ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 19, No. 4. 2013

The Influence of Three-Layer Knitted Fabrics' Structure on Electrostatic and Comfort Properties

Sandra VARNAITĖ-ŽURAVLIOVA *, Laimutė STYGIENĖ, Romutė ČEPLIAUSKIENĖ, Sigitas KRAULEDAS, Audronė SANKAUSKAITĖ

Textile Institute of Center for Physical Sciences and Technology, Demokratų 53, LT-48485 Kaunas, Lithuania

crossref http://dx.doi.org/10.5755/j01.ms.19.4.2235

Received 20 August 2012; accepted 17 January 2013

In our times, when electricity and electrical devices are around us every day, it is very important to be protected from electrostatic discharge. The best protection from electric charge dissipation provides conductive textile materials. For the last few decades fine and flexible conductive yarns were developed, which ensure very good electrostatic properties. Unfortunately, due to their chemical nature, these yarns do not distinguish good comfort properties. The main purpose of development of such textiles is to determine the influence of conductive yarns and hollow fiber yarns arrangements in the middle layer of the three layer weft-knitted fabrics to electrostatic and comfort properties. So, in order to have flexible textile materials with good electrostatic and comfort properties, multifunctional three layer weft-knitted fabrics of combined pattern were designed and manufactured for this research work. Two groups of polyester based three layer knitted fabrics with different arrangement of conductive yarns (such as carbon core yarn and polyester silver coated yarn) and polyester yarn of special design (Coolmax®, Thermolite®) were investigated. The parameters of electrostatic characteristics, such as surface and vertical resistances as well as charge decay properties were measured. The results have showed that all tested fabrics have excellent shielding properties. The main influence on the electrostatic properties of tested fabrics has the arrangement of conductive carbon core yarns inserted in the knits. In order to evaluate the comfort of knitted fabrics the air permeability, hygroscopicity, time of absorption and drying degree of fabrics were evaluated. It was determined, that the values of comfort parameters depend on the quantity and distribution of Coolmax® and Thermolite® yarns in the fabrics.

Keywords: electrostatic properties, comfort, carbon core yarn, Coolmax®, Thermolite®.

INTRODUCTION

Fast progress in technology has brought high increase in usage of various electrical and electronic devices, which are the source of electromagnetic radiation [1]. An electrostatic discharge also appears after touching such charged devices. The electrostatic charge accumulates on the garments despite their fiber content [2]. So, people who work with various electrical devices, especially while working with high voltage, must wear protective clothing with very good shielding properties [3].

Even when conductive yarns, which are flexible and conformable, are inserted into the protective clothing to prevent electrostatic discharge, the garment, which is usually manufactured from woven fabric, is still very hard and unpleasant while wearing [4].

It was found in some articles [5 – 7] that with increase in tightness factors, wale density and course density in conductive fabrics, the shielding effectiveness increases. The interlock knitted fabric with inserted copper wire has better shielding effectiveness than rib and plain conductive knitted fabrics [5]. Also it is known that the following factors have great influence on electrostatic features: the electro conductivity of fibres, the electro conductive share of the fibres in the total volume of the fabric, the type and arrangement of the fibres in the fabric, the type of the basic yarn and the structure of textiles [6].

Knitted spacer fabrics offer many attributes and characteristics which have not been possible to achieve by using other technologies. These fabrics continue to find new and novel product applications [8].

So, in order to have flexible textile materials with good electrostatic and comfort properties, multifunctional three layer weft-knitted fabrics of combined structure were designed and manufactured for this research work.

Comfort is a qualitative term and it is one of the most important aspects of clothing, which can be divided into three groups: psychological, tactile and thermal [9]. We will analyze the third group of comfort in this research work, because thermal comfort of garments depends on heat and vapour transport, sweat absorption and drying ability [10 – 13]. Water vapour transportation and condensation depends on the thickness of air gaps in the textiles, air humidity and water absorption of fabrics [14, 15].

The main purpose of this research work is to determine the influence of conductive yarns and hollow fiber yarns arrangements in the middle layer of the three layer weft-knitted fabrics to electrostatic and comfort properties.

EXPERIMENTAL

Two groups of polyester based three layer knitted fabrics of combined pattern with different arrangement of conductive yarns (such as carbon core yarn and polyester silver coated yarn) and polyester yarn of special design (Coolmax®, Thermolite®) were manufactured and investigated. The detailed description of tested fabrics is presented in Table 1. The combined structure of the three layer weft knitted fabric is presented Figure 1.

