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Microbial barrier permeability and thermophysiological and mechanical properties of static dissipative woven fabric system

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Abstract. Some of the most significant properties of static dissipative woven fabric systems, in applications where contact of textile material and human body is present, beside antistatic properties are definitely microbial barrier permeability and thermophysiological properties. Application of such materials with associated properties is of great importance in bedding upholstery and comfortable apparel. Based on the conducted relevant tests, according to standardized and newly developed methods, it can be concluded that the such static dissipative woven fabric fulfils all the highly set criteria's, resulting in a system that can, with certainty, provide the necessary health protection and comfort.

1. Introduction

Antistatic protection and control of static electricity is important and necessary parameter in a wide range of applications. Static electricity occurs, when two surfaces separate, and both surfaces become charged with an electrical static charge. A static discharge can cause discomfort, serious personal injury or major industrial damage. To provide control or elimination of static electricity and thereby to provide protection against a range of risks and hazards, conducting yarns are used as interwoven part of textile materials [1].

Such yarn that represents a new standard in static dissipative systems is Nega-Stat®, to provide optimum antistatic protection in grounded and ungrounded applications according to end-use specifications. Nega-Stat® P190 is a fine filament bi-component core yarn, with triobal shaped conducting core surrounded by a sheath of Polyester (Figure 1).

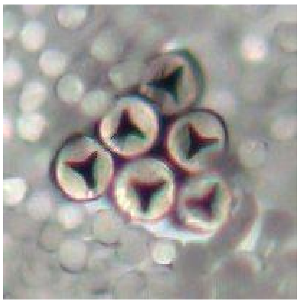

Figure 1. Overview of the Nega-Stat® yarn cross section using a SEM

Trilobal conducting core provides the outstanding static dissipative performance, while outer sheath of polyester provides exceptional durability to wear, washing, sterilization and chemical attack. It neutralizes the surface charges on the base material by induction and dissipates the charge by conduction when grounded or ungrounded by air-ionization, referred to as corona discharge. Whilst other conducting yarns work by conducting electric charges along the surface of the yarn, this yarn works by inducing the surface charge into its unique trilobal conducting core, which attracts the electric field from the surface of the fabric and neutralizes all the free charge on the surface of the material. As a result, the surface charge can be reduced to zero volts (Figure 2). Such fabrics provides static control according to specific industrial requirements and international Standards such as EN 61340, EN 1149/5 etc., and meets all requirements according to OekoTex 100 and REACH requirements for harmful substances [2].

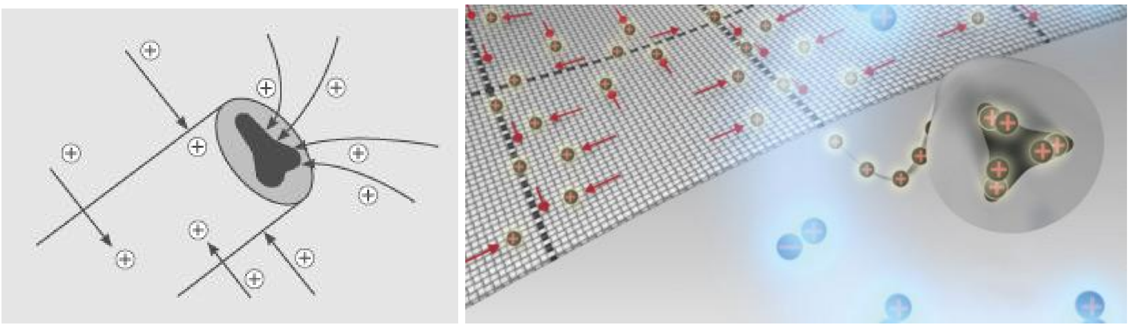

Figure 2. Mode of functioning of Nega-Stat® yarn [2]

Woven fabric with static dissipative yarns can be used in wide range of applications, like: bedding upholstery - to achieve neutralization of body level, comfortable apparel (lingerie, outerwear, sportswear) - to achieve comfort and relaxation, automotive upholstery - to achieve body voltage control, protective garment (clean areas, paint-shops, industrial work-wear, medical clothing, operating gowns, food processing) - for prevention of incendiary discharges, industry (container bags, conveyor belts, filters) - for elimination of explosion risk, etc [2].

As mentioned before, static dissipative woven fabric system have an important role in application where the direct contact of material and skin is present, whereby the microbial barrier permeability and comfort properties are of extreme importance. The features of thermophysiological properties and microbial barrier permeability can be an important factor that affects the use of fabric. Comfort and security of textiles for a specific application as well as type and level of activity and environmental condition is mainly determined by the type of raw material, yarn and fabric structure.

