Maja Jankoska*,
Goran Demboski

Influence of Structure Variation and Finishing on Woven Fabric Thermal Properties

DOI: 10.5604/01.3001.0010.7807

University „Ss. Cyril and Methodius",
Faculty of Technology and Metallurgy,
Department of Textile,
Skopje, Macedonia
*E-mail: maja@tmf.ukim.edu.mk

Abstract
The paper investigates the influence of fabric structure variations and finishing on the thermal properties of woven fabrics for a tailored garment. Four distinctive pairs of fabrics were investigated, where the weft density, weft yarn count or type and finishing were varied within the fabrics in each pair. Several thermal properties such as conductivity, diffusivity, absorptivity, resistance, the ratio of maximal and stationary heat flow density and the stationary heat flow density were measured using an Alambeta device. The results obtained showed that variation of the weft yarn count and finishing have a significant effect on several thermal properties. Increasing the weft count increased the thermal conductivity, absorptivity, resistance and the ratio of maximal and stationary heat flow density. The application of oilproof and waterproof finishing affected thermal diffusivity, thermal absorptivity and thermal resistance. Milled finishing contributed to increasing the thermal resistance.

Key words: *thermal properties, woven fabric, waterproof finishing, oilproof finishing, milled finishing.*

Introduction

Ensuring the thermal stability of the human body is one of the most important functions of clothing. The influence of clothing on the heat exchange between the human and its surroundings is very complex. It depends on many factors connected with the environment and the properties and structure of clothing [1]. The influence of clothing on human comfort is a complex phenomenon influenced by the material type and clothing structure [2]. Matusiak and Sikorski [3] investigated the relation between the weave and linear density of weft yarn and the thermal properties of woven fabrics. They found a strong and statistically significant correlation between the thermal insulation properties of the fabrics and these structural parameters. Marmarali and Kretzschmar found that the transfer of heat and water vapour are affected by atmospheric conditions, activity of the human body and by the properties of the fabric, such as the type of fibre, yarn structure, weave and fabric thickness [4]. Das *et al*. [5] gave a detailed explanation of the heat and water vapour transmission of different types of multi-layered fabrics. They proved that regardless of the fibre type, an increase in the density and fabric weight increases the thermal resistance and decreases the water vapour permeability of fabrics. Some recent studies include the implementation of a computer-controlled instrument, the Alambeta, to measure insulation and thermal contact properties of fabrics. The heat flow passing between the textile samples and the measuring head during thermal contact is measured directly by a special thin sensor, whose thermal inertia is similar to that of human skin [6, 7]. Other thermal parameters are calculated based on the properties measured and suitable algorithms [8]. Matusiak [9] investigated the thermal insulation properties of single and multilayer textile materials as well as the relationships between the thermal insulation properties of a set of materials and the parameters of the particular components of sets, including the configuration of layers. Hes [10] described and analysed some non-destructive methods of testing the mechanical and comfort properties of fabrics/garments. He investigated the possibility to characterise the sensorial and thermo-physiological properties of fabrics/garments in their full complexity by means of the so-called "comfort matrix". Rego *et al*. [11] showed that the weft stretch has a significant influence on tactile comfort as well as on mechanical properties and fabric thermal resistance. He found that polyester content and the application of functional treatment are the key design elements in controlling fabric performance. Bajzik and Hes [12] investigated the effect of moisture on the thermal comfort properties of different cotton fabrics which were subjected to different finishing treatments. It was found that the presence of moisture affected substantively all thermal insulation and thermal contact properties. Khoddami *et al.* [13] examined the effect of finishing on the thermal properties of hollow PES/wool fibre fabric and proved that the finishing does not have a negative impact. They also found that hollow fibre fabrics always have lower thermal conductivity than similar fabrics with solid polyester fibres, as well as which the fabric thermal properties are greatly affected by the dyeing process. Boguslawska-Baczek and Hes [14] studied the impact of moisture on the thermal parameters of fabrics designed for special clothing. As follows from the original results, even a small content of sodium chloride salt influences the thermal comfort properties of wetted fabrics. Ahmad *et al.* [15] investigated the relationship between the fabric weave structure and its thermal resistance. They studied two basic weave structures and four derivatives for each weave structure selected. While the plain weave structure showed the highest thermal resistance, the 2/2 matt weave had the lowest thermal resistance. Kakvan *et al.* [16] studied the thermal comfort properties of woven fabrics made of Kermel, cotton/nylon and cotton/nylon/Kermel-blended yarns. The results showed that the thermal resistance increases along with the Kermel fibre blend ratio. Mahbub *et al.* [17] investigated the thermal comfort properties of woven Kevlar/wool and woven Kevlar ballistic fabrics, where the thermal resistance of Kevlar/wool fabric was higher than that of Kevlar. Özdemir [18] investigated the effects of weave and raw material on the thermal and water vapor resistance of some commonly used clothing 65/35 and 33/67% PES/CO blend woven fabrics, whose weaves were 2/2, twill, matt twill, cellular and diced weaves. The results indicate that both the fabric construction and constituent fibre properties affect the thermal comfort properties of clothing woven fabrics.

