Abhijit Majumdar · Deepti Gupta · Sanjay Gupta *Editors*

Functional Textiles and Clothing

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Preface

Textile materials, be it fabric or home furnishing, are primarily chosen based on their aesthetic appeal and comfort. However, the perception about textiles is changing as they are expected to possess some functionality apart from fulfilling their basic purpose. A new domain of functional textiles has emerged in the last few decades which encompasses the areas like protective textiles, medical textiles, industrial textiles, sports textiles, automotive textiles, and packaging textiles. All these materials must have specific functional features to meet the end-use requirements. Therefore, material selection, product design, and manufacturing are rather complex and therefore challenging in case of functional textiles.

Functional textiles and clothing sector has emerged as the growth area in recent times. Recent reports peg the global market to reach USD 4.72 billion by 2020, at a CAGR of 33.58% between 2015 and 2020, on the strength of commercial market applications in healthcare, sports, fitness, fashion, military, and automotive sectors. India, as the second largest producer and fourth largest exporter of textile and apparel goods in the world, has already identified this area under its technical textiles push a decade back. With its domestic apparel market showing signs of maturing and a healthy growth rate, India is looking forward to make a place for itself in this high-value, high-tech textile and apparel sectors.

Looking at the emerging needs of industry and academia and to cope with the impending challenges of designing and manufacturing of functional textiles, an international event entitled ‘Functional Textiles and Clothing Conference 2018’ was organized by Indian Institute of Technology Delhi during February 9–11, 2018, in collaboration with World University of Design, Sonipat, and PSG College of Technology, Coimbatore. The conference provided an interdisciplinary platform to leading scientists, academicians, researchers, research scholars, entrepreneurs, and market stakeholders to have in-depth exchanges on the recent scientific developments, research results, cutting-edge technologies, innovations, trends, concerns, supply chain issues and challenges and opportunities in the field of functional textiles and clothing.

This book contains selected papers presented in the conference. The papers are organized under eight sections, namely protective textiles, medical textiles, smart textiles, textile chemical processing, garment and accessory design, testing and characterization, supply chain management and sustainability, and traditional textile art and crafts. Interested readers may contact the editors or the authors in case they have any query.

New Delhi, India — Abhijit Majumdar
New Delhi, India — Deepti Gupta
Sonepat, India — Sanjay Gupta

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About the Editors

Abhijit Majumdar is a Chair Professor in the Department of Textile Technology, Indian Institute of Technology, Delhi. He has done his M. Tech in Textile Engineering and MBA in Technology Management from IIT Delhi, and his Ph.D. in Production & Operations Management from Jadavpur University, Kolkata. His research interests include fabric manufacturing technologies, protective textiles, soft computing based modeling and sustainable operations and supply chain management. He has edited 2 books, and authored 2 books, 1 monograph, 6 book chapters and 95 research articles in refereed journals. He is a recipient of Outstanding Young Faculty Fellowship (2009–2014) of IIT Delhi, Teaching Excellence Award (2015) of IIT Delhi and Gandhian Young Technological Innovation Award (2017).

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Sanjay Gupta is the Vice Chancellor of the World University of Design, Sonepat, India, and was previously the Dean of National Institute of Fashion Technology and the Founding Dean of the School of Design at GD Goenka University. He has done his Ph.D. in textile technology from IIT Delhi. He was a UNDP fellow to Fashion Institute of Technology (FIT), New York and a Visiting Professor at École Nationale Supérieure des Arts et Industries Textiles (ENSAIT), France. He was involved in the key initiative of bringing fashion schools worldwide under the umbrella of the International Foundation of Fashion Technology Institutes (IFFTI). He has over 100 publications and, over 30 presentations in national/international conferences and seminars. He has also been a member of committees & bodies at national/international level like ASSOCHAM, CII, IFFTI, BIS, NISTI besides being on the editorial boards of scientific journals.

Part I
Protective Textiles

Thermal Resistance of Leather and Membranes for Summer Desert Military Footwear Under Different Climate Conditions

Dragana Kopitar, Jadranka Akalovic and Zenun Skenderi

Abstract The desert climate is characterized by a big gap between day and night temperatures. In summer dry season, daytime temperatures can approach 45 °C and drop to 15 °C during the night. Aim of the paper is to investigate thermal resistance of footwear layers in military footwear for dry desert season under different climate conditions focusing on the temperature difference between day and night. Thermal resistance was determined using the Sweating Guarded Hotplate equipment according to the standard ISO 11092 and under climate condition known in deserts, respectively, 15 and 30 °C with relative humidity of 40%. Increasing the temperature, thermal resistance of leather for collar have tendency to decreases, while thermal resistance of leather for vamp and quarter have tendency to increase. The thermal resistance differences are not great but different tendencies of thermal resistance change is visible. It can be concluded that leather thickness influences on thermal resistance change under temperatures range of 15–30 °C. Behavior of the membranes under different temperatures is various. With the temperature increase, thermal resistance of two-layered membrane for tongue decreases for 5.9%. Thermal resistance differences, in temperature range of 15–30 °C, between minimum and maximum values for quarter and lining membranes are 17% for quarter and 13% for lining. Thermal resistance of fabrics for special uses, as protective footwear, should take in consideration climatic conditions under which fabrics will be used.