*Corresponding author. Tel.:+370-37-308661, fax: +370-37-308668.
E-mail address: *varnaite@lti.lt* (S. Varnaitė-Žuravliova)

Table 1. Description of three layer weft knitted fabrics

Fabric No.	Type of separate layer	Type of yarn	Arrangement of yarns in separate course (E)	Linear density, tex	Content of yarn in the knitted fabric,%	Number of stitches, cm^{-1}		Mass per unit area, g/m^2
						per unit length	per unit area	
1A	I -inner	Coolmax®	E3, E6, E9, E12	20	36	20	12	397
	II-middle	Nega Stat®P190	E1, E4, E7, E10	15.6	30			
	III- outer	Cotton-PES with 0.02 % carbon fibre (67/33%) yarns	E2, E5, E8, E11	20	34			
2A	I –inner	Coolmax®	E3, E6, E9, E12	20	36	20	12	397
	II-middle	Thermolite® Nega Stat®P190	E1, E13 E4, E7, E10	7.8×2 15.6	7.5 22.5			
	III- outer	Cotton-PES with 0.02 % carbon fibre (67/33%) yarns	E2, E5, E8, E11	20	34			
3A	I –inner	Coolmax®	E3, E6, E9, E12	20	36	20	12	383
	II-middle	Thermolite® Nega Stat®P190	E1, E7, E13 E4, E10, E16	7.8×2 15.6	15 15			
	III- outer	Cotton-PES with 0.02% carbon fibre (67/33%) yarns	E2, E5, E8, E11	20	34			
4A	I –inner	Coolmax®	E3, E6, E9, E12	20	36	20	12	377
	II-middle	Thermolite® Nega Stat®P190	E4, E7, E10 E1, E13	7.8×2 15.6	22.5 7.5			
	III- outer	Cotton-PES with 0.02 % carbon fibre (67/33%) yarns	E2, E5, E8, E11	20	34			
1B	I –inner	Coolmax®	E3, E6, E9, E12	20	35	21	12	381
	II-middle	Shieldex® Thermolite®	E1, E4, E7, E10	17 7.8×2	8.5 23.5			
	III- outer	Cotton-PES with 0.02 % carbon fibre (67/33%) yarns	E2, E5, E8, E11	20	33			
2B	I –inner	Coolmax®	E3, E6, E9, E12	20	35	21	12	389
	II-middle	Shieldex® Thermolite®)	E1, E7 E4, E10	17 7.8×2	16 16			
	III- outer	Cotton-PES with 0.02 % carbon fibre (67/33%) yarns	E2, E5, E8, E11	20	33			
3B	I –inner	Coolmax®	E3, E6, E9, E12	20	35	21	12	390
	II-middle	Shieldex® Thermolite®	E1, E4, E7 E10	17 7.8×2	23.5 8.5			
	III- outer	Cotton-PES with 0.02 % carbon fibre (67/33%) yarns	E2, E5, E8, E11	20	33			
4B	I –inner	Coolmax®	E3, E6, E9, E12	20	35	21	12	407
	II-middle	Shieldex®	E1, E4, E7, E10	17	32			
	III- outer	Cotton-PES with 0.02 % carbon fibre (67/33%) yarns	E2, E5, E8, E11	20	33			

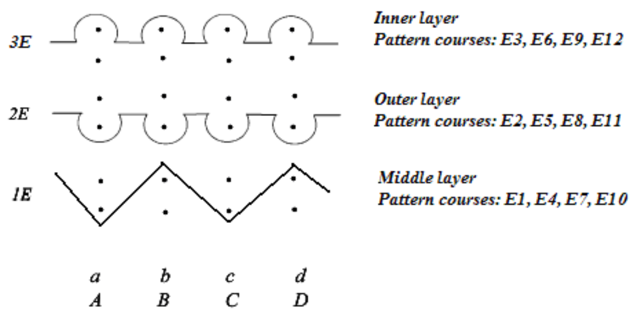

Fig. 1. Schematic illustration of the three layer weft knitted fabric structure (combined pattern)

All fabrics were knitted on the circular interlock knitting machine Metin Nov of gauge 20E. The number of stitches was calculated according to LST EN 14971 standard and the mass per unite area was determined according to LST EN 12127 standard.

Coolmax® is a trademark and a brand name for a polyester spun yarn from four channels of cross section type, developed by DuPont Textiles with improved breathability compared to natural fibres like cotton.