Table 1. Fabric properties investigated.

Fabric	A	A1	B	B1	C	C1	D	D1
Fibre composition	98% wool 2% lycra		100% wool		100% wool		44% wool 54% PES 2% lycra	
Yarn count, warp, Tex	17x2	17x2	15x2	15x2	17x2	17x2	18x2	18x2
Yarn count, weft, Tex	17x2	17x2	24	15x2	17x2	17x2	18x2	18x2
Warp density, cm^{-1}	32	32	31.2	31.2	30.8	30.8	35.4	35.4
Weft density, cm^{-1}	24.80	26.2	27.6	28	25.6	28.2	24.4	24.4
Fabric thickness, mm	0.36	0.41	0.29	0.34	0.39	0.41	0.45	0.45
Fabric weight, g/m^2	213	227	167	187	213	227	250	250
Finishing	standard		standard		milled		standard	oilproof waterproof
Weave	2x1 twill	2x1 twill	2x1 twill	2x1 twill	2x2 twill	2x2 twill	2x2 twill	2x2 twill

The aim of this paper was to investigate the influence of modification of the fabric structure, such as increasing the weft density and weft yarn count, as well as the influence of waterproof and oilproof finishing on woven fabric thermal properties.

Experimental

Materials and methods

The object of investigations were four distinctive pairs of fabrics, where every second fabric in the pair is produced with variation of fabric structure parameters, or by varying the finishing treatment. The variation of fabric structure parameters imposed was such that it can be easily set in the course of everyday industrial production: variation of weft density or variation of weft yarn count.

Details of fabric structure parameters are shown in ***Table 1***.

- Fabrics of the first pair, A and A1, differ in weft density; namely, A1 has higher weft density than A. The magnitude of the increase in weft density is 5.6%. All other parameters, including fibre composition, yarn count, warp density and finishing treatment are identical.
- The second pair of fabrics designated, B and B1, have all structure parameters identical, except the weft yarn count. The first fabric of pair B has single ply weft yarn of lower count, while the second fabric B1 has double ply weft yarn of higher count.
- The third pair of fabrics, C and C1, also have all the fabric structural parameters identical, except weft density. Fabric C has lower weft density, while C1 has 10.2% higher weft density.
- The fourth pair of fabrics, D and D1, also have all structural parameters identical, except the type of finishing. Here also the first fabric in the pair has standard clear cut finishing, while D1 has an additional waterproof and oilproof finish. Waterproof and oilproof finishing was carried out by teflon impregnation on a foulard, with an 80% degree of sizing, 25 g/l of Tubiguard 66, 3 g/l of Tubiguard fix and 5 g/l of Collosal FD, followed by drying or thermal fixation at a temperature from 130 to 150 °C.

Regarding fibre composition, the first three pairs of fabric have 100% wool or 100% wool with Lycra. Concerning the weave, they are similar, and have a twill 2/1 or twill 2/2 weave.

The fibre composition in the fourth pair of fabrics is a blend of wool, PES and Lycra. Also the fabrics of this pair have identical warp and weft counts.

