous media. This paper is focused on wetting, contact angle, wicking and capillarity, executes in measuring comfort and liquid moisture transport behavior of fabric.*

Keywords*: wetting, wicking, contact angle, liquid transportation, capillarity.*

1 INTRODUCTION

Liquid transport through fabrics is well desired phenomenon in many fields. It has been studied for both fundamental and applied points of view. It plays an important role not only in textile industry but also in the success of many other industrial processes, such as oil recovery, lubrication and fluid filtration. Also it judges the performance of clothes, in different activities, either they are comfortable or not. In fact, liquid transmission behavior of fabrics is one of the most important factors that affect thermo-physiological clothing comfort, especially in sweating conditions [1-4].

When perspiration takes place to cool the human body, the water exuded from the skin appears initially in its liquid form [5]. Evaporation of perspiration is major mean of body cooling, so fabric must intercept the build-up of perspiration on human body to keep it dry by enabling the body water to outer layer of clothing [6-8].

The build-up of sweat on the skin is considered as the main factor contributing to discomfort [9-11]. This problem can be solved with the use of appropriate fabrics that have excellent water absorption and transport properties. Thus extensive researches are focused on the study of the processes which are involved in liquid transportation through fabrics especially wetting and wicking theories [12-16].

Furthermore, when fibres come into contact with water, firstly the fibre surfaces must be wet and after that water can be transported through the inter-fibre pores to the amorphous regions. Thus the interaction between solid-air interfaces in the fibre is replaced by a solid-liquid interface and this phenomenon is called ‘wetting’ [12].

Wicking, wetting, absorbency or transportation is belonging to "Moisture Management" which means the ability of a textile fabric to transport moisture away from the skin to fabric’s outer surface in multi-dimensions. It is one of the key performance criteria in today’s apparel industry since it has a significant effect on the human perception of moisture sensations [17].

2 WETTING AND WICKING

Wetting and wicking are considered the most important parameters for absorption and transportation of liquid in textile clothing. Kissa [12] made a clear distinction between wetting and wicking. In fact, liquid transport takes place through these two sequential processes of wetting followed by wicking [18-19] as shown in Figure 1. 'Wettability' is defined as the first impression of fabric when get into touch with liquid however, 'wickability' is defined as the capacity to sustain capillary motion. It occurs when fibres with capillary spaces in between them are wetted by a liquid. The resultant capillary forces draw the liquid into the capillary spaces. The interaction between the forces of cohesion (within the liquid) and the forces of adhesion (between the fibers and the liquid) determines whether wetting takes place or not and also determines spreading and absorption of the liquid over the surface of the textile material [20].

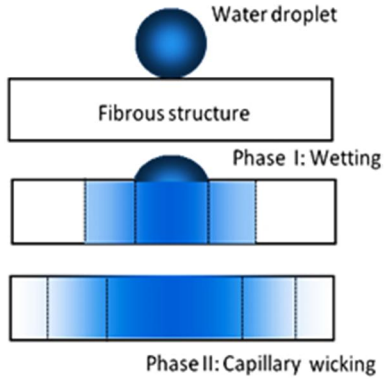


Figure 1 Liquid transport process through fabrics

2.1 Wetting

Wetting is a fundamental phenomenon that takes place at the first moments when fabrics come into touch with liquid [12]. Wetting is characterized by the displacement of fiber-vapor interface to fibre-liquid interface. Wettability studies usually involve the measurement of contact angles as the primary data, which indicates the degree of wetting when a solid and liquid interact [12].

The wettability of fibrous assembly [21-23] is affected by the chemical nature of fiber surface, the fiber geometry and the surface roughness [24-26].

2.1.1 Contact angle

The contact angle is related to general thermodynamic quantities and it presented as the angle formed between the tangent of the liquid-vapor interface and the solid-liquid interface at the line of intersection of the three interfaces (liquid-vapor, liquid-solid, solid-vapor) [27] as shown in Figure 2. According to Young-Dupre equation [28]:

$$\cos\theta = \frac{\gamma_{sv} - \gamma_{sl}}{\gamma_{lv}} \quad (1)$$

where *s, v* and *l* are the solid, vapor and liquid surfaces for γ (interfacial tension) with θ (equilibrium contact angle).

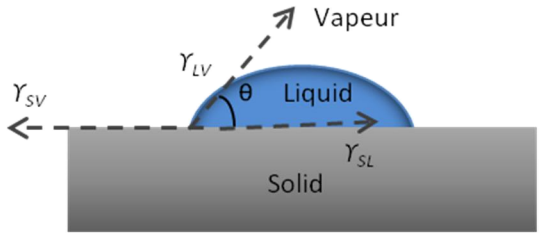


Figure 2 Contact angle on ideal surface, Young contact angle

When the contact angle between a liquid drop and the paper surface is lower than 90°, there is an attraction between the liquid and the solid phase, while when the contact angle exceeds 90°, there is repulsion between the liquid and the solid phase [19]. According to Figure 3, contact angles (<90°) correspond to high wettability, while contact angles (>90°) correspond to low wettability.

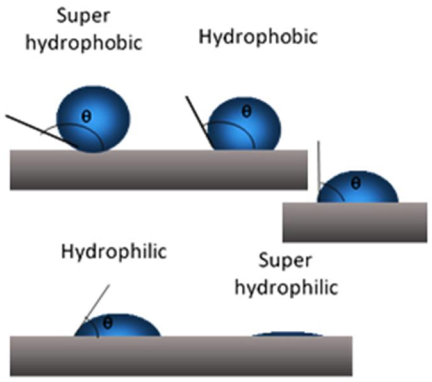


Figure 3 Illustration of different contact angles

The wetting of a fabric depends upon the nature of the wetting liquid and the surface energy of the textile substrate, which is largely dependent upon the structure, perimeter, surface purity and molecular orientation of the fibre, yarn, fabric, capillary forces, cover factor, area density and surface roughness [18]. Due to the heterogenic surface of textile materials, the previous equation of contact angle becomes invalid.