Thermolite® provides warmth and comfort and is made with ADVANSA engineered polyester textured filament yarns made of round hollow-core fibres that trap air for greater insulation.

Fabrics, manufactured from Coolmax® yarns have very good comfort system, which is presented in Figure 2. While Thermolite® yarns have good isolation properties.

Nega-Stat®P190 is an antistatic Polyester bicomponent yarn with carbon core, which neutralizes the surface charges on the base material by induction and dissipates the charge by conduction when grounded or when ungrounded by air-ionization, referred to as corona discharge. The image and scheme of this yarn is presented in Figure 3.

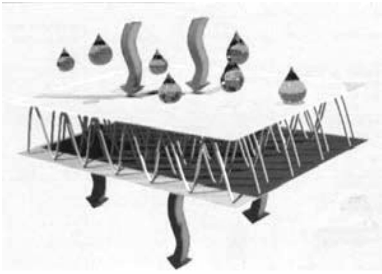

Fig. 2. Comfort system scheme in three layer weft knitted fabric [8]

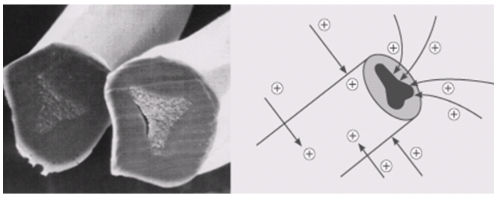

Fig. 3. Polyester multi-filament bi-component yarn with a unique trilobal conducting carbon core [16]

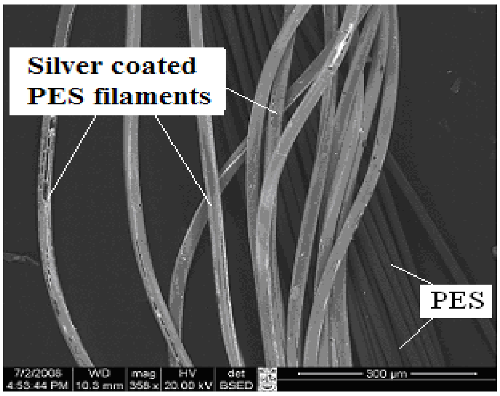

Fig. 4. The microscopical image of Shieldex® yarn

Shieldex® is conductive yarn (twist factor Z 300 m^{-1}), consisting of two twisted components: polyester 11.3 tex (f32) and polyester silver coated 4.4 tex (f12). The view of this yarn, made with scanning electron microscope FEI Quanta 200 FEG is seen in Figure 4.

All these fabrics were manufactured for protective clothing to prevent electrostatic discharge. So, at first shielding factor and half decay time were determined according to LST EN 1149-3, 2 method (induction charging). The conditioning and the test was carried out in dry conditions, i. e. relative humidity 25 %, temperature 23 °C, for three specimens. The charge decay parameters were determined with the electric charge meter ICM-1, produced by STFI. The instrument is controlled by a microprocessor, which makes measurements, provides automatic calculations and displays measured data. The value of the shielding factor (*S*) was obtained using the equation:

$$S = 1 - \frac{E_R}{E_{\max}} \quad (1)$$

where E_R is maximum electric field strength indicated by the recording device with the test specimen in the measuring position, and $E_{\max}$ is electric field strength indicated by the recording device without test specimen in the measuring position.

The coefficient of variation of half decay time and shielding factor values was less than 1 %.

Vertical and surface resistances were measured according to LST EN 1149-2 and LST EN 1149-1 standards respectively and with Terra-Ohm-Meter 6206 produced by Eltex. The range of measured values: $10^3\ \Omega - 10^{14}\ \Omega$. The conditioning and testing were carried out in dry conditions. The mean values out of five specimens are presented in this work. The coefficient of variation of resistances' values was less than 5 %.

In order to analyse comfort parameters of three layer knitted fabrics, air permeability, hygroscopicity, absorption duration, wicking and drying time were determined.

The air permeability tests were carried out with Frazier low differential pressure apparatus FAP-1034-LP according to LST EN ISO 9237 standard, with pressure drop of 100 Pa. The coefficient of variation of air permeability was less than 5 %.

The hygroscopicity (*H*) of fabrics was calculated according to the equation:

$$H = \frac{m_d - m_s}{m_s} \cdot 100 \quad (2)$$

where m_d is the mass of specimen kept for 4 hours in 100 % humidity environment, and m_s is the mass of specimen after drying to constant mass and cooling.