Regarding the purpose of the fabrics, pairs A-A1 and B-B1 are designed for summer clothing, while C-C1 and D-D1 for winter clothing.

Measurements of the thermal insulation parameters were performed on fabric using the Alambeta device, constructed by Hes [19]. Six parameters were determined : thermal conductivity - λ, thermal diffusivity - *a,* thermal absorptivity - *b,* thermal resistance - *R,* ratio of maximal to stationary heat flow density - *p* , and stationary heat flow density - *q*.

- Thermal conductivity, λ, is based on ***Equation 1***:

$$\lambda = \frac{Q}{F\tau\frac{\Delta T}{\sigma}}, Wm^{-1}K^{-1} \qquad (1)$$

where, Q - amount of conducted heat in J, F - area through which the heat is conducted in m^2, τ - time of thermal conductivity in *s*, ΔT - drop in temperature in *K*, σ - fabric thickness in *m*.

- Thermal diffusivity, *a,* is defined by ***Equation 2***:

$$a = \frac{\lambda}{\rho c}, m^2 s^{-1} \qquad (2)$$

where, λ - thermal conductivity in $Wm^{-1}K^{-1}$, ρ - fabric density in kgm^{-3}, c - specific heat of fabric in $J\,kg^{-1}K^{-1}$.

- Thermal absorptivity, *b,* can be expressed as ***Equation 3***:

$$b = \sqrt{\lambda \cdot \rho c}, Ws^{1/2}m^{-2}K^{-1} \qquad (3)$$

where, λ - thermal conductivity in $Wm^{-1}K^{-1}$, ρ - fabric density in $kg\ m^{-3}$, c - specific heat of fabric in $J\,kg^{-1}K^{-1}$.

- Thermal resistance, *R,* is connected with fabric thickness by means of ***Equation 4***:

$$R = \frac{\sigma}{\lambda}, Km^2W^{-1} \qquad (4)$$

where, σ - fabric thickness in m, λ - thermal conductivity in $Wm^{-1}K^{-1}$.

- The maximum heat flow density, *p,* from the skin to the fabric appears at the moment of contact of the cold fabric with human skin. With time, the heat flow stabilised itself at a determined level *q*, which is called the stationary heat flow density.

- Stationary heat flow density is defined by ***Equation 5***:

$$q = \frac{Q}{F\tau}, \quad Wm^{-2} \qquad (5)$$

where, Q - amount of heat in *J*, F - area through which the heat is conducted in m^2, τ - time to flow in *s*.

Results and discussion

Results of the thermal properties investigated, such as average values and the coefficient of variation (CV) are given in ***Table 2***. The effects of fabric structure variation and finishing on thermal properties was evaluated by analysis of variance (ANOVA), the results of which are shown in ***Table 3***.

The results of thermal conductivity (λ) measurements show an increase in thermal conductivity in every second fabric in the pairs investigated.

Table 2. *Thermal properties of fabric tested.*

Fabric	A	A1	B	B1	C	C1	D	D1
λ, Wm^{-1}K^{-1}x10^{-3}	53.24	53.54	46.00	47.92	49.72	50.50	58.42	60.62
CV, %	1.53	1.54	2.26	1.92	1.02	1.73	3.51	1.52
a, m^{2}s^{-1}x10^{-6}	0.048	0.047	0.043	0.042	0.075	0.074	0.073	0.068
CV, %	3.94	2.82	4.74	3.58	4.81	4.76	3.21	3.81
b, Ws$^{1/2}$m^{-2}K^{-1}	241.4	249.6	221.0	232.0	184.8	188.4	219.6	230.4
CV, %	2.99	3.61	1.60	2.40	4.83	4.59	2.08	3.21
R, Km^{2}W^{-1}x10^{-3}	7.30	7.22	7.00	7.30	8.72	8.50	8.20	7.94
CV, %	2.93	2.40	2.02	2.17	2.20	1.86	2.11	1.91
p	1.43	1.44	1.36	1.40	1.38	1.36	1.42	1.42
CV, %	1.69	1.91	0.81	1.85	2.37	5.12	1.11	2.24
q, Wm^{-2}	1.23	1.24	1.19	1.19	1.05	1.05	1.14	1.15
CV, %	2.29	3.02	1.94	2.43	3.12	4.80	1.72	1.56