Keywords Thermal resistance · Military footwear · Climate conditions · Cattle velour suede leather

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1 Introduction

The desert climate, also known as an arid climate, is frequently characterized by three different climates; "cool" dry season where daytime temperatures peak between 35 and 45 °C and fall to 10–15 °C at night. Daytime temperatures can approach 45 °C during the "hot" dry season and drop to 15 °C during the night. During the rainy season, temperatures can range from 35 °C in the daytime to 20 °C at night [1]. Most of the time, desert is very dry, not humid, but after the desert has a good amount of rainfall, the desert becomes very humid. Summers in semi-arid deserts are long and have average temperatures between 21 and 27 °C where temperatures usually stay below 38 °C. During the evening, temperatures in semi-arid deserts drop to around 10 °C. If the outside temperature is in the range 18–25 °C, most people without clothing would begin to feel uncomfortable. If the outside temperature is in the range 30–40 °C, for any length of time, it can be life threatening. From a physiological point of view, the human body feels comfortable at about 26 °C with insulation of 0.093 m^2 °C W^{-1} [2]. Keeping the feet warm during day and night, where the temperature gap in the desert is significant, could be a problem and could jeopardize thermal comfort. Generally, a recognized solution for footwear is building up thin breathable layers of insulation as footwear liner [3]. Aim of the paper is to investigate thermal resistance of footwear layers in military footwear for dry desert season under different climate conditions focusing on the temperature difference between day and night.

2 Materials and Methods

2.1 Materials

The research of thermal resistance under different climate conditions of fabrics incorporated in summer desert military footwear was carried out (Fig. 1).

Military footwear, with inbuilt thermoplastic toe cap, is made of natural sand-colored chrome tanned leather of two thicknesses, as well vegetable and water repellent finished leather. The lining is three-layered beige-colored water repellent/waterproof and vapor permeable membrane of following raw material composition: the first layer is 85% PA/15% PES fiber, the second layer is PTFE membrane where the third layer is made of 100% PA fiber. The footwear tongue is made of two-layered laminate in which front side is made of PA fiber, backside from PES fiber bonded with adhesive. The quarter is made of two-layered laminate in which front side is made of PA/PUR, backside made of PES fiber mutually bonded with adhesive.

Fig. 1 Summer desert military footwear

2.2 Method of Thermal Resistance Measurement Under Steady-State Conditions

Thermal resistance was determinate using the Sweating Guarded Hotplate equipment according to the standard ISO 11092 and under climate condition known in deserts. The sample to be tested is placed on the heated plate at 35 °C temperature with the conditioned air ducted to flow along and parallel to its upper surface with a speed of 1 m s^{-1}. For the determination of thermal resistance (R_{ct}), the air temperature is set at 20 °C, relative humidity of 65% and airspeed at 1 m s^{-1}. After reaching the test conditions and steady state, the recording of values can be started [4, 5].

The thermal resistance of the fabric is calculated according to the following equation [4]:

$$R_{ct} = \frac{(T_m - T_a) \cdot A}{H - \Delta H_c} - R_{ct0} \tag{1}$$

where: R_{ct} is the thermal resistance [m^2 °C W^{-1}], T_m is temperature of measuring unit [°C], T_a is the air temperature during testing [°C], A is the area of the measuring unit [m^2], H is the heating power supplied to the measuring unit [W], ΔH_c is the correction term for heating power for the measurement of thermal resistance, and R_{ct0} is the apparatus constant for the measurement of thermal resistance [m^2 °C W^{-1}].

Thermal resistance R_{ct} of the tested material is determined as the arithmetic mean of the values of three individual specimens (Fig. 2).

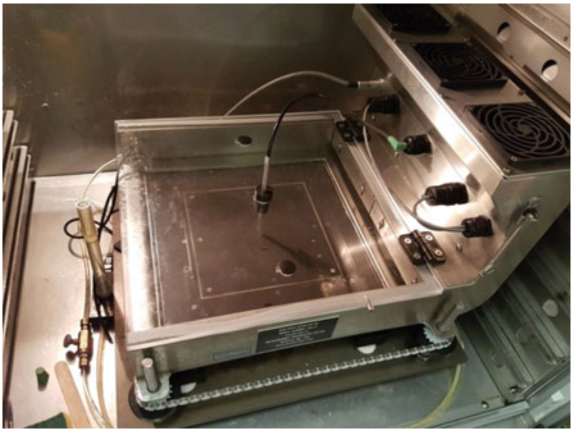

Fig. 2 Sweating guarded hot plate

Table 1 Parameters of material incorporated in summer desert military footwear

Samples			m (g m^{-2})	t (mm)
Cattle velour suede leather	Collar	M	719	0.95
		SD	0.59	0.02
Cattle velour leather	Vamp, quarter	M	1689	2.15
		SD	0.73	0.05
Two-layered membrane	Tongue	M	443	1.08
		SD	0.17	0.01
Two-layered membrane	Quarter	M	423	0.72
		SD	0.46	0.01
Three-layered membrane	Lining	M	230	0.53
		SD	0.09	0.01

Besides determination of thermal resistance under standard conditions, thermal resistance of samples was determined under summer desert temperatures (15 and 30 °C) with relative humidity setup at 40%.