The absorption duration is defined as the arithmetic mean of five immersion times. At first specimens of (100×100) mm were conditioned for 24 hours in standard atmosphere according to LST EN ISO 139 standard. Then specimens were laid on the surface of the water and the time, when specimens were completely immersed was recorded.

Drying degree was calculated as ratio between quantities of evaporated water and all absorbed water, expressed in percent. The quantities of water were determined by immersing five specimens of each fabric in water and then recording their mass instantly after taking them from the reservoir with water, after 5, 20, 60, 120, 240 and 360 minutes of drying. The specimens, taken from water reservoir at first were slightly squeezed between two filter papers. The air conditions during test were: temperature 24 ºC and 55 % relative humidity.

RESULTS AND DISCUSSION

The measurements of shielding factor and half decay time of the electrical discharges were performed by the induction method based on impulse generation of the electrical charges with the use of an electrode. For the materials, which are pure dielectrics, the value of the electrical field intensity obtained by the measurement is equal to the maximum value. Whereas for materials characterised by some electro-conductivity, the values obtained by measurements are smaller than the maximum value. The decreased value of electrical field intensity is related to the electrostatic charge drainage through the tested fabric. The time period after which the value of the field intensity is equal to the half value of the maximum field intensity is called the half decay time of the electrostatic charge for the fabric tested. Values of shielding factor and half decay time of tested fabrics are presented in Table 2.

Table 2. Shielding factor and half decay times of tested fabrics

Fabric No.	Shielding factor	Half decay time, s
1A	0.97	<0.01
2A	0.97	<0.01
3A	0.97	<0.01
4A	0.95	<0.01
1B	1	<0.01
2B	1	<0.01
3B	1	<0.01
4B	1	<0.01

Table 3. Vertical resistance and surface resistance of tested fabrics

Fabric No.	Vertical resistance, Ω	Surface resistance, Ω
1A	$6.08 \cdot 10^{10}$	$1.19 \cdot 10^{11}$
2A	$1.56 \cdot 10^{11}$	$6.68 \cdot 10^{11}$
3A	$1.46 \cdot 10^{11}$	$7.56 \cdot 10^{11}$
4A	$1.88 \cdot 10^{11}$	$7.54 \cdot 10^{11}$
1B	$<2 \cdot 10^{3}$	$<2 \cdot 10^{3}$
2B	$<2 \cdot 10^{3}$	$<2 \cdot 10^{3}$
3B	$<2 \cdot 10^{3}$	$<2 \cdot 10^{3}$
4B	$<2 \cdot 10^{3}$	$<2 \cdot 10^{3}$

It can be seen from the data presented in Table 2, that all tested fabrics can be assigned to the group of electro-conductive materials, because the values of shielding factor is very close to 1 and half decay time for all fabrics are less than 0.01 s, i. e. the electric charges do not accumulate on the surface of fabrics. This means, that all fabrics have excellent shielding properties. Other authors [2, 6] received similar test results.

Other characteristics of electrostatic properties were determined also, i. e. vertical resistance and surface resistance. The results are presented in Table 3.

The values of vertical and surface resistances are less than at a scale of 10^3 Ω of fabrics of B group. So, electrostatic properties of these fabrics are better compared to the values of A group. The values of vertical and surface resistances of B group fabrics vary in the scale of 10^{11} Ω. The difference between these two tested groups of fabrics is due to the different nature of conductive yarns, knitted in the fabrics. It is seen from the Table 1, that in all eight fabrics 33 % – 34 % of Cotton-PES with 0.02 % carbon fibre (67/33%) yarns are presented. So, we can conclude, that this yarn gives the same value of resistances to all tested fabrics. But, it is also seen; that Nega Stat®P190 yarns is knitted in the fabrics of group A. This conductive yarn is carbon nature. Carbon is conductive additive, but its resistance is quite big, while comparing to resistance of metal. So, the resistances of fabrics of group A are quite high. The Shieldex® yarns, one of the components of which is silver coated filaments are knitted in the fabrics of B group. The resistance of silver is obviously less than that of carbon. So, the vertical and surface resistances of fabrics belonging to B group are so small.

In order to determine comfort properties of tested fabrics, air permeability of fabrics was measured at first.