Table 3. *F-test and p-values for thermal properties of fabrics.*

Samples	A/A1	B/B1	C/C1	D/D1
Factor	Weft density	Weft thread count	Weft density	Finishing
λ - thermal conductivity	0.53	9.74*	2.99	4.77
p - value	0.49	0.01	0.12	0.06
a - thermal diffusivity	2.18	0.49	1.38	8.60*
p - value	0.18	0.50	0.27	0.02
b - thermal absorptivity	2.57	13.94*	0.42	7.71*
p - value	0.15	0.01	0.53	0.02
R - thermal resistance	0.61	10.00*	3.90	6.38*
p - value	0.45	0.13	0.08	0.04
p - ratio of max. and stationary heat flow density	0.11	10.13*	0.41	0.02
p - value	0.75	0.01	0.54	0.90
q - stationary heat flow	0.23	0	0	1.03
p-value	0.64	1	0.98	0.34
* F-values and p-values marked with an asterisk indicate the significant influence of the factors investigated on the properties measured				

This means that an increase in weft density (A to A1 and C to C1) and weft yarn count (B to B1) and the application of oilproof and waterproof finishing (D to D1) result in an increase in thermal conductivity (***Figure 1***). Increasing the weft density or weft count increases the thickness of the fabric (***Table 1***), which, in turn, increases the thermal conductivity. The fabric with oilproof and waterproof finishing in the fourth pair has a higher thermal conductivity compared to standard fabric due to the finishing, which makes the fabric more covered.

With respect to the effect of the factors investigated on thermal conductivity, it appears that only an increase in the weft thread count has a significant effect on the thermal conductivity (***Table 3***). Thermal diffusivity (*a*) is a property concerning the transport of thermal flow through the fabric structure‘s air. For the first (A-A1) and third (C-C1) pair of fabrics, where the weft density is increased, and for the second pair (B-B1), where the weft count is increased, there are small differences in thermal diffusivity. However, regarding the fourth pair, the standard fabric has higher thermal diffusivity than the finished one (***Figure 2***). The application of special finishing decreased the thermal diffusivity of the fabric by 6.9%.

The analysis of variance (***Table 3***) also confirms finishiing to be a statistically significant factor for thermal diffusivity. It can be seen that thermal diffusivity is substantially greater in the third and fourth pairs than in the first two. The reason for this is the milled finishing of the third pair and greater thickness of the fourth.

The first (A-A1) and third (C-C1) pairs have identical warp and weft counts and weight, and differ only in finishing. As a esult of milled finishing, the third pair have 56 - 57% higher thermal diffusivity than the first. Also we can see that the thermal diffusivity values clearly distinguish fabrics for summer clothing (A-A1 and B-B1) and for winter clothing (C-C1 and D-D1).

The thermal diffusivity is almost doubled for winter clothing fabrics.

Thermal absorptivity (*b*) is a parameter indicating the warm-cool feeling at the first brief contact of the fabric with human body skin [20]. Fabrics of lower thermal absorptivity provide a "warm" feeling and are not suitable for summer clothing, whereas those with a high value of thermal absorptivity give a "cool" feeling. Increasing the weft density and weft count (which, in turn, increases the fabric weight, fabric thickness and cover factor) results in an increase in thermal absorptivity (***Figure 3***) i.e. a decrease in warm feeling (pairs A-A1 and C-C1). Also the standard fabric (D) has lower values of thermal absorptivity and therefore provides greater warm feeling compared to the finished one (D1).