3 Results and Discussion

Results of mass per unit area and thickness of fabrics incorporated in summer desert military footwear are presented in Table 1.

The thermal resistance tested according to the standard conditions and at temperatures of 15 and 30 °C with relative humidity at 40% is presented in Table 2 and Fig. 3.

Table 2 Thermal resistance of material incorporated in summer desert military footwear under standard and summer desert climate conditions

Samples			$R_{ct\_15°C}$ (m^2 °C W^{-1})	R_{ct} (m^2 °C W^{-1})	$R_{ct\_30°C}$ (m^2 °C W^{-1})
Cattle velour suede leather	Collar	M	0.0150	0.0149	0.0142
		SD	0.0004	0.0018	0.0008
		CV	2.68	12.21	5.49
Cattle velour leather	Vamp, quarter	M	0.0186	0.0187	0.0202
		SD	0.0013	0.0018	0.0003
		CV	7.04	9.60	1.64
Two-layered membrane	Tongue	M	0.0372	0.0360	0.0350
		SD	0.0017	0.0015	0.0002
		CV	4.60	4.13	0.47
Two-layered membrane	Quarter	M	0.0155	0.0169	0.0128
		SD	0.0009	0.0008	0.0002
		CV	5.79	4.87	1.48
Three-layered membrane	Lining	M	0.0146	0.0141	0.0165
		SD	0.0010	0.0013	0.0035
		CV	6.73	9.22	20.95

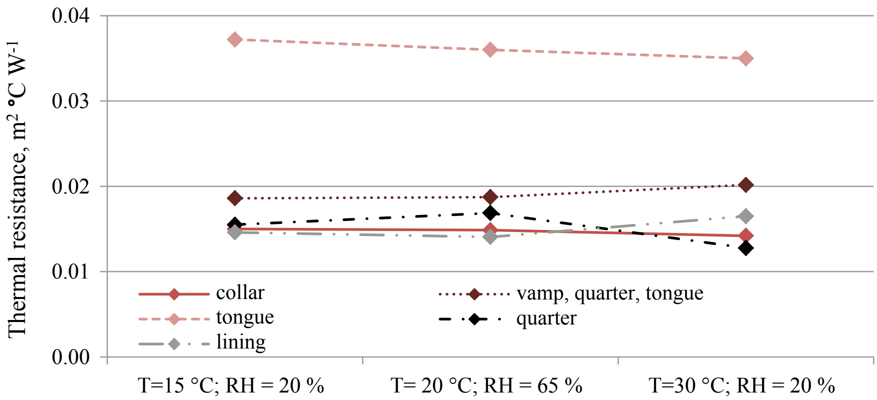

Fig. 3 Thermal resistance of military footwear layers under different climatic conditions

Comparing thermal resistance of cattle velour leather with different thicknesses and under different temperatures, different tendencies are visible (Table 2). With the increase of temperature (from 15 to 30 °C), thermal resistance of leather for collar (0.95 mm thickness) has tendency to decrease. Contrary to leather for collar, thermal resistance of cattle velour leather (2.15 mm thickness) intended for vamp and quarter has tendency to increase (from 0.0186 to 0.0202 m^2 °C W^{-1}) with temperature increase. Thermal resistance differences of cattle velour leather in temperature range from 15 to 30 °C are not great (5.3% decrease of 0.93 leather thickness and 8.60% increase of 2.15 mm leather thickness), but different tendencies of thermal resistance change are interesting. Since both cattle velour leathers have same finishing and quite difference in thickness (126%), it can be concluded that leather thickness influence on thermal resistance change under temperatures range of 15–30 °C.

The significance analysis of thermal resistance of cattle velour suede leather for collar and cattle velour leather for vamp, quarter, and tongue under different climatic conditions was conducted. The statistical analysis shows that the thermal resistance of two different types of leather under different climatic conditions is significant ($p = 0.001$).

Behavior of the membranes under different temperatures is various. Thermal resistance of two-layered membrane for tongue decreases for 5.9% (from 0.0372 to 0.0350 m^2 °C W^{-1}) with temperature increase.

Thermal resistance of two-layered membrane for quarter at standard condition is highest (0.0169 m^2 °C W^{-1}), while thermal resistance of three-layered membrane for lining is highest at 30 °C (0.0165 m^2 °C W^{-1}). Thermal resistance differences, in temperature range of 15–30 °C, between minimum and maximum values for quarter and lining membranes are 17% for quarter and 13% for lining.

The significance analysis of thermal resistance of three different membranes for tongue, quarter, and lining under different climatic conditions was conducted. The statistical analysis shows that thermal resistance under different climatic conditions of membrane for tongue and quarter ($p = 1.03 \times 10^{-4}$) and membrane for tongue and lining ($p = 2.73 \times 10^{-5}$) is significant. Thermal resistance under different climatic conditions of membrane for quarter and lining ($p = 0.99$) is not significant.

The thermal resistance values of materials incorporated in footwear measured under standard conditions show that thermal comfort of the footwear at 20 °C and 65% relative humidity is provided [6, 7]. The significance analysis of thermal resistance under standard condition as well as at 15 °C ($p = 0.99$) and 30 °C ($p = 0.94$) is not significant. We can conclude that summer desert military footwear in summer semi-arid desert climate is providing thermal comfort.