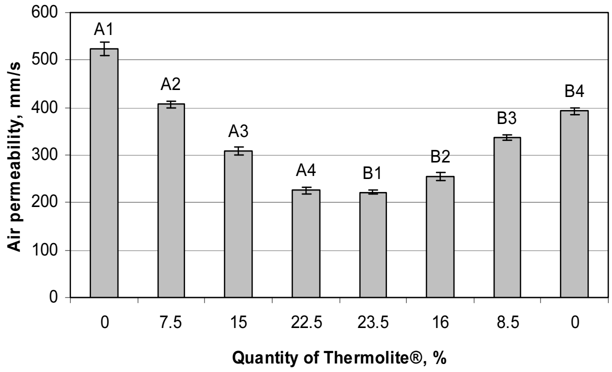

Fig. 5. The dependence of air permeability upon the quantity of Thermolite® yarns in the fabrics

As it is seen from Table 1, the quantity of Coolmax® yarns in tested fabrics remains the same, i. e. 36 % – 35 %. But, the quantity of Thermolite® yarns in all fabrics differs. The results in Figure 5 show that the presence of Thermolite® yarns decreases air permeability of tested fabrics distinctly. This means that when there is no Thermolite® yarn in the fabrics, air permeability of fabrics is higher, compared to fabrics with Thermolite® yarns in the structure. For example, air permeability is approximately 225 mm/s of A4 and B1 fabrics, because the quantity of Thermolite® is approximately 23 %. The values of air permeability of tested fabrics increase with the decrease of Thermolite® yarns in the fabrics, i. e. when there is no Thermolite® yarns in the fabrics, air permeability of fabric A1 is over 500 mm/s, of fabric B4 – approximately 400 mm/s. Comparing the values of air permeability of A group fabrics with group B fabrics we also can say that 1 % of Coolmax® also influences air permeability of fabrics. The quantity of Coolmax® yarns in fabrics of A group is 36 % and the values of air permeability is higher than those of B group fabrics with 35 % of Coolmax® yarns.

It was determined, that the hygroscopicity of all eight tested fabric is approximately 3 % and does not depend on the quantity of any yarn in the fabric.

The investigations of absorption duration did not give good results, because specimens have not completely immersed after 30 minutes.

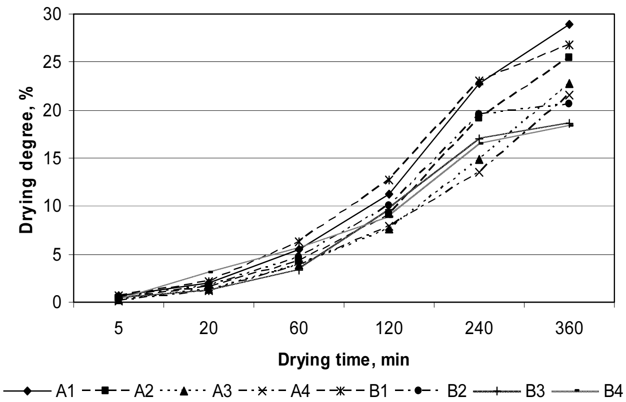

Fig. 6. Drying degree versus drying time of fabrics

The drying degree increases in time. It is seen from the Figure 6, that after 360 min the degree of fabric is more than 20 %. The intensiveness of drying can be explained the same as for air permeability dependence on the presence of Thermolite® yarns. The Thermolite® yarns decreases the drying intensity of fabrics. This special yarn, which usually is used to increase comfort properties of fabrics negatively influences properties, which gives Coolmax® yarn.

CONCLUSIONS

Eight knitted fabrics were investigated in this research work. The values of shielding factor and half decay time showed that investigated fabrics have excellent shielding properties. Very small values of half decay time indicate that electric charges will not accumulate on the surface of tested fabrics. It was also determined, that the nature of conductive yarns has significant big influence upon the values of vertical and surface resistance. The fabrics with silver coated conductive yarns have smaller values of resistances, so their electrostatic properties are better, compared to the resistances of fabrics with carbon core yarns.

Also, comfort properties of the tested fabrics were investigated. It was determined, that the presence of polyester spun yarns with four channels and polyester textured filament yarns with hollow fibers have very big influence to air permeability and drying degree of tested fabric. The presence of polyester textured filament yarns with hollow fibers decreases values of these parameters quite distinctly. This means that when there are only polyester textured filament yarns with hollow fibers, and no polyester textured filament yarns with hollow fibers, in the fabrics, the air permeability and drying degree of fabrics is higher, comparing to fabrics with polyester textured filament yarns with hollow fibers in the structure.

The investigations also have showed that hygroscopicity and absorption time remains the same for all tested fabrics and did not vary with the change of polyester textured filament yarns made of round hollow-core fibres quantity.