Wenzel model

Wenzel [29] defined the relationship between roughness and wetting. In fact, he state that in case of solid with rough surface (like textile materials), contact angle between the liquid and solid is defined as apparent contact angle (θ^*). Cosine apparent contact angle (θ^*) is function of the surface roughness of solid (r_g) and the contact angle obtained in the case of ideal surface of the same solid (Young contact angle (θ)). The following equation was proposed by Wenzel [29]:

$$\cos\theta^* = r_g . \cos\theta \quad (2)$$

Cassie- Baxter model

In case of chemically heterogeneous surfaces with two chemistries, Cassie [30] developed the above equation:

$$\cos\theta^* = \phi_1 \cos\theta_1 + \phi_2 \cos\theta_2 \quad (3)$$

where Φ is the area fraction characterized by the given chemistry and subscripts 1 and 2 indicate two different surface chemistries. If the second area is air instead of having different chemistries of surface, then equation (3) can be written as:

$$\cos\theta^* = \phi_1(\cos\theta + 1) - 1 \quad (4)$$

2.1.2 Wetting hysteresis

As known, textile materials are characterized by their rough surface and heterogeneity that caused changes in surface energy and affect adsorption of liquid. Hence the contact angle exhibits hysteresis which is defined as the gap between the receding contact angle and the advancing contact angle. The receding contact angle (θ_r) is obtained when the contact line recede of static liquid and the advancing contact angle (θ_a) is measured in advance of line contact. Although, the advancing contact angle is usually used with wicking. Hence, capillary flow depends on dynamic contact angle that is defined as the contact angle of moving liquid front and it can depend on the velocity of moving contact line and/or on time [31, 32]. The difference between θ_a and θ_r is called the hysteresis (H) [33]:

$$H = \theta_a - \theta_r \tag{5}$$

The principle of measurement of these two angles is as shown in Figure 4.

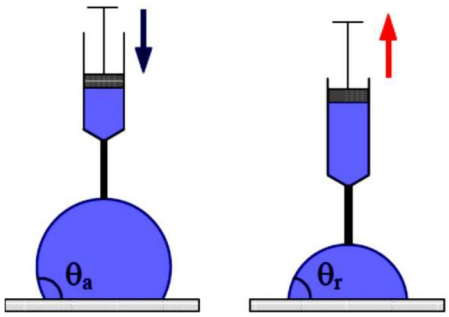


Figure 4 Advancing angle and receding angle

2.1.3 Measurement of contact angle

Wetting is a result of the work of adhesion between the solid and liquid (W_{SL}). In fact, it is the work necessary to separate these two phases (liquid and solid) from each other against the adhesive forces between them. Dupre reported the relations between the work of adhesion and tension surface as follows [34]:

$$W_{SL} = \gamma_{SV} + \gamma_{LV} - \gamma_{LS} \tag{6}$$

By combinning equation (1) and equation (6) and with the elimination of unknown surface tension, we get [34]:

$$W_{SL} = \gamma_{LV} + \gamma_{LV} \cos\theta \tag{7}$$

Above equation explain why the contact angle has been used as the main parameter to measure the wettability of a surface by a liquid [35]. The methods used for the measurement of contact angle can be classified into two categories, direct and indirect methods.

Direct Method

In this method, a liquid drop is placed on the surface and a microscope allows the drop image to be shown. Image analysis software is used to analyze the image. Contact angles are measured at tangent lines to the surface and they are calculated on both sides of drop [36].

Another direct method suggested by Barnell et al [37] and used by Hollies [14] where the solid is vertically immersed in horizontal liquid interface, in the form of rod. The solid-liquid-vapour contact angle is measured using a microscope in horizontal position focusing on the material with the contact line. The contact angle is the angle between the edge of the solid surface and the tangent line of liquid-solid interface as shown in Figure 5.

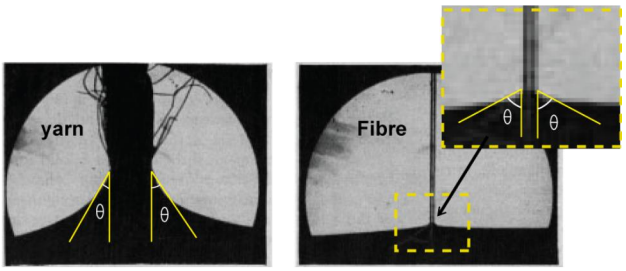


Figure 5 Measurement of contact angle on yarn and fibre using the vertical rod method [14]

Indirect Method

The most effective method for measuring liquid contact angle on fibers indirectly is the Wilhelmy wetting force technique [34]. In fact, when a solid is partially immersed in liquid, there is an attractive force exerted by liquid on solid (F_w). Wilhelmy reported that the source of this attractive force is the surface tension of liquid and express the following equation [16]:

$$F_W = p.\gamma_{LV} \cos\theta \tag{8}$$

where F_W is the measured force and p is the perimeter of the solid.

If the liquid-solid contact angle becomes zero (total wetting liquid), $\cos\theta$ is 1.0. Thus the perimeter (p) can be calculated with known liquid surface tension (γ_{LV}) as follow [16]:

$$p = \frac{F_W}{\gamma_{LV}} \tag{9}$$

The cosine contact angle and the contact angle can be derived if the liquid surface tension and liquid-solid interface dimension are known [16]

$$\cos\theta = \frac{F_W}{p.\gamma_{LV}} \tag{10}$$

2.2 *Wicking*

When a textile material is placed in contact with liquid, spontaneous uptake of liquid may occur, the term 'spontaneous' meaning that the movement of liquid takes place against a zero or negative liquid-head pressure gradient [38]. Regarding the direction of water flow, spontaneous uptake in the plane of a fabric is always called wicking. Wicking is an unconstrained transport of liquid in a porous substrate, driven by capillary forces which are caused by wetting [12]. Hence, wicking is a result of wetting.

Wicking is based on two important characteristics, which are capillary pressure and permeability [39]. With an increase in the saturation of pores with liquid, the capillary pressure decreases and it reaches zero for totally saturated material. However, the permeability of the media increases with the increase in saturation [40]. When saturation level is low, small pores of the media fill up first than larger pores. Hence, liquid flow would be faster in small pores and then it will be distributed, uniformly, to interconnected pores [41, 42].