Application of such materials with associated properties is of great importance in bedding upholstery. A person in bed can generate a body voltage by movement of between 10 000 V up to 20 000 V. It is known that high and varying levels of body voltage can effect sleep patterns. Static dissipative woven fabric reduce the voltage to a body neutral level, which can benefit sleeping behaviour.

Application is also significant in the field of comfortable and protective apparel, in terms of achieving comfort and relaxation, but at the same time security (lingerie, outerwear, sportswear, medical clothing, operating gowns, clothing in food processing). Clothing made in wholly or partly from synthetic materials which is in direct contact with the skin can generate static electricity, whose quantity depends on the garment design, particularly tide fitting garments, can cling to the body and cause discomfort. Antistatic yarn interwoven into the fabric can eliminate the clinging effect and provides comfort and relaxation to the wearer [2].

2. Experimental and results

The material observed in this research is static dissipative fabric system, in raw and finished state. Fabric was produced in tt. Čateks d.d. Croatia, and was woven from three components - PES/cotton warp and two kinds of weft: main PES/cotton weft and antistatic Nega-Stat® yarn as second weft.

The fabric was woven in twill 2/2 weave, with selectively interwoven yarn with Nega-Stat®, in stripe pattern, as every third weft (Figure 3), to provide effective static dissipation for the life of the material. After weaving process the produced fabric was dyed with vat dyes and finished with a variety of protective finishing treatments: waterproofness, water repellency, oil repellency, resistance to infrared light, UV radiation, heat, fire, soiling, anti-static treatment, etc. [3].

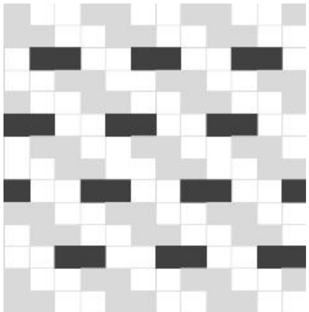

Figure 3. Weave structure of static dissipative woven fabric system

To test the yarn and fabric samples, standardised methods were used. Determination of yarn linear density was tested according to ISO 2060:2003, and yarn hairiness was tested on the basis of registering fibres protruding from the yarn structure according to ASTM D 5674-01 on a Zweigle G 565 tester. Yarn twist was tested on a MesdanLab Twist tester according to Standard ISO 17202, while breaking properties (breaking force, breaking elongation, work to rupture and yarn tensile strength) of the yarn were tested according to Standard ISO 2062 on a Textechno Statimat M tensile tester.

The fabric density or number of threads per length unit was determined according to Standard EN 1049-2:1993, and determination of the mass per unit area was performed according to Standard ISO 3801:1977. The breaking force and breaking elongation of the fabrics before and after all treatments was tested on a Textechno Statimat M tensile tester according to Standard ISO 13934-1:1999, in both warp and weft direction.

Important properties of static dissipative woven fabric, especially for bedding upholstery and comfortable apparel applications, along mechanical breaking properties, are thermophysiological properties and microbial barrier permeability. Therefore, such tests are also conducted.

Microbial barrier permeability of dry woven fabric was determinated according to newly developed method, described in Figure 4. Textile samples were prepared by fixing them on an O-ring device and then placed in transparent packaging. The packaged samples were subsequently exposed to sterilization at 134 ºC for 5 min, after which the packaging was opened in a sterile environment to prevent contamination. In aseptic conditions, the spores were rubbed in equal motions on the front side of the tested samples. The procedure was then repeated in the same order with the biological indicator stick reversed. A print was taken using a CT3P agar print plate (bioMe´rieux SA, Marcy I'Etoile, France), first from the back side, and then the front side, with a new plate. Agar plates were incubated for 72 h at 35 ºC, after which colony forming units (CFUs) were counted.

Bacterial spores of the Bacillus genus *Geobacillus stearothermophilus* 10^5 (ATCC 12980, DSM 22) and *Bacillus atrophaeus* 10^6 (ATCC 49337, DSM 7264) were used as their primary purpose is to serve as a biological sterilization control. This work was specific because of the use of spores, which can survive in a dry environment, while suspensions of various types of microorganisms were used in similar evaluations. The use of a suspension moistens the fabric and the permeability is changed [4, 5].