For providing good thermal comfort, the thermal resistance of all incorporated materials for summer desert military footwear at highest temperature (30 °C) should be lowest, respectively, and take away heat from feet. At lowest temperature (15 °C), the thermal resistance of the footwear layers should be highest, keeping feet warm and providing good thermal comfort.

4 Conclusion

The protective footwear, sometimes, is subject to very high or very low temperature, so it is necessary to evaluate capability of footwear to resist these two extreme situations.

The fabric incorporate in military footwear for summer dry desert climate conditions shows changes in thermal resistance under temperature range of 15–30 °C and 40% of relative humidity.

With the increase of temperature (from 15 to 30 °C) thermal resistance of leather for collar (0.95 mm thickness) has tendency to decrease, while thermal resistance of leather for vamp and quarter (2.15 mm thickness) has tendency to increase. The thermal resistance differences are not great (5.3% decrease of 0.93 leather thickness and 8.60% increase of 2.15 mm leather thickness), but different tendencies of thermal resistance change are visible. Since both cattle velour leathers have same finishing and quite difference in thickness, it can be concluded that leather thickness influence on thermal resistance change under temperature range of 15–30 °C.

Behavior of the membranes under different temperatures is various. With temperature increase, thermal resistance of two-layered membrane for tongue decreases for 5.9%. Thermal resistance of two-layered membrane for quarter at standard condition is highest, while thermal resistance of three-layered membrane for lining is highest at 30 °C. Thermal resistance differences, in temperature range of 15–30 °C, between minimum and maximum values for quarter and lining membranes are 17% for quarter and 13% for lining. We can conclude that studied summer desert military footwear in summer semi-arid desert climate is providing good thermal comfort.

For providing good thermal comfort, the thermal resistance for summer desert military footwear at highest temperature (30 °C) should be lowest and take away heat from feet, while at lowest temperature (15 °C) the thermal resistance should be highest keeping feet warm. Thermal resistance of fabrics for special uses, as protective footwear, should take in consideration climatic conditions under which fabrics will be used.

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References

1. Food and agriculture organization of the United Nations, Forestry Department The arid environments, http://www.fao.org/docrep/t0122e/t0122e03.htm. Last accessed 2017/10/12
2. Williams, J.T.: Textiles for Cold Weather Apparel. Woodhead, Cambridge (2009)
3. Kuklane, K.: Footwear for Cold Environments Thermal Properties, Performance and Testing, Doctoral Thesis. National Institute for Working Life, Stockholm (1999)
4. ISO 11092 Textiles—Physiological effects—Measurements of thermal and water-vapour resistance under steady-state conditions (sweating guarded-hotplate test)
5. Operators Manual for Material Evaluation Hotplate Model SGHP-8.2 S/N 223-xx, Measurement Technology Northwest (2006)
6. Colak, S.M., Ozdil, N., Ekinci, M., Kaplan, O.: Thermophysiological comfort properties of the leathers processed with different tanning agents. Tekstil ve Konfeksiyon **4**(26), 436–443 (2016)
7. Frydrych, I., Sybilska, W., Wajszczyk, M.: Analysis of selected physical properties of membrane fabric influencing the utility comfort clothing. Fibres Text. East. Eur. **6**(17), 50–55 (2009)

Woven Military Fabrics from the Aspect of the Microbial Barrier Permeability

Ivana Schwarz, Beti Rogina-Car and Ruzica Brunsek

Abstract Functionality is of utmost importance for fabrics designed for military purposes, where woven fabric structural parameters and finishing processes greatly affect the definition and achievement of high set properties demands. Considering the application conditions of military fabrics and the high exposure to microorganisms from environment, as well as from the direct and indirect transfer between users, the possibility of contamination is unavoidable. Therefore, the aim of this paper is to determine whether and to what extent military fabrics have the properties of microbial barrier permeability. Determination of microbial barrier permeability was conducted according to the newly developed method. The most resistant forms of microorganisms were used, the bacterial endospores of apatogenic species: *Geobacillus stearothermophilus* and *Bacillus atrophaeus*. The analysis of the obtained results and the analysis of correlations between some relevant fabric properties confirm the extremely complex structural aspect of the woven fabrics. Tested woven fabrics designed for military purposes show a very good microbial barrier permeability with a different adhesion of microorganisms, conditioned by the complex woven fabric structure, based on which can be approached to further targeted functional designing of specific elements.

Keywords Microbial barrier permeability · Military purposes · Woven fabric structures

1 Introduction

Military fabrics must meet a number of high set demands, and it is crucial that clothing and related equipment are lightweight, compact and durable and have high performance. The purpose of military camouflage fabrics is not only to assimilate with the environment, but also to protect from various conditions and situations in

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which body protection is of vital importance. Functional criteria of military fabrics should meet high camouflage and physical–mechanical and thermal requirements. Camouflage properties are achieved by specific patterns and colours application onto woven fabric, depending on the end-use conditions, with the aim of breaking the silhouette of the human body and achieving imperceptibility. Requirements of physical and mechanical properties set for these fabrics have a direct impact on psychological factors of individuals, which can cause psychological discomfort and instability that interfere with motivation and readiness to perform high-risk tasks. Military fabrics are produced in a combination of natural and synthetic fibres, which, with their specific properties and structural parameters, as well as additional chemical finishing (resistance to UV, water, heat, flame, wind), meets a wide range of requirements, all in order to achieve the needed properties [1–3]. Physiological (skin and temperature) and environmental variables (conditions of temperature, humidity and wind) are extremely important in achieving maximum comfort and safety while wearing a fabric. Its insufficient properties can cause a variety of negative phenomena (discomfort, climate imbalance, heat stress, the emergence of a large amount of nuisance, visual and cognitive disruption) affecting the person's mental and physical stability [4].