Wicking through the inter-fibre and inter-yarn channels is affected by the way the fibres or yarns are arranged into a fabric [12]. The capillary radius and the number of capillaries formed affects wicking [43]. Moreover, fibrous assembly are known by their irregularities in fiber diameter or pore interfiber and intrafiber, which is represented by the tortuosity. The wicking process can be affected by the tortuosity of the pores. Hence, an increase in the tortuosity of pores produces a decrease in its wicking potential [42, 44]. Rossi et al. [45] pointed out that the moisture absorption capacities of the fibres (hygroscopicity) as well as its surface properties (hydrophilicity or hydrophobicity) are very important parameters determining the wicking effect. Figure 6 presented the moisture regain of some fibers at standard conditions.

Wicking is also affected by the properties of the liquid, decreasing for liquids with higher viscosity and/or surface tension. Further to these factors, the moisture content of the sample, the ambient temperature and humidity also affect the penetration process [49].

2.2.1 *Wicking calculation*

Wicking is a salient feature in moisture management which permits an idea about absorbency and dye intake along with the fabric comfort. Wicking got the attention of scholars from every field of study, generally engineers, especially textile engineering and technology.

Lukas-Washburn equation

Washburn and Lucas were two scientists who set the base of wicking and describe the capillary flow [50].

The law, which is commonly applied to describe the flow as a result of a pressure drop gradient along the tube, is the Hagen-Poiseuille law for laminar flow through pipes. The law describes the velocity of the liquid front as follows:

$$\frac{dL}{dt} = \frac{r^2}{8\mu} \cdot \frac{\Delta P}{L} \tag{11}$$

where dL/dt is the liquid velocity, ΔP is the pressure drop, μ the liquid velocity, r pipe radius and L is the wetted length. When the pressure applied is the capillary pressure only, Lucas and Washburn derived the well-known equation for flow through horizontal pipes [51]:

$$L^2 = \frac{r_c \gamma_{LV} \cos\theta}{2\mu} \tag{12}$$

where r_c is the capillary radius and t is the time taken for the liquid to travel the distance L.

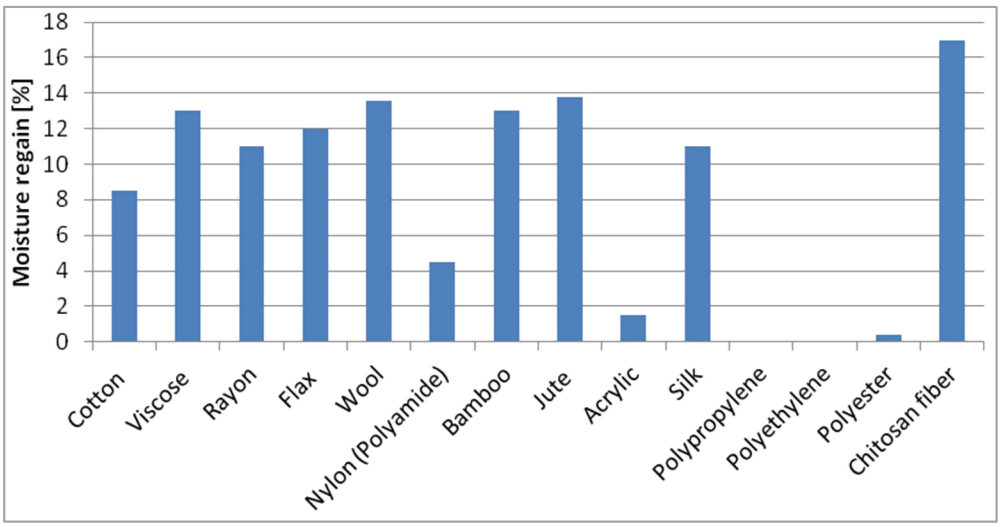


Figure 6 Moisture regain of different fibers at 20°C and RH 65% [46-48]

Darcy law

Darcy's law is one of the early theories that investigated in fluid flow through porous media. It describes laminar flow through porous media, and it is given by the equation below:

$$Q = -K\frac{\Delta P}{L_0} \tag{13}$$

where Q is the rate of flow, ΔP is the pressure drop across the material, L_0 is the length of the sample and K is a constant. This constant K depends on the characteristics of the fluid and the pore structure of the media. The constant K is often defined as:

$$K = \frac{k}{\eta} \tag{14}$$

where k is the permeability of the medium and η is the viscosity of the liquid.

2.2.2 Wicking measurement

Table 1 illustrated the various methods used for the measurements of absorption and wicking behavior of fabric, namely: longitudinal wicking strip test, transverse wicking plate test and vertical strip wicking test. Harnett and Mehta [41] summarized four popular laboratory test methods for measuring wicking. It represents the basis of future review articles where lists of practical test methods were discussed. In 2006, Patnaik et al [52] conducted a more comprehensive review on which they initially differentiated the methods into two aspects: wetting and wicking. Moreover they classified wicking processes that are with finite (limited) reservoir and infinite (unlimited) reservoir. Additionally, since Patnaik's review, many novel measurement methods have been developed, e.g. the Transplanar water transport Tester [53], Moisture Management Tester [54, 55], and some international standard test methods have been introduced, such as vertical-wicking test method [56] and horizontal-wicking test method [57].

3 CAPILLARITY

Capillarity can take place under various conditions and situations. To define these conditions [63] propose to distinguish between two phenomena related to the transport of liquid through a textile fabric: wettability and capillarity. According to Harnet and Mehta [41], capillarity is the ability to cause capillary flow, while wettability describes the initial behavior of a fabric, yarn, or fiber contacted with water. Although wettability and capillarity are well studied as two separate phenomena, they can be described by a unique process: fluid flow caused by capillary pressure [40], that is, in the absence of external forces, the liquid through a porous medium is entrained by capillary forces resulting from wetting of a fabric. Capillary progression can be defined as a macroscopic flow of a liquid under the influence of its own interface forces [63]. Since capillary forces are caused by wetting, capillarity is a result of spontaneous wetting in a capillary system [12]. Therefore, these two phenomena are coupled and one of them cannot occur in the absence of the other. Physically, impregnation is the flow in a porous medium under the action of capillary forces. This type of flow depends on the properties of the liquid, the solid-liquid surface interactions and the geometrical configuration of the pores of a porous medium [13, 64-67].