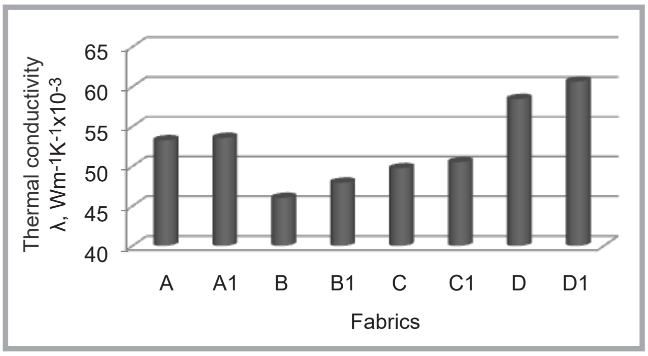

Figure 1. *Thermal conductivity of fabrics.*

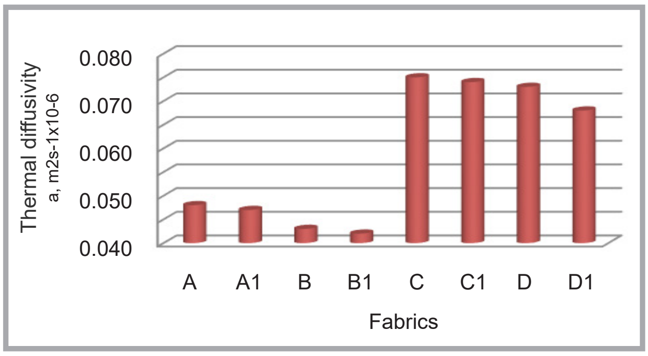

Figure 2. *Thermal diffusivity of fabrics.*

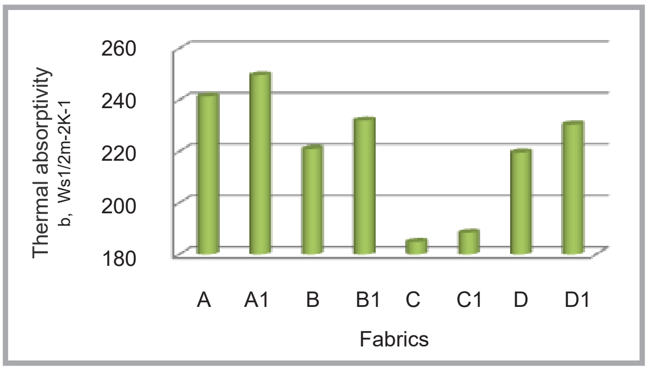

Figure 3. *Thermal absorptivity of fabrics.*

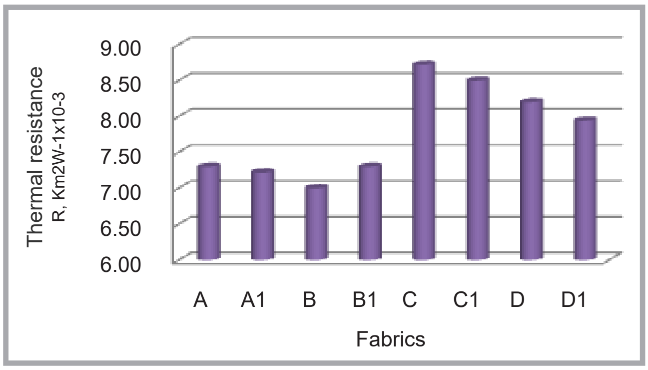

Figure 4. *Thermal resistance of fabrics.*

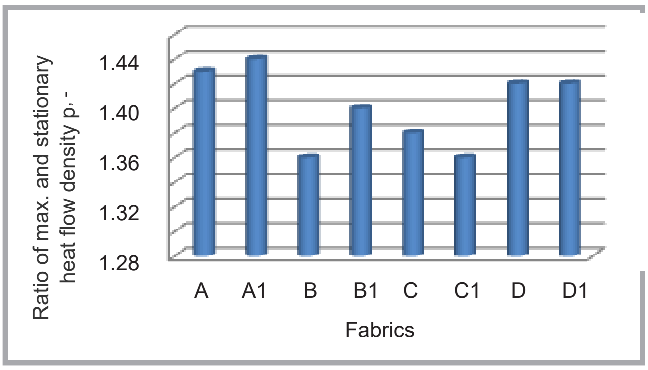

Figure 5. *Ratio of max. and stationary heat flow density of fabrics.*

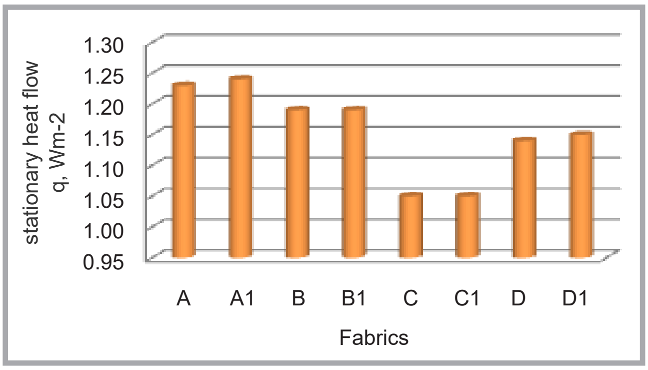

Figure 6. *Stationary heat flow of fabrics.*

In the second pair, the introduction of higher count weft yarn (B1) increases the thermal absorptivity, leading to the improved performance of the fabric as summer clothing.

The fabrics in the third pair (C-C1) have substantially lower values of thermal conductivity, which is as a result of milled finishing intended for winter clothing, providing a warm touch feeling for these fabrics and favouring them for winter clothing (***Figure 3***). Compared to the first pair, (which have the same thread count, weight and density, but standard finishing), the third have about 30% lower thermal absoprtivity.

Analysis of variance (***Table 3***) confirms that statisticaly significant factors affecting thermal condictivity are changes in the weft yarn count (B-B1) and application of oilproof and waterproof finishing (D-D1).

Thermal resistance (*R)* is an important parameter from the point of view of thermal insulation. This feature is connected with the structure and thickness of the fabric [4, 5]. ***Figure 4*** shows that the thermal resistance decreases with increasing weft density (A-A1 and C-C1). Opposite to increasing the weft density, the introduction of a higher double ply weft count results in an increasing in thermal resistance (B-B1). It was confirmed by the F-test that increasing the weft count has a significant influence on the increase in thermal resistance (F-test, ***Table 3***). The third pair of fabrics, with milled finishing, obtained the highest value of thermal resistance compared to all other fabrics, which again favors this fabric for use in winter clothing. The oilproof finishing proved to have a significant influence on decreasing the thermal resistance (F-test, ***Table 3***). The higher values of thermal resistance are clearly shown by fabric pairs intended for winter clothing (C-C1 and D-D1).