Another extremely important feature of the fabric for military clothing, regarding the exposure to microbial influences, is the ability of body protection and control of microorganisms. Therefore, the question is whether and to what extent military fabrics have microbial barrier properties.

The subject of this research is fabrics designed for certain specific purposes, with high requirements for the human body protection, in order to preserve mental and physical health. The use of fabrics for military purposes in real application conditions (in various areas of habitation and activity) represents indispensable exposure to a possible microbial contaminated environment and thus a danger of microorganism's penetration and body contamination. The reason for this is the fabric ability to retain moisture, which represents a possible cause of endangering the health of an individual. Textile materials are in constant contact with microorganisms, not only from skin but also from the environment. Textile material is a media that supports the microorganism's growth and development, because it provides them an environment rich in nutrients necessary for their survival (moist air or wet textile product). Microorganisms are fed with skin cells and various substances used in chemical finishing processes (and also dirt) [5–8]. The growth of microbes implies increasing their cells, but also increasing their number after multiplication, resulting in colony formation. Microorganism's growth and development depend on many factors, both physical and chemical, as well as about the environment in which they are located. Methods of microbial transmission are different, through direct and indirect contact with contaminated surfaces, contaminated environment (water) and even non-hygienic conditions [9]. In order to provide maximum body protection from microorganism penetration in real application conditions, the fabric should have sufficient microbial barrier properties.

2 Materials and Methods

The fabrics used in this research are designed and produced for military purposes in tt. Čateks, Croatia. The fabric samples contain equal ratios of natural and synthetic fibres (cotton/PA 6.6 and cotton/PES), with mass per unit areas from 220 to 280 g/m^2, and woven in different weaves (Fig. 1). After weaving process, the fabrics were subjected to dyeing process, using reductive dyes to print camouflage patterns ("forest" and "desert" patterns) depending on the fabric end-use conditions. To achieve the needed properties, the fabrics were treated with protective coatings of water and oil repellents, which, together with the properties achieved by the fabric structural parameters, provides exceptional characteristics of strength, durability, comfort and stability.

The relevant structural parameters of woven fabrics were determined in accordance with the standardized testing methods, based on which further analysis was carried out:

- mass per unit area—m (g/m^2)—determination of mass per unit length and mass per unit area, in accordance with the standard HRN ISO 3801:2003,
- fabric thickness—t (mm)—determination of thickness of textiles and textile products, in accordance with the standard HRN EN ISO 5084:2003,
- fabric density—d (threads/10 cm)—determination of the number of threads per unit length, in accordance with the standard HRN EN 1049-2-2003.

The following tests were also performed:

- determination of fabric air permeability, according to the standard HRN EN ISO 9237:2003

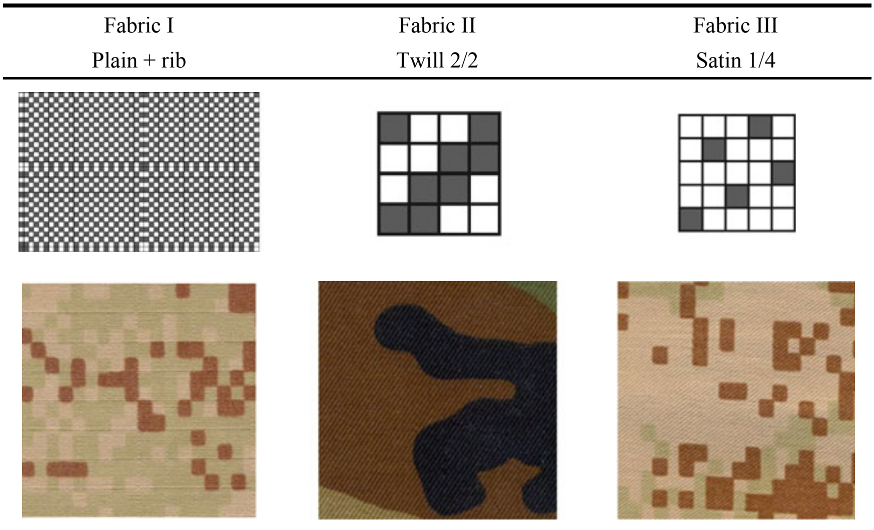

Fig. 1 Woven fabric samples used in the research

Fig. 2 Presentation of prepared samples for microbial barrier permeability testing