Capillary action is responsible for the movement of liquid flow in fibrous material and mainly depends on the geometry of pore structure and capillary force. Before being transported, liquid wet the fibrous material which causes to determine its liquid's effect and fibre surface wetting characteristics [13].

Capillary forces caused by wetting and due to the pressure difference created by surface tension of liquid across the curved liquid-air interface drive the liquid into the capillary spaces.

Table 1 Well known wicking methods

	Methods	References	Comments
Infinite reservoir	Transverse wicking	Kissa 1981 a-b[58] [59] Harnett & Mehta 1984 [41] Saville 1999 [60]	The fabric is laid flat while water is supplied from beneath and the amount absorbed is recorded.
	Vertical wicking	BS3424 [61] AATCC 197Vertical Wicking of Fabric [56] Person et al [62] Hsieh&yu[13]	An electronic microbalance,an Oriel reversible translator additive in the testing liquid may change its surface tension as well
	Horizontal wicking	AATCC 198 horizontal wicking of textiles [57]	It used to evaluate the ability of horizontally aligned fabric specimens to transport liquid along and/or through them.
Finite reservoir	Contact angle	Kissa 1996 [12] Harnett & Mehta 1984 [41]	See section 2.1.3

The capillary pressure is commonly described through the well known Laplace equation which idealizes capillary tubes as follows:

$$\Delta P = \frac{2\gamma_{LV}\cos\theta}{r} \quad (15)$$

where P is the difference capillary pressure, γ_{LV} is the surface tension of the interface liquid-vapor, θ is the solid-liquid contact angle and r is the capillary radius.

In fibrous assembly, the capillary spaces are not uniform so that it is preferred to use the effective capillary radius instead of the radius r. The surface energy of fibers depends on many characteristics such as perimeter, surface purity and molecular orientation of fibers [68].

As the pressure gradient increases, the amount of liquid wicks through capillaries increases. According to the Lucas-Washburn equation, it is expected that, at a specific time, with a larger pore size, we will obtain a faster capillary rise. However, Miller [69] showed that in some cases, wicking through capillaries with larger diameter has been overtaken by those with smaller diameter. Thus, the distance of liquid advancement is higher in smaller radius pores. This is can be explained by the fact that when the capillary radius decreases, the capillary pressure will be higher and causes faster liquid flow through the capillary.

4 CONCLUSIONS

Comfort of human body is directly related to the liquid water vapor permeability of a material used for clothing. Test methods used to measure the material properties are extremely significant because of getting accuracy. Methods must simulate all the environmental conditions, closely related to wearer. Many patents and research articles report different results due to different testing conditions for wetting, wicking and transport of liquid water in fabric. By considering actual wear condition, results predicted by mathematical models and tested by experiments are excessively helpful in understanding the theory behind the scientific behavior of materials, leads to betterment in product development. Textile material properties are influential parameters for heat and moisture transmission phenomena. Diffusion, convection and moisture content are the hidden parameter affects the wetting and wicking of textile material whereas fabric structure, thickness, density, permeability, porosity and yarn used are main physical factors helps in capillary action. Fabric used for hard weather conditions or sportswear, must acquire best comfort properties by liquid transportation to get rid of perspiration. Twist multiplier (TM) and capillary pressure in the yarn also affects the transport performance, lower the yarn twist, more obvious the transient transport of liquid water in the wearing fabric. Similar fiber behavior with its pore size is quite important with wicking point of view, responsible for instant wicking velocity, wicking height and wicking time. Transportation of liquid water in fabric cannot be defined at only one condition – but a range of conditions should be measured regarding the fabric ability to transport liquid moisture.

5 REFERENCES

1. Kerry A., Martin T.: Effect of textile hygroscopicity on stratum corneum hydration, skin erythema and skin temperature during exercise in the presence of wind and no wind, The Journal of Exercise Science and Fitness 2011 9(2), pp. 100-108
2. Youngmin J., Chung HP., Tae JK.: Effect of heat and moisture transfer properties on microclimate and subjective thermal comfort of caps, Textile Research Journal 2010 80(20), pp. 2195-2203
3. Geraldes M.J., Hes L., Araujo M.: Improvement of the athlete performance through new knits structures and new PP fibers, In proceedings of 6th Health and Textile International Meeting. Piella, Italy
4. Fangueiro R., Filgueiras A., Soutinho F., Meidi X.: Wicking behavior and drying capability of functional knitted fabrics, Textile Research Journal 80(15), 2010, pp. 1522-1530
5. Das D., Kothari V.K.: Moisture vapour transmission behaviour of cotton fabrics, Indian Journal of Fibre & Textile Research 37(2), 2012, pp. 151-156
6. Zhang P., Watanabe Y., Kim S.H., Tokura H., Gong R.H.: Thermoregulatory Responses to Different Moisture-transfer Rates of Clothing Material during Exercise, Journal of the Textile Institute 92(4), 2001, pp. 373-379
7. Park S-J., Tokura H., Sobajima M.: Effects of Moisture Absorption of Clothing on Pitching Speed of Amateur Baseball Players in Hot Environmental Conditions, Textile Research Journal 76(5), 2006, pp. 383-387
8. Hes L., Dolezal I.: Precise Measurement of Water Vapour Permeability of Wet Fabrics, in "Proceedings of the AUTEX International Textile Conference", Tampere, June 2007
9. Fourt L., Hollies N.R.S.: Clothing: Comfort and function., Marcel Dekker, Inc, NY, USA, 1970
10. Cena K., Clark J.A.: Thermal physiology and comfort, Bioengineering, 1981, pp. 288
11. Gagge A.P.: Rational temperature indices of thermal comfort, Studies in environmental science, Vol. 10, 1981, pp. 79-98
12. Kissa E.: Wetting and Wicking, Textile Research Journal 10(66), 1996, pp. 660-668
13. Hsieh Y-L.: Liquid Transport in Fabric Structures, Textile Research Journal 66(5), 1995, pp. 299-307
14. Hollies N.R.S., Kaessinger M.M., Bogaty H.: Water Transport Mechanisms in Textile Materials Part I: The Role of Yarn Roughness in Capillary-Type Penetration, Textile Research Journal 26(11), 1956, pp. 829-835