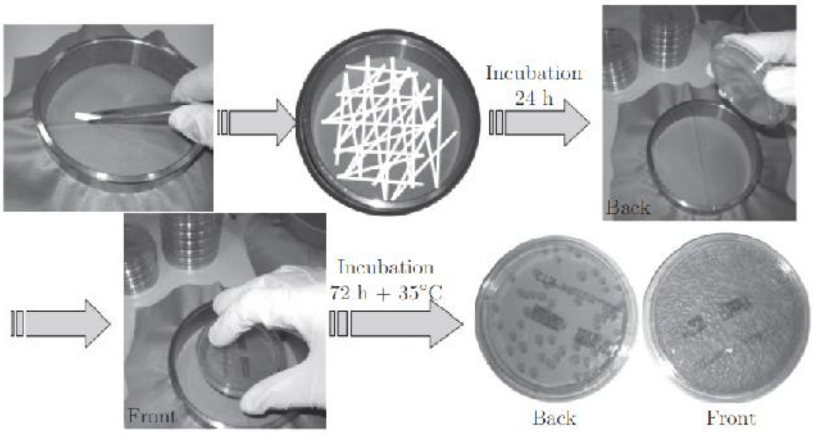

Figure 4. Schematic representation of testing microbial barrier permeability [4]

Thermophysiological properties (comfort) were determinate by measuring water-vapour resistance under steady-state conditions, using the Sweating Guarded Hot Plate (SGHP) equipment (Figure 5). A SGHP simulates the moisture transport through textiles and clothing assemblies worn next to the human skin, regarding it measures the water vapour resistance of the textile fabrics by measuring the evaporative heat loss in the steady state condition [6, 7]. The temperature of the guarded hot plate is set and kept at 35 °C respectively the temperature of the human skin and the air is ducted to flow across and parallel to the upper surface of heated plate with constant speed of 1 m/s. During testing the metal plate is covered by water vapour permeable and liquid impermeable membrane. The water-vapour resistance is measured after the steady-state conditions have been reached [8]. The test condition for measuring water vapour resistance is the standard atmospheric condition for testing; 65 % of relative humidity and 20 °C of ambient temperature

The water vapour resistance of the fabric (Ret) may be calculated according to ISO 11092 standard as it follows [9]:

$$R_{\text{et}} = \frac{\left(p_m - p_a\right) \cdot A}{H - \Delta H_e} - R_{\text{et},0} \quad (1)$$

where: Ret is the water-vapour resistance in m^2 Pa W-1, pm is the saturation of water-vapour partial pressure in Pa at the surface of the measuring unit at temperature Tm in °C, pa is the water-vapour partial pressure in Pa of the air in the test enclosure at Ta °C, A is the area of the measuring unit in m^2, H is the heating power supplied to the measuring unit in W, ΔHe is the correction term for the heating power in W, and Ret,0 is the bare plate evaporative resistance in m^2 Pa W-1.

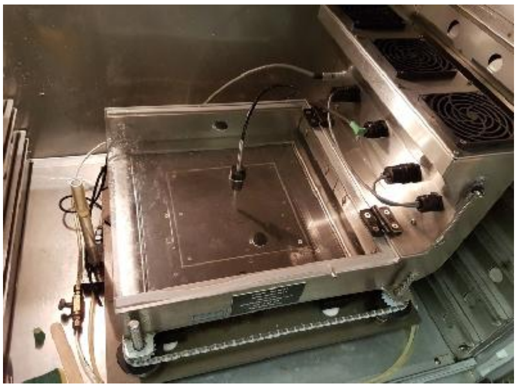

Figure 5. Sweating guarded hot plate, Measurement Technology Northwest

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3. Results and discussion

Tested parameters of yarns used for weaving static dissipative fabric are shown in Table 1. Interesting data that are evident from the table are the exceptional properties of anti-static yarn, which despite its low linear density has extraordinary breaking properties.

Table 1. Basic yarn parameters.

Properties		Warp	Weft	
			Weft 1	Weft 2
Yarn composition		50% PES / 50% cotton	50% PES / 50% cotton	86% PES / 14% Nega-Stat® (39dtex, f6)
Tt, tex		40 (20x2)	20	28
T , m^{-1}		600	800	470
H, No. of protruding fibres		375.60	1 394.40	598.60
F, cN	$\bar{x}$	938.97	325.50	931.54
	CV, %	4.48	7.75	5.86
ε, %	$\bar{x}$	9.77	6.98	13.39
	CV, %	4.80	9.75	4.76
W, cN cm	$\bar{x}$	2 366.48	658.02	2 902.64
	CV, %	9.57	17.64	10.53
σ, cN tex^{-1}	$\bar{x}$	23.42	16.27	33.27
	CV, %	4.48	7.57	5.86

where: Tt is the yarn unevenness in tex; T is number of twist per 1 m in m^{-1}; H is number of protruding fibres; F is the breaking force in cN; ε is breaking elongation in %; W is work to rupture in cN cm; σ is tenacity in cN tex^{-1}; $\bar{x}$ is mean value; CV is standard deviation.