Acknowledgments

Support of the Research Council of Lithuania, agreement No. MIP-088/2012

REFERENCES

1. **Brzezinski, S., Rybicki, T., Malinowska, G., Karbownik, I., Rybicki, E., Szugajew, L.** Effectiveness of Shielding Electromagnetic Radiation, and Assumptions for Designing the Multi-layer Structures of Textile Shielding Materials *Fibres & Textiles in Eastern Europe* 1 (72) 2009: pp. 60 – 65.
2. **Stankutė, R., Grinevičiūtė, D., Gutauskas, M., Žebrauskas, S., Varnaitė, S.** Evaluation of Electrostatic Properties of Fiber-forming Polymers *Materials Science* (*Medžiagotyra*) 16 (1) 2010: pp. 72 – 75.
3. **Avloni, J., Ouyang, M., Florio, L., Henn, A. R., Sparaviga, A.** Shielding Effectiveness Evaluation of Metallized and Polypyrrole-coated Fabrics *Journal of Thermoplastic Composite Material* 20 (3) 2007: pp. 241 – 254. http://dx.doi.org/10.1177/0892705707076718
4. **Cheng, K. B., Cheng, T. W., Nadaraj, R. N., Giri Dev, V. R., Neelakand, R.** Electromagnetic Shielding Effectiveness of the Twill Copper Woven Fabrics *Journal of Reinforced Plastics and Composites* 25 (7) 2006: pp. 699 – 709. http://dx.doi.org/10.1177/0731684406060578
5. **Perumalraj, R., Dasaradan, B. S.** Electromagnetic Shielding Effectiveness of Copper Core Yarn Knitted Fabrics *Indian Journal of Fibres & Textile Research* 34 (2) 2009: pp. 149 – 154.
6. **Pinar, A.**, **Michalak, L.** Influence of Structural Parameters of Wale-Knitted Fabrics on their Electrostatic Properties *Fibres & Textiles in Eastern Europe* 5 (59) 2006: pp. 69 – 74.
7. **Chen, H. C., Lin, J. H., Lee, K. C.** Electromagnetic Shielding Effectiveness of Copper/Stainless Steel/Polyamide Fiber Co-Woven-Knitted Fabric Reinforced Polypropylene Composites *Journal of Reinforced Plastics and Composites* 27 (2) 2008: pp. 187 – 204. http://dx.doi.org/10.1177/0731684407082628
8. **Anand, S. C.** Knitted Three – Dimensional Structures for Technical Textiles Applications *12th World Textile Conference AUTEX* 2012: pp. 69 – 74.
9. **Das, I., Ishtiaque, S. M.** Comfort Characteristics of Fabrics Containing Twist-less and Hollow fibrous Assemblies in Weft *Journal of Textile and Apparel Technology and Management* 3 (4) 2004: pp. 1 – 7.
10. **Onofrei, E., Rocha, A. M., Catarino, A.** The Influence of Knitted Fabrics' Structure & on the Thermal and Moisture Management Properties *Journal of Engineered Fibres and Fabrics* 6 (4) 2011: pp. 10 – 22.
11. **Debnath, S., Madhusoothanan, M.** Thermal Insulation, Compression and Air Permeability of Polyester Needle-punched Nonwoven *Indian Journal of Fibre &Textile Research* 35 2010: pp. 38 – 44.
12. **Senthilkumar, P., Kantharaj, M., Vigneswaran, C.** Thermal Comfort Characteristics of Plain Woven Fabrics *Journal of the Textile Association* 11 (12) 2010: pp. 188 – 195.
13. **Barauskas, R., Valasevičiūtė, L., Jurevičiūtė, A.** Computational Analysis and Experimental Investigation of Heat and Moisture Transfer in Multilayer Textile Package *Materials Science* (*Medžiagotyra*) 15 (1) 2009: pp. 80 – 85.
14. **Kobiela-Mendrek, K., Marcinkowska, E.** Kinetics of Humidification and Drying Clothing Microclimate in Simulating Researches *Fibres & Textiles in Eastern Europe* 15 (5–6) 2007: pp. 91 – 93.
15. **Keiser, C., Becker, C., Rossi, R. M.** Moisture Transport and Absorption in Multilayer Protective Clothing Fabrics *Textile Research Journal* 78 (1) 2008: pp. 604 – 613.
16. Internet source: http://www.barnet-europe.com/en/yarns/nega-stat/nega-stat-p190.html, last watched 10 08 2012

Presented at the 14-th International Conference-School "Advanced Materials and Technologies" (August 27–31, 2012, Palanga, Lithuania)