15. Hollies N.R.S., Kaessinger M.M., Watson B.S., Bogaty H.: Water Transport Mechanisms in Textile Materials: Part II: Capillary-Type Penetration in Yarns and Fabrics, Textile Research Journal 27(1), 1957, pp. 8-13
16. Hsieh Y-L., Bangling Y., Michelle H.M.: Liquid Wetting, Transport, and Retention Properties of Fibrous Assemblies: Part II: Water Wetting and Retention of 100% and Blended Woven Fabrics, Textile Research Journal 62(12), 1992, pp. 697-704
17. Alina C., Dorin V., Costea B.: The Influence of Raw Material on the Liquid Moisture Transport Through Knitted Fabric, Annals of the University of Oradea. Fascicle of Textiles, Leather Work 15(1), 2014, pp. 29-34
18. Uddin F., Mike L.: Wettability of Easy-Care Finished Cotton, Fibres & Textiles in Eastern Europe 18(4), 2010, pp. 56-60
19. Karppinen T., Kassamakov I., Haeggstrom E., Stor-Pellinen J.: Measuring paper wetting processes with laser transmission, Measurement Science and Technology 15(7), 2004, pp. 1223-1229
20. Petrulyte V., Baltakyte R.: Liquid Sorption and Transport in Woven Structures, Fibres & Textiles in Eastern Europe 17(2), 2009, pp. 39-45
21. Miller B.: Surface Characterization of Fibers and Textiles, Part II, M.J. Schick, Ed., Marcel Dekker NY, 1977, pp. 417
22. Miller B., Young R.A.: Methodology for Studying the Wettability of Filaments, Textile Research Journal 45(5), 1975, pp. 359-365
23. Miller B.: Absorbency, P.K. Chatterjee, Ed., Elsevier, NY, 1985
24. Cazabat A.M., Stuart M.A.C.: Dynamics of wetting: Effects of surface roughness, The Journal of Physical Chemistry 90(22), 1986, pp. 5845-5849
25. Dettre R.H., Johnson R.E.: Contact Angle, Wettability, and Adhesion, R.F. Gould, Ed., Advances in Chemistry Series, American Chemical Society 43, Washington, D.C., 1964, p.136
26. Sanders E.M., Zeronian S.H.: An analysis of the moisture-related properties of hydrolyzed polyester, Journal of Applied Polymer Science 27(11), 1982, pp. 4477-4491
27. Marmur A.: Modern Approaches to Wettability, M.E. Schrader and G.I. Loeb, Ed., Plenum Press NY, 1992
28. Young T.: An essay on the cohesion of fluids, Philosophical Transactions of the Royal Society of London, Vol. 95, 1805, p. 65-87
29. Wenzel R.N.: Resistance of solid surfaces to wetting by water, Industrial & Engineering Chemistry 28(8), 1936, pp. 988-994
30. Cassie A.B.D., Baxter S.: Wettability of porous surfaces, Transactions of the Faraday Society, Vol. 40, 1944, pp 546-550
31. Grader L.: On the modelling of the dynamic contact angle, Colloid and Polymer Science 264(8), 1986, pp. 719-726
32. Jeje A.A.: Rates of spontaneous movement of water in capillary tubes, Journal of Colloid and Interface Science 69(3), 1979, pp. 420-429
33. Good R.J.: Contact angle, wetting, and adhesion: A critical review, Journal of adhesion science and technology 6(12), 1992, 1269-1302
34. Schick M.J.: Surface Characteristics of Fibers and Textiles (Fiber Science, 2; New York and Basel: Marcel Dekker), 1977
35. Adam K.N.: The Physics and Chemistry of Surfaces (London: Oxford University Press), 1941
36. Patanaik A., Rengasamy R.S., Kothari V.K., Ghosh A.: Wetting and Wicking in Fibrous Materials, Textile Progress 38(1), 2006, pp. 1-105
37. Bartell F.E., Culbertson J.L., Miller M.A.: Alteration of the Free Surface Energy of SolidsI: Vertical-Rod Method for the Measurement of Contact Angles and Preliminary Study of Effect of Heat Treatment on Magnitude of Contact Angles, Journal of Physical Chemistry 40(7), 1936, pp. 881-888
38. Miller B., Tyomkin I.: Spontaneous Transplanar Uptake of Liquids by Fabrics, Textile Research Journal 54(11), 1984, pp. 706-712
39. Adams KL., Rebenfeld L.: In-plane flow of fluids in fabrics: Structure/flow characterization, Textile Research Journal 57(11), 1987, pp. 647-654
40. Gali K., Jones B., Tracy J.: Experimental techniques for measuring parameters describing wetting and wicking in fabrics, Textile Research Journal 64(2), 1994, pp. 106-111
41. Harnett P.R., Mehta P.N.: A Survey and Comparison of Laboratory Test Methods for Measuring Wicking, Textile Research Journal 54(7), 1984, pp. 471-478
42. Hsieh Y-L.: Liquid Transport in Fabric Structures, Textile Research Journal 66(5), 1995, pp. 299-307
43. Das B., Das A., Kothari V.K., Fangueiro R., Araujo M.: Studies on moisture transmission properties of PV-blended fabrics, The Journal of The Textile Institute 100(8), 2009, pp. 588-597
44. Perwuelz A., Mondon P., Caze C.: Experimental Study of Capillary Flows in Yarns, Textile Research Journal 70(4), 2000, pp. 333-339
45. Rossi R.M., Stampfli R., Psikuta A., Rechsteiner I., Bruhwiler P.A.: Transplanar and in-plane Wicking Effects in Sock Materials Under Pressure, Textile Research Journal 81(15), 2011, pp. 1549- 1558
46. ASTM D1909-04, Standard Table of Commercial Moisture Regains for Textile Fibers
47. GB 9994- 2008, Conventional Moisture Regains of Textiles
48. Hearle J.W.S., Morton W.E.: Physical properties of textile fibres, 4th Edition, Elsevier, 2008
49. Karppinen T., Kassamakov I., Aaltonen J., Pajari H., Hæggström E.: Measuring liquid penetration in the thickness direction of paper, European Physical Journal Applied Physics 32(1), 2005, pp. 65-71
50. Subramaniam V., Raichurkar P.: A review on wicking of yarns and fabrics, International Journal on Textile Engineering and Processes 1(2), 2015, pp.1-4
51. Washburn E.W.: The dynamics of capillary flow, Physical review 17(3), 1921, pp. 273
52. Patnaik A., Rengasamy R.S., Kothari V.K., Ghosh A.: Wetting and wicking in fibrous material, Textile Progress 38(1), 2006, pp. 1-105