The ratio of maximal and stationary heat flow density (p) from the human skin to the fabric occurs in the moment of contact of the cool fabric with human skin. Maximum heat flow is one of the parameters characterising the thermal insulation and thermal absorptivity of fabrics, which are surface features. The results (***Figure 5***) show that the introduction of double ply weft yarn (B-B1) increases the ratio of maximal and stationary heat flow density, which is statisticaly confirmed by the F-test (***Table 3***).

Increasing the weft density as well as waterproof and oliproof finishing has no significant effect on this feature.

When the heat flow gets stabilised after a certain amount of time, it does so at the level q, which is called stationary heat flow density. The values obtained for stationary heat flow (***Figure 6***) suggest that the structural changes and finishing of the fabric do not affect the stationary heat flow. It can be seen that the first pair of fabrics have the greatest stationary heat flow (summer clothing), while the third pair of fabrics, with milled finishing (C-C1), have the smallest, which again favors this pair for winter clothing.

Conclusions

The influence of fabric structure variation and oilproof and waterproof finishing on thermal properties for a range of fabrics for a tailored garment was investigated.

It was shown that fabric structure variation and finishing have a specific effect on various thermal properties. Nevertheless, on the basis of the investigation carried out, the following conclusions can be drawn:

- The introduction of double ply weft yarn of higner count has a significant influence on thermal conductivity, thermal absorptivity, thermal resistance and the ratio of maximal and stationary heat flow density.