- determination of fabric breaking properties, according to the standard ISO 13934-1:1999
- determination of fabric thermal resistance ("hot plate"), according to the standard ISO 11092:1993
- determination of microbial barrier permeability according to the newly developed method. Tests were performed according to the following procedure: A test specimen of 22 cm × 22 cm is fixed to a ring-shaped device (Fig. 2) and placed into a transparent sterilization pouch. It is sterilized in the steam sterilizer Selectomat PL MMM (Münchener Medizin Mechanik) at 134 °C for 5 min. After the sterilization procedure under sterile conditions, the bacterial endospores of apatogenic species, in this case *Geobacillus stearothermophilus* 10^5 and *Bacillus atrophaeus* 10^6, are applied to the test area of the specimen. This is followed by incubation for 24 h. Afterwards, a CT3P agar print plate is used to take prints, first from the face side and afterwards from the back side. After taking prints, CT3P agar print plates are placed into a thermostat at 35 °C in order to perform incubation for 72 h, after which the number of bacterial colonies on the face and back sides of the fabric is read [10, 11].

3 Experimental and Results

The materials used in this paper are woven fabrics which are mainly used for the purpose of military clothing. The materials are composed of natural and synthetic fibres blends (cotton and PA 6.6, cotton and PES, in equal proportions of 50%) with a nominal yarn finesses (Tt) shown in Table 1. The natural fibre component provides comfort and flexibility, while the synthetic fibre component provides strength and resistance properties necessary for final application.

The basic structural parameters of tested woven fabric samples are shown in Table 1.

The difference of PA 6.6 and PES fibre properties, in a certain part, affects the yarn properties and thus the properties of finished woven fabrics. The values of standard

Table 1 Fabric structural parameters

Properties	Fabric I		Fabric II		Fabric III	
	Warp	Weft	Warp	Weft	Warp	Weft
Raw material	PA 6.6/cotton 50%/50%		PES/cotton 50%/50%		PA 6.6/cotton 50%/50%	
m (g/m^2)	220		250		280	
t (mm)	0.436		0.439		0.557	
Tt (tex)	17 × 2	40	20 × 2	20 × 2	30	50
d (thread/10 cm)	360	207	362	210	467	291

m—fabric mass per unit area (g/m^2), t—fabric thickness (mm), Tt—yarn finesses (tex), d—fabric density (thread/10 cm)

Table 2 Tested results of fabric breaking properties, thermal resistance and air permeability

Woven fabric properties		Fabric I		Fabric II		Fabric III	
		$\bar{x}$	CV (%)	$\bar{x}$	CV (%)	$\bar{x}$	CV (%)
F (N)	Warp	691.37	3.55	774.73	2.19	777.99	2.55
	Weft	441.30	2.22	500.14	1.96	845.01	5.00
ε (%)	Warp	43.17	5.47	18.67	5.58	32.33	6.25
	Weft	22.50	3.71	17.00	2.94	35.67	5.67
R_{et} (m^2 kW^{-1})		0.0185	3.9	0.0203	2.0	0.0127	1.3
R (mm/s)		22.244	4.2	35.972	6.3	10.220	4.6

F—breaking force (N), ε—elongation at break (%), R_{et}—thermal resistance (m^2 kW^{-1}), R—air permeability (mm/s), $\bar{x}$—mean value, CV—coefficient of variation (%)

strength range from 30 to 68 cN/tex for PA 6.6 and from 25 to 55 cN/tex for PES fibres. Apart from the raw material that carries the basic characteristics of the yarn, many other parameters, such as yarn structure and the fabric construction (density and weave), have an influence on the final woven fabric properties. The results of breaking properties, as well as thermal resistance and air permeability properties of tested fabric, are shown in Table 2.

Thermal resistance property of woven fabric used for military clothing is of utmost importance, regarding the extreme application conditions, where the influence of the environment (coldness in the winter and the heat in the summer days) affects the psychophysical condition of a person wearing a certain fabric. The results of tested woven fabrics show that the highest thermal resistance has Fabric II, with value of 0.0203 m^2 KW^{-1}, which is woven in a twill 2/2 weave with two-ply yarns (with more closed structure), preventing heat transfer through the yarn (Table 2). This means that such fabric has better properties of heat retention near the body, which is suitable for application during colder periods. Conversely, Fabric III shows the lowest thermal resistance with 0.0127 m^2 KW^{-1}, despite the fabric highest mass per unit area. The reason for this can be found in the structural characteristics of the fabric, which is woven with one-ply yarns, whose structure is more open and thus more susceptible to heat penetration. Furthermore, this Fabric III is woven in satin weave characterized by strong flotation, which additionally provides easier heat penetration between the threads.

Analysing the results of the air permeability tests (Table 2), it can be concluded that the structural parameters of the fabric, as well as the applied apertures, have influenced the low air permeability of the tested samples. The obtained results diametrically follow the thermal resistance values, where Fabric II provides the highest values of air permeability (35.972 mm/s) and Fabric III the lowest values (10.220 mm/s). This can be explained by structural parameters of Fabric III, i.e. in highest density of the warp and weft threads, which with its compactness affects the fabric cover and porosity, thus making the air transfer through such woven structure difficult.