53. Sarkar M., Fan J., Qian X.: Transplanar Water Transport Tester for Fabrics, Measurement of Science and Technology 18(5), 2007, pp. 1465-1471
54. Yao B.G., Li Y., Hu J.Y., Kwok Y.L., Yeung K.W.: An improved test method for characterizing the dynamic liquid moisture transfer in porous polymeric materials, Polymer Testing 25(5), 2006, pp. 677-689
55. Hu J., Yi Y., Yeung K.W., Wong A.S.W., Xu W.: Moisture management tester: a method to characterize fabric liquid moisture management properties, Textile Research Journal 75(1), 2005, pp. 57-62
56. American Association of Textile Chemists and Colorists, AATCC 197: Vertical wicking of Textiles, 2011
57. American Association of Textile Chemists and Colorists, AATCC 198: Horizontal wicking of Textiles, 2011
58. Kissa E.: Capillary sorption in fibrous assemblies, Journal of Colloid and Interface Science 83(1), 1981, pp. 265-272
59. Kissa E.: Wetting and detergency, Pure Apparel Chemistry 53(11), 1981, pp. 2255-2268
60. Saville B.P.: Physical testing of textiles (Vol. 10): CRC Press, 1999
61. Testing coated fabrics. Methods 21A and 21B. Methods for determination of resistance to wicking and lateral leakage, BS 3424-18:1986, British Standards Institution.
62. Pezron I., Bourgain G., Quéré, D.: Imbibition of a Fabric. Journal of Colloid and Interface Science 173(2), 1995, pp. 319-327
63. Schwartz A.M.: Capillarity-theory and practice, Industrial & Engineering Chemistry 61(1), 1969, pp. 10-21
64. Hsieh Y-L., Miller A., Thompson J.: Wetting, Pore Structure, and Liquid Retention of Hydrolyzed Polyester Fabrics, Textile Research Journal 66(1), 1996, pp. 1-10
65. Rajagopalan D., Aneja, A., Marchal, J-M.: Modeling Capillary Flow in Complex Geometries, Textile Research Journal 71(9), 2001, pp. 813-821
66. Staples T.L., Shaffer D.G.: Wicking flow in irregular capillaries, Colloids and Surfaces A: Physicochemical and Engineering Aspects 204(1), 2002, pp. 239-250
67. Zhang Y., Wang H., Zhang C., Chen Y.: Modeling of capillary flow in shaped polymer fiber bundles. Journal of Materials Science 42(19), 2007, pp. 8035-8039
68. Whang H.S., Gupta B.S.: Surface Wetting Characteristics of Cellulosic Fibers, Textile Research Journal 70(4), 2000, pp. 351-358
69. Miller B.: Critical evaluation of upward wicking tests, International Nonwovens Journal 9(1), 2000, pp. 35-40

PROGNOSING DEVELOPMENT OF TEXTILE NANOTECHNOLOGIES

O. V. Yezhova

Department of Engineering Training Theory and Methodology, HSE
Central Ukrainian Volodymyr Vynnychenko State Pedagogical University
Shevchenka str. 1, Kropyvnytsky, Ukraine
oyezhova70@gmail.com

Abstract: *The article investigates current state and perspectives of developing sewing nanotechnologies in sewing cloths by analysing the peculiarities of textile nanotechnologies and the sphere of their application. Theoretical and information analysis of the patents of the database World Wide EPO according to the D01D and D06 classes has witnessed a considerable growth in the quantity of registered patented inventions both in the ways of chemical nanofibre production as well as applying nano-treatments for finishing textile fabrics. This fact gives us grounds to forecast a vivid growth of textile cloths production with the help of innovative nanotechnologies in the nearest 10-15 years. This growth will concern not only chemical fibre and thread production with the help of nanotechnologies, but it will also influence the methods of finishing in textile cloths by means of the latter ones.*

Keywords: *textile nanocloths, chemical nanofibre, nano-treatment, prognosis, patent.*

1 INTRODUCTION

Usage of science intensive technologies, namely nanotechnologies, has gained a considerable priority in textile material development.

There are several definitions of the notion «nanotechnology», but we will provide only those of the international standards and organizations.

Technical committee ISO/TK 229 provides the following definition to «nanotechnology» [1]:

1. Understanding and control of matter and processes at the nanoscale, typically, but not exclusively, below 100 nanometres in one or more dimensions where the onset of size-dependent phenomena usually enables novel applications,
2. Utilizing the properties of nanoscale materials that differ from the properties of individual atoms, molecules, and bulk matter, to create improved materials, devices, and systems that exploit these new properties.

According to the international standard [2], nanotechnology is a set of technological methods, applied while learning, projecting and producing materials, devices and systems, including purposeful control and management of constructing chemical composition and interrelation between certain elements of nanorange, out of which those systems consist.

Nanomaterials – are the materials that have such structural elements, geometrical sizes of which do not go beyond 100 nm at least in one direction and have new qualities, function and application characteristics.

Nanotechnologies are widely used in different spheres: i.e. building industry, medical technology, food production industry and colouring agents [3]. Being created in 1986, this technology is considered by some experts to be a new technological breakthrough. Jack Uldrich, one of the authors of the handbook in nanotechnologies, states that «nanotechnologies provide for quality improvement of everything produced with their help» [4]. In March 2012 he presupposed nanotechnology market has reached 2.6 billion dollars by 2015.

The aim of the article is to investigate current state and perspectives of developing sewing nanotechnologies in sewing materials by reaching the following objectives:

- analysis of the current state of art in nanotechnology use during sewing items production;
- prognosis of the nanotechnologies development in textile material production on the basis of theoretical and information patents' analysis.

