ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

DEFORMATION BEHAVIOR OF CONDUCTIVE TEXTILE FABRICS

GROSU Marian-Cătălin[1], VISILEANU Emilia[2], POPESCU Georgeta[3], Rădulescu Ion-Răzvan[4]

[1, 2, 3, 4] The National Research & Development Institute for Textiles & Leather, 16, Lucretiu Patrascanu, 030508, Bucharest, Romania, catalin.grosu@incdtp.ro, e.visileanu@incdtp.ro, georgeta.popescu@incdtp.ro, razvan.radulescu@incdtp.ro

Corresponding author: Grosu Marian-Cătălin, catalin.grosu@incdtp.ro

Abstract: *Conductive textiles play a key role in making highly specialized clothing. While clothing made of conductive fabrics can experience mechanical stress during wearing, this paper presents a comparative study of the deformation behaviour of two conductive fabrics (knitted and woven fabrics). Based on the physical and mechanical tests and analysis, we calculated the anisotropy and Young modulus for both fabrics and also we simulated their wearing behaviour of them using a pattern design software (PDS) from OPTITEX.*
Both values were compared with the bending behaviour simulation on a human avatar using PDS-3D. The map of the simulated bending stress reveals the high peaks at elbows, hips, knees, thoracic and armpit areas. All the highest values obtained by simulation are lower than the calculated ones, which means that at maximum stress the fabrics will not be damaged.

Keywords: *Conductive fabrics, anisotropy, stress, deformation, simulation, pattern design software*

1. INTRODUCTION

The field of conductive fabrics is rapidly evolving, and new research is being conducted to explore