Results obtained by testing show that finishing process have influence on fabric properties, but not in terms of negative influence on the relevant fabric properties. Mass per unit area has increase for just 2.3%, what is actually negligible. As opposed to that, fabric thickness decreased for even 25%. This reduction did not negatively affected the other physical-mechanical properties, but has contributed to better palpable features in terms of application. Furthermore, thickness decrease of finished fabric did not affect water-vapour resistance i.e. comfort properties, neither microbial barrier permeability.

The conducted tests of breaking properties, for raw and finished fabrics, shows significantly better results in warp then in weft directions because of the higher density of warp threads. Results also show that tested breaking properties of finished woven fabric are better than of the raw one. It is interesting that after all finishing treatments, significant increase of tested parameters are present in warp direction and just minimum increase in weft direction of woven fabric: breaking force (F) and tenacity (σ) increased in warp direction for 14% and just 3% in weft direction, while work to rapture (W) increased for 33% in warp and just 6% in weft directions. Concerning elongation at break (ε), the situation is much different. The significant increase in finished woven fabric is present in weft direction, by as much as 19%, and just 5% in warp direction.

Table 2. Physical-mechanical and thermophysiological properties and microbial barrier permeability of static dissipative woven fabric.

Properties		Raw woven fabric		Finished woven fabric	
		Warp	**Weft**	**Warp**	**Weft**
d, threads/10cm		36	26	36	26
t, mm		0.468		0.351	
m, g m^{-2}		218.48		223.55	
F	$\bar{x}$, N	1 428.88	572.53	1 626.30	591.02
	CV, %	4.91	2.45	5.11	1.96
	SD, N	70.11	14.03	93.08	11.56
ε	$\bar{x}$, %	18.53	14.80	19.46	17.62
	CV, %	16.36	3.12	7.06	2.29
	SD, %	3.03	0.46	1.37	0.40
W	$\bar{x}$, cN cm	206 211.80	81 637.91	274 112.30	86 285.17
	CV, %	19.33	4.67	14.60	4.68
	SD, cN cm	39 861.24	3 810.41	40 013.34	4 042.08
σ	$\bar{x}$, cN tex^{-1}	714.44	286.26	813.15	295.51
	CV, %	4.91	2.45	5.11	1.96
	SD, cN tex^{-1}	35.06	7.01	41.54	5.78
R_{et}	$\bar{x}$, m^2 Pa W^{-1}	5.57		4.73	
	CV, %	10.25		1.76	
	SD, m^2 Pa W^{-1}	0.57		0.08	
CFU	Mean, -	4		3	
	SD (range), -	1.3 (3-6)		1.5 (1-5)	

where: d is the fabric density in threads/10cm; t is fabric thickness in mm; m is mass per unit area in g m^{-2}, F is breaking force in N; ε is breaking elongation in %; W is work to rupture in cN cm; σ is tenacity in cN tex^{-1}; R_{et} is water-vapour resistance in m^2 Pa W^{-1}; CFU is colony forming unit; $\bar{x}$ is mean value; SD is standard deviation; CV is standard deviation.

The mean values of water vapour resistance (R_{et}) of raw woven fabric is 5.57 m^2 Pa W^{-1} and finished woven fabric 4.73 m^2 Pa W^{-1} (Table 2). According to the literature and from the physiological point of view, a textile material has to be judged the better the lower its water vapour resistance is. A lower water vapour resistance is the better the possible evaporation of moisture (sweat) from the wearer's or sleeper's body. The textile having the water vapour resistance up to 5 m^2 Pa W^{-1} is, according to the literature, a material with very good physiological properties [10, 11]. It can be concluded that the static dissipative woven fabric before and after finishing have very good physiological properties and thus great wearing and feeling comfort.

Based on the conducted tests of microbial barrier permeability, it can be concluded that this static dissipative woven fabric, with a minimum number of colony formed bacteria, has exceptional properties.

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4. Conclusion

Static dissipative woven fabric are system with mail role of antistatic protection and control of static electricity that can occur between textile material and human body. A static discharge that may occur can cause discomfort or serious health injuries. For such textile materials, which are in direct and tight contact with skin, beside antistatic properties, other features, like thermophysiological properties and microbial barrier permeability are also of paramount importance. Tested static dissipative woven fabric with interwoven Nega-Stat® yarn, fulfils all the highly set criteria's, resulting in a system that can, with certainty, provide the necessary health protection and comfort in terms of listed applications.

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