2 QUALITIES OF SEWING NANOMATERIALS AND THEIR APPLICATION

Experts from the NanoPRO magazine introduce a list of advantages, inherent to nanotextile, that includes their resistance to dirt accumulation, ability of self-cleaning, antimicrobial qualities, and so-called «intelligent» perspectives, like implementation of sun batteries, sensor indicators, and means of protection

[5]. The spheres of their usage incorporate medical industry, protective ware and casual clothes of improved quality.

At the same time, there is not so much research on the risks of nanotechnologies to human health and ecology, underline Centres on disease monitoring and prevention. Another statement worthy of attention concerns introduction of highly-dispersive powders, nano-tubes and other nano-elements into the objects of immediate human use, which should not be only aimed at a desirable effect, but should observe security demands and be economically appropriate [6].

The leader in the sphere of invention nanotextile materials in the USA is believed to be Nano-Tex Company.

Due to newly invented technologies of this company, materials obtain such qualities as additional fabric strength, dirt resistance, one-way water permeability from the human body to the outer layer. More than 80 textile factories are using such innovative materials, which are being supplied to more than 100 clothes-wear manufacture brands [7].

Levi Strauss Company uses nanomaterials for gaining additional fabric elasticity, strength and some other qualities of their goods [3].

Such clothes-wear brands as Tommy Hilfiger and Brooks Brothers are producing dirt-resistant trousers, shirts and ties [3].

Production of protective clothes for the employees of nuclear power plants from the new polymer materials is one more aspect worthy of researching [8].

3 TEXTILE NANOMATERIALS PRODUCTION

While fabrics production nanotechnologies are applied in two directions:

1) in nanofibre production itself,
2) in finishing of traditional textile fibres and materials with the help of nanosubstances.

3.1 Nanofibre production

There are two ways nanofibres are being created:

1) by filling traditional polymers with nanoparticles of different substances;
2) by producing super-thing fibres (up to 100 nanometres in diameter).

Fibres filled with nanoparticles have been produced since 1990 [9]. Such fibres are characterized by a less shrinking ability, diminished inflammability and increased resistance to tear and wear. These characteristics can vary depending on the composition of nanoparticles used.

Carbon nanotubes are being widely used nowadays. Fibres with nanotubes woven are 6 times stronger and 100 times lighter than steel. Additionally, they may acquire capability to electrical conduction and resistance to chemical reagents. The sphere of such materials usage encompasses production of special protective clothes against electromagnetic radiation, explosions and chemical substances.

Filling chemical fibres with alumina nanoparticles increases their heat and electrical conduction, their chemical activity and strength, protection against UV-radiation and fire. Such fibres are used for protective clothes production, e.g. helmets. Syntactical fibres, filled with nanoparticles of metal oxides such as TiO_2, Al_2O_3, ZnO, MgO, obtain as a result abilities of photocatalyst function, UV-protection, anti-microbe characteristics, electrical conduction and dirt resistance.

Superslim fibres (100 nanometers in diameter) owning to their high quantity of surface area obtain increased capability of absorption.

Research conducted in England, France, USA and Israel is focused on creation of protein fibres, restructuring spider's web (up to 100 nanometers in diameter). These light, flexible and strong fibres will be used in future for production of body armour, surgical instruments, fishing rods etc.

3.2 Use of nanosubstances in finishing of textile fibres

During the finishing nanoparticles are applied in a form of nanoemulsion or nanodispersion. This makes possible to provide fabrics with water- and oil-resistance, low inflammability, dirt resistance, softness, antistatic and antimicrobial effects, thermo and shape stability, etc.

First nanomaterials for fibre evaporation, containing silver particles, were produced and released to the market by Du Pont firm [9]. Now much cheaper means of finishing are being used for these purposes.

For example, Teflon finishing guarantees water-, oil- and dirt resistant effects. At the same time, nanoparticles do not constitute a barrier for pores of the material and it breathes well [10]. These fabrics are widely used in interior textile production of furniture upholstery, curtains, tablecloths etc.

Due to the application of nanoemulsions, new cotton textile materials have been created with the right side being water-, oil- and dirt resistant, and with the reverse side staying hydrophilic, i.e. capable to absorb water. Such materials are used for producing military, sports and manufacturing clothes.

The following article [11] describes the technology for manufacturing of planar textile fabrics bonded by the perpendicular lying of polymer melt, where threads with nano-coating are probably to be used in manufacturing process.

The article [12] aims to introduce and compare spinning methods which are used to create nanofibers and nanofibrous materials.

Thorough analysis of the perspective directions in textile material development for sewing industry allowed us to formulate a working hypothesis: in 10-15 years' period of time fibre materials, made with the help of nano-technologies will be in prevailing use in future sewing industry.

4 METHODOLOGY OF TEXTILE DEVELOPMENT PROGNOSIS

As it has been mentioned [13, p.30] all prognostic methods can be divided into:

1) general scientific (or logical means);
2) inter-scientific;
3) purely scientific.

This research applies hereby inter-scientific method of extrapolation. This method is based on the assumption that, some defined tendency either in the past or in present will be true in future as well, as long as the causing factors do not change.

Analysis of patent information represents here one of the kinds of scientific and technical development prognosis with the help of extrapolation method. In the second half of the XX century a technical invention, described in the patent form was believed to be introduced into serial industrial production within 10-16 years [13, p. 56]. Anyhow there is no verified scientific data proving this time frame today in the world of highly technologically developed economy. But there is a world tendency for the time frame between invention and implementation into practice to be shortened.

In accordance with the method of technical progress prognosis on the basis of theoretical and information patents' analysis by V.A. Lisichkin [13, p. 72], last 6-year period, named as ground time for prognosis, is considered. The first year of the period is believed to be crucial for defining a starting point. The number of patents issued that year is taken as a basic starting quantity and then compared with the quantity of the patents in the following years. Depending on the decrease or increase in the patent quantity, conclusion about positive or negative perspectives of the technological branch development is formulated. Namely this method, with time-frame modification to 10 years, has been chosen in this research for prognosis of innovative development in sewing industry [14].