- The introduction of higher weft yarn count significantly increased the thermal resistance and, consequently, contributed to the improved performance of this fabric for summer clothing.
- The results confirmed that waterproof and oilproof finishing significantly affect thermal diffusivity, thermal absorptivity and thermal resistance.
- Oilproof and waterproof finishing increased the values of thermal absorptivity, which consequently lowered the warm feeling of the fabric and decreased its performance for winter clothing. It was found that oilproof and waterproof finishing decreased the thermal diffusivity of the fabric by 6.9%.
- The fabric with milled finishing obtained the highest value of thermal resistance, which favours itm for application in winter clothing. Compared to similar standard finished fabrics, the milled finished fabrics obtained 56-57% higher thermal diffusivity and 30% lower thermal absoprtivity.

References

1. Matusiak M. Investigation of the Thermal Insulation Properties of Multilayer Textiles. *FIBRES & TEXTILES in Eastern Europe* 2006; 14, 5(59): 98-102.
2. Matusiak M. Thermal Comfort Index as a Method of Assessing the Thermal Comfort of Textile Materials. *FIBRES & TEXTILESin Eastern Europe 2010; 18,* 2(79): 45-50.
3. Matusiak M, Sikorski K. Influence of the Structure of Woven Fabrics on Their Thermal Insulation Properties. *FIBRES & TEXTILES in Eastern Europe 2011; 19,* 5(88): 46-53.
4. Marmarali A, Kretzschmar S D, Özdil N, Oğlakcioğlu N G. Parameters that affect thermal comfort of garment. *Tekstil ve Konfeksiyon 2006;* 16(4): 241-246.
5. Das A, Biswas B. Study on heat and moisture vapour transmission characteristics through multilayered fabric ensembles. *Indian Journal of Fibre & Textile Research* 2011; 36(4): 410-414.
6. Hes L, Dolezal I. New Method and Equipment for Measuring Thermal Properties of Textiles. *Journal of the Textile Machinery Society of Japan 1989;* 42(8): 124-128.
7. Hes L, Araújo M, Djulay V V. Effect of Mutual bonding of Textile Layers on Thermal Insulation on Thermal Contact Properties of Fabric Assemblies. *Textile Research Journal 1996;* 66(4): 245-250.
8. Ozcelik G, Cay A, Kirtay E. A study of thermal properties of textured knitted fabrics. *FIBRES & TEXTILES in Eastern Europe* 2007; 15(1): 55-58.
9. Matusiak M. Investigation of the Thermal Insulation Properties of Multilayer Textiles. *FIBRES & TEXTILES in Eastern Europe 2006;* 14(5): 98-102.
10. Hes L. Non-destructive determination of comfort parameters during marketing of functional garments and clothing. *Indian Journal of Fibre & Textile Research* 2008; 33: 239-245.
11. Rego J M, Verdu P, Nieto J, Blanes M, Comfort Analysis of Woven Cotton/Polyester Fabrics Modified with a New Elastic Fiber Part 2: Detailed Study of Mechanical, Thermo-Physiological and Skin Sensorial Properties. *Textile Research Journal* 2010; 80(3): 206-215.
12. Bajzik V, Hes L. The Effect of Finishing Treatment on Thermal Insulation and Thermal Contact Properties of Wet Fabrics. *Tekstil ve Konfeksiyon* 2012; 22(1): 26-31.
13. Khoddami A, Soleimani M I, Gong H. Effects of finishing on the mechanical and thermal properties of fabrics from wool and hollow polyester fibres. *Textile Research Journal* 2011; 81(19): 2006-2016.
14. Boguslawska-Baczek M, Hes L. Thermal conductivity and resistance of Nomex fabrics exposed to salty water. *Tekstil ve Konfeksiyon* 2014; 24(2): 180-185.
15. Ahmad S, Ahmad F, Afzal A, Rasheed A, Mohsin M, Ahmad N. Effect of weave structure on thermo-physiological properties of cotton fabrics. *AUTEX Research Journal* 2015; 15(1): 30-34.
16. Kakvan A, Najar S S, Psikuta A. Study on effect of blend ratio on thermal comfort properties of cotton/nylon-blended fabrics with high-performance Kermel fibre. *The Journal of The Textile Institute* 2015; 106(6): 674-682.
17. Mahbub R F, Wang L, Arnold L, Kaneslingam S, Padhye R. (2014). Thermal comfort properties of Kevlar and Kevlar/wool fabrics. *Textile Research Journal* 2014; 84(19): 2094-2102
18. Özdemir H. Thermal comfort properties of clothing fabrics woven with polyester/cotton blend yarns. Autex Research Journal 2017; 17(2): 135-141
19. Instruction manuals of Alambeta instrument SENSORA Liberec Registered Company, Czech Republic, 1990
20. Hes L. Recent Developments in the Field of Users Friendly Testing of Mechanical and Comfort Properties of Textile Fabrics and Garments, *World Congress of the Textile Institute*, Cairo, 2002.