The results of microorganism permeability through the fabric structure testing, carried out according to the newly developed method, are shown in Table 3. It is important to note that all tested samples were equally contaminated, with the same number of microorganisms (10^5 *Geobacillus stearothermophilus* and 10^6 *Bacillus atrophaeus*) applied on the face side of the fabrics. An interesting indication is that the number of microorganisms transmitted from the biological indicator to the face of the fabric differs significantly between the tested samples. This is caused by the fabric surface, conditioned by the fabric structural parameters and the applied apertures. Fabric III, woven in Satin weave (with a large flotations and a rare thread interlacing) retain on face side 992 CFU, Fabric II 540 CFU (45.6% less than Fabric III) and Fabric I (with the most frequent threads interlacing) even 82.5% less than Fabric III, only 174 CFUs. Despite the largest number of bacterial colonies on the face side of Fabric III, not one microorganism has passed through fabric to the back side, which shows its exceptional microbial barrier properties (Fig. 3). Furthermore, the remaining two samples, Fabric I and Fabric II, with a minimum number of only 1 CFU on the back side of fabrics, prove good fabric properties of microbial barrier permeability.

By analysing the ratio of applied and passed through CFUs from face to back sides of the fabrics, it can be concluded that there is a significant difference between Fabric I and Fabric II. The ratio of CFU on the face side and back side of Fabric II is 540:1, whereas this ratio in Fabric I is 174:1. Above mentioned shows that for the transition of 1 CFU on the back side of the Fabric I is required 174 CFU applied

Table 3 Results of microbial barrier permeability of tested fabrics after extreme contamination

Sample	The average number of bacterial colonies on the fabric face side (CFU)	The average number of bacterial colonies on the fabric back side (CFU)	Ratio (CFU)
Fabric I	174	1	174:1
Fabric II	540	1	540:1
Fabric III	992	0	–

CFU Colony-forming unit

Fig. 3 Display of CT3P agar plate on the face and back sides of tested sample Fabric III

Table 4 Values of correlation coefficient of some significant fabric parameters

	d_{warp} (thread/10 cm)	d_{weft} (thread/10 cm)	t (mm)	R (mm/s)	R_{et} (m^2 KW^{-1})	CPU
CPU	−0.75819	−0.76798	−0.76170	0.27867	0.57745	1
R_{et} (m^2 KW^{-1})	−0.97015	−0.96637	−0.96883	0.94500	1	
R (mm/s)	−0.83749	−0.82912	−0.83453	1		
t (mm)	0.99999	0.99995	1			

on face side; while in Fabric II, the required amount of applied bacterial colonies is three times higher. This points to the conclusion that Fabric II has a better microbial barrier property, which can, once again, be explained by the fabric weave, regarding the approximately uniform structural fabric parameters. The twill 2/2 weave does not have abrupt or irregular thread interlacing, but the warp and weft threads are lined in identical proportions, with slight gradual shift, without any major bending. In contrast, the weaves with the most frequent interlacing and transitions from the face to the back sides of the fabric in a specific pattern (plain, rib) define more pronounced pores, allowing easier penetration of microorganisms through the fabric.

Correlation analysis was used to discover the degree of correlation between tested parameters, and the most interesting correlations, based on which significant conclusions were drawn, are presented in Table 4.

The air permeability property shows a very good correlation with the fabric thickness parameter ($r = -0.83453$), which is directly influenced by the fabric density, i.e. the density of warp and weft threads.

Statistical analysis of correlation indicators shows a strong dependent relation of thermal resistance property with the fabric thickness parameter ($r = -0.96883$). The results also show a strong correlation of thermal resistance with air permeability property ($r = 0.94500$), where the increase of air permeability (caused by decrease of fabric thickness) affects the increase of fabric thermal resistance, i.e. the ability of fabric heat retaining near the body.

Placing into correlation relations, the microbial barrier fabric properties with the fabric structural parameters indicate weaker correlation connections, which are still classified as good correlation ($r = -0.76170$). This is understandable considering that the microbe penetration is performed in a dry state, i.e. by mechanical penetration, which is affected by the fabric thickness parameter and thus the fabric density. Air permeability and thermal resistance properties are in poor correlation with the fabric microbial barrier property. The reason for this is, already mentioned, complex structural aspect of woven fabric, i.e. the constructional parameters and specific weave. The way of interlacing of warp and weft threads, which affects the fabric cover and compactness, as well as the pores structure, greatly influences the ability of adhesion and transition of microorganisms through the fabric.

All of the above findings are of utmost importance for the design process of woven fabric for specific purposes, which enable defining and achievement of the desired fabric properties depending on the end use, i.e. application conditions.

4 Conclusion

Based on the conducted research, it can be concluded that all of the relevant military fabric properties, including the microbial barrier property, are greatly affected, besides finishing processes, by the fabric structural parameters. The analysis of the obtained results and the analysis of correlations between some relevant properties confirm the extremely complex structural aspect of the woven fabrics. Tested fabrics for military purposes show very good microbial barrier properties, with the indicated differences, based on which can be approached to further targeted functional designing of specific elements.