5 RESULTS AND DISCUSSION

In order to prove our working hypothesis in the part of chemical nano-fibre production we have conducted patent search according to the following initial conditions:

- class D01 «Natural or artificial threads or fibres, spinning»; sub-class D01D «Mechanical methods or apparatus in the manufacture of artificial filaments, threads, fibers, bristles or ribbons» [15];
- «nano» as a key word in the title or in the abstract.

Approximately 1753 results found in the Worldwide database for: «nano» in the title or abstract and D01D as the IPC classification. Previous search resulted in the quantity of 1753 patents in general. From 2007 till 2016, 1662 patents have been registered, giving us grounds to consider this decade to be an active development period of this branch in material production. Analysis of the patents' distribution according to the years has shown a sweeping growth (by 3.3 times) in the quantity of patented inventions from 2007 till 2016, – from 66 to 220, and a slight decline in quantity from 2013 to 2014, compared with the year of 2012 (correspondently 193, 180 and 220 patents) (Figure 1). As a result, our hypothesis, about positive perspectives for developing innovations in the sphere of chemical fibres and threads with the help of nano-technologies, has proved to be true, forecasting considerable growth of this branch in future.

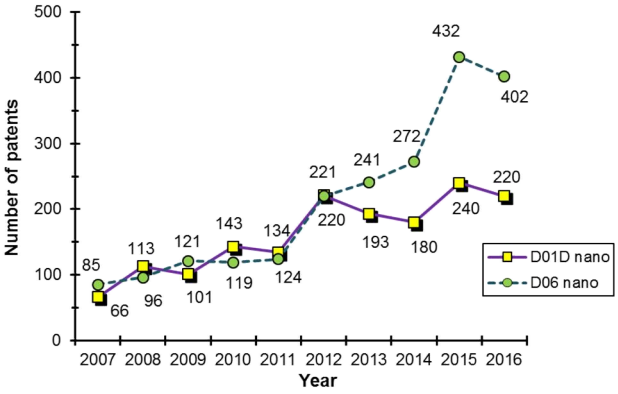


Figure 1 Quantity of patents on the ways of producing chemical nano-fibres and finishing of textile materials with nano-treatment (according to the database World Wide EPO retrieved on 24.04.2017)

In order to check our working hypothesis in the part of finishing textile materials with the help of nano-technologies, we have conducted patent search according to the class D06 «Treatment of textiles or the like, laundering, flexible materials not otherwise provided for» with a key word «nano» in the title or abstract.

Previous search resulted in the following: approximately 2367 results found in the Worldwide database [15] for «nano» in the title or abstract and D06 as the IPC classification. From the year 2007 till the year 2016, the quantity of registered patents constituted 2178, signalling vivid growth of this branch in material production for the last decade namely. Distribution year per year analysis suggested swift (by 4.7 times) increase in the quantity of patented inventions from the year of 2007 to the year of 2016 – from 88 to 402 inventions correspondently (Figure 1). As a result, our hypothesis, about positive perspectives

in development of textile finishing methods with the use of nano-technologies, has turned out to be true, providing expectations for considerable growth of innovations in this direction.

6 CONCLUSIONS

Having conducted theoretical and information patent analysis, a sweeping growth in the quantity of registered patents concerning innovative ways of chemical nano-fibre production and finishing textile materials with the help of nano-treatments has been defined. This fact allows us to presuppose a considerable growth of innovations in the sphere of textile nano-materials in the nearest 10-15 years. This growth will concern not only chemical fibre and thread production with the help of nanotechnologies, but it will also influence the methods of finishing textile fabrics with the help of nanotechnologies.

7 REFERENCES

1. ISO/TC 229 Nanotechnologies, available from http://www.iso.org/iso/iso_technical_committee?commid=381983, (accessed 24.04.2017)
2. Nanotechnologies, Part 1. Key terms and definitions: GOST ISO/TS 80004-1-2014, Moskow: Standartinform, 2015 (in Russ)
3. Gustke C.: Nanotechnology Now an Unseen Success, May 2012, available from http://www.cnbc.com/ (accessed 24.04.2017)
4. Uldrich J.: The Next Big Thing is Really Small: How Nanotechnology Will Change the Future of Your Business Crown Business, 2003, p. 208
5. Nanotechnology Benefits, 2013/nanopro, Available from: http://www.nanopro.biz/ (accessed 01.04.2017)
6. Nikiforov Yu: Textile industry will make nanotechnology closer to people, Russian electronic nanojournal 2010, available from http://nanorf.ru (accessed 24.03.2017), (in Russ)
7. Nano-Tex announces new way of providing moisture management, March 2012, available from http://www.sportstextiles.com/ (accessed 01.04.2017)
8. 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 23(4), 2016, pp. 27-35
9. Nanotechnology in the textile industry, Research centre for light industry 2013, available from http://cnilegprom.by/ (accessed 24.04.2017), (in Russ)
10. Teflon® fabric protector meets interior exceiience, DuPont, News from DuPont Home Textiles Division 2012, available from http://www2.dupont.com/ (accessed 24.04.2017)
11. Sirkova B., Ježik K., Sanetrnik F.: Manufacturing of planar textile fabric structures bonded by perpendicular laying of polymer melt, Vlakna a Textil 22(1), 2015, pp. 17-20
12. Blažková L., Hlavatá J., Horáková J., Kalous T., Novák P., Pelcl M., Strnadová K., Šaman A., Chvojka J.: Comparison of the well-known spinning and electrospinning methods for polyvinyl alcohol, Vlakna a Textil 23(1), 2017, pp. 57-63
13. Gvishiani D.M., Lisichkin V.A.: Prognostics, Moskow: Znanie, 1968. p. 92, (in Russ)
14. Yezhova O.: Projections of innovative educational contents when training specialists in the sewing industry, St. Petersburg State Polytechnical University Journal. Humanities and Social Sciences 4, 2014, pp. 197-204, (in Russ)
15. European patent office, available from http://ep.espacenet.com (accessed 24.04.2017)

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 ***double-column format*** *(width 8.1 cm)* ***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.

Figures, tables, schemes and photos, please, send in separate file.

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

[2] Surname N., Surname N.: Name of paper, Name of Journal Vol. (No.), YYYY, pp. xxx-yyy

[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, 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