Received 14.11.2016   Reviewed 30.10.2017

3RD EUROPEAN FOOD & BEVERAGE PLASTIC PACKAGING SUMMIT

14th & 15th March 2018 - Amsterdam, The Netherlands

CIRCULAR ECONOMY & LATEST TECHNOLOGIES LEADING THE INDUSTRY

KEY TOPICS:

- Market trends for sustainable packaging in 2018 and beyond
- Latest innovations in design, manufacturing, additive and convertor technology
- Case studies from retailers/brands on packaging and design needs in the food & beverage industry
- What does the European Commission circular economy package mean for the plastics packaging supply chain
- Expectations and targets of EU waste legislation on packaging and packaging waste
- Analysis and comparison of performance materials in different applications
- Advancing plastics converters and manufacturers capabilities and technologies
- Life cycle assessments and environmental impact

PAST ATTENDEES INCLUDE SENIOR REPRESENTATIVES FROM:

ACR+ * **Addivant Belgium SPRL** * Aliplast Spa * **Amcor** * Apeldoorn Flexible Packaging B.V. * **Aptar Europe** * A-Star * **Avantium** * Biobag Ireland * **Bosch, Packaging Technology** * Braskem Europe GmbH * **Brueckner** * Buergofol GmbH * **Burg Groep** * Carbotech AG * **CE Delft** * Chevron Phillips Chemicals International NV * **Constantia Flexibles International** * Corbion Group Netherlands * **Corbion Purac** * CROWN Technology * **Danone Waters Division** * Denkstatt * D**OW EMEA Packaging & Specialty Plastics** * DuPont de Nemours International Sàrl * **Ecoemballages** * Ellen MacArthur Foundation * **EMS-CHEMIE AG** * EMSUR * **EPRO** * European Commission * **European Plastics Recyclers** * EXPRA * Flexible Packaging Europe * **Fortum Power and Heat Oy** * Fraunhofer ISC * **FTI, Förpacknings- Och Tidningsinsamlingen** * Gentronix - Innovation and Service * **Gneuss Kunststofftechnik GmbH** * Green Chemistry Cluster * **Group Gheys NV** * Hapa AG * **Innovia Films** * ISCC * **KHS Corpoplast GmbH** * Krones AG * **Licella** * Mano Vendors * **Mol Germany GmbH** * Mondi Consumer Packaging Technologies GmbH * **Nampak Plastics** * Napco Modern Plastic Products Company * **NatureWorks LLC** * Nestle Waters * **Novamont** * Omya International * **Quantis GmbH & Co KG** * Radiant Color * **Repsol** * Roquette * **SABIC** * Saperatec * **Sidel Group** * Smithers Pira * **Suntory Business Expert Limited** * Swiss Prime Pack * **Synvina** * Total * **Total Research & Technology Feluy** * Universidad De Los Andes * **Veolia** * Versalis Eni * **Waldorf Technik** * Wolf Plastics * **Verpackungen GmbH** * WRAPs

COMMERCIAL & SPONSORSHIP OPPORTUNITIES
KRISZTINA MARIA SZABO
44 (0) 203 141 0603 / KSZABO@ACIEU.NET

ACI

MORE INFORMATION & REGISTRATION
DIMITRI PAVLYK
+44 (0) 203 141 0627 / DPAVLYK@ACIEU.NET