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References

1. Wilusz, E.: Military textiles. Woodhead Publishing Limited, Cambridge, England (2008)
2. Sparks, E.: Advances in military textiles and personal equipment. Woodhead Publishing Limited, Cambridge, England (2012)
3. Winterhalter, C.A., Lomba, R.A., Tucker, D.W., Martin, O.D.: Novel approach to soldier flame protection. J. ASTM Int. **2**(2), 227–232 (2005)
4. Mijović, B., Skenderi, Z., Salopek, I.: Comparison of subjective and objective measurement of sweat transfer rate. Coll. Antropol. **33**(2), 315–320 (2009)
5. Thiry, M.C.: Prescription textile protection. AATCC Rev. **10**, 30–36 (2010)
6. Teufel, L., Redl, B.: Improved methods for the investigation of the interaction between textiles and microorganisms. Lenzing. Ber. **85**, 54–60 (2006)

7. Beck, W.C., Carlson, W.W.: Aseptic barriers. Arch. Surg. **112**(2), 2240–2244 (1981)
8. Borkow, G., Gabbay, J.: Biocidal textiles can help fight nosocomial infections. Med. Hypotheses **70**, 990–994 (2008)
9. Duraković, S.: Opća mikrobiologija. Prehrambeno-tehnološki inženjering, Zagreb (1996)
10. Rogina-Car, B., Budimir, A., Katović, D.: Microbial barrier properties of healthcare professional uniforms. Text. Res. J. **87**(15), 1860–1868 (2017)
11. Rogina-Car, B., Budimir, A., Turčić, V., Katović, D.: Do multi-use cellulosic textiles provide safe protection against the contamination of sterilized items? Cellulose **21**(3), 2101–2109 (2014)

Development of Thermal Insulative Nonwoven Fabric Through Advance Material Application

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Abstract In recent years, as a sway of high pace development in science and technology, people tend to have more aptitude towards using clothing for new functions, which ultimately contributes to opening of opportunities for further development and incorporation of new technologies along with novel materials. In this context, textiles are of fast decalescence or fast heat radiation media as far as comfort accountability of textile articles is concerned. The structure and texture of textiles play a very vital role in determining the thermal comfort level of the human body; hence, people need to obtain various advantages of the functional material design in order to improve the heat–moisture balance of textiles. Thermal comfort depends on the extent to which the clothing influences heat and moisture transport between the human body and environment. In order to come up with solution for this, the use of silica aerogels gains extreme attention due to their surprising properties and their existing potential applications in a wide of variety technological areas. Aerogel basically exhibits nanostructure which offers high porosity, high specific surface area, low density and outstanding heat insulation properties. This paper emphasis on development of thermal insulative PET nonwoven fabric with the application of silica aerogel which gives excellent thermal insulation with reduced bulk and weight which are generally enforced to insulative textile materials to induce functionality. Findings are supported by various analyses and testings followed by STATISTICA 6 software for ensuring statistical significance of all parameters. The developed product shows the potential to be used at various technical textile product ranges.

Keywords Silica gel · Thermal insulation · Nonwoven fabric

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1 Introduction

On sway of development in science and technology, people have increasing requirements on uses of clothing for new functions, which ultimately going to contribute towards release of new opportunities for further development and incorporation of new materials and technologies in the recent years. In the aspect of the comfort textiles, we hope that the textiles are of fast decalescence or fast heat radiation. The microstructure and texture of textiles play a very important role in determining the heat–moisture comfort level of the human body. Fabric, especially in cold environment, is designed to keep the body in its critical internal temperature by offering a specific rate of heat loss and works as a thermal barrier. Heat transfer through the textile occurred due to the mechanism of radiation, convection and conduction. Most of the methods for the determination of heat transfer through textile take into account all the three mechanisms as a whole. Considerable studies on heat and moisture transfer through woven and knitted fabrics structure have been conducted over the year [1–3]. In cold atmosphere, human body loses substantial amount of the heat through fabric, which is mostly attributed to conduction mode of heat transfer than other two modes viz. convective and radiative [4]. Designing lower thermal conductive fabrics involves the use of different fibre types, constructional parameters, special finishing and other techniques like membrane and composite [5]. In case of high-loft textile structures, method of incorporating hollow fibres has well established itself; which is practised for high-altitude clothing too. The study made by Yoshihiro et al. (2008) related to use of composite fabric/resin material to further reduce the thermal conductivity. Another way to achieve this is to make composite of fabric with the use of low thermal conductive material such as inorganic nanoporous silica sols.

Textiles material is discontinuous materials; in that, they are produced from macroscopic sub-elements (finite length fibres or continuous filaments). The discrete nature of textile fabric is generally a porous media that comprises two phases: solid (consisting of solid fibres) and gas (consisting of water vapour and dry air) that contribute directly to some of the transportation properties of the textiles, for example, thermal insulating characteristics, liquid absorption properties, softness and other tactile characteristics. Clothing functionality and performance have been a major concern over the years. Clothing combines both the functions: it acts as a barrier to the outside environment, and at the same time, it is the transporter of heat and moisture from the body to the surrounding environment; hence, it is essential to keep thermal balance between heat production and heat loss by maintaining transport of heat and moisture through the human–clothing–environment system [6]. The impact of clothing on thermal comfort depends on the extent to which the clothing influences heat and moisture transport between the human body and surrounding environment [7]. Fabric can be designed to render a specific rate of loss of insensible perspiration for assisting the skin in conserving essential levels of body fluids. Specific rates of heat loss are essential to keep the body at its critical internal temperature in a cold environment, so understanding of heat and mass flow through textile material becomes necessary. Now a days, there are many techniques used to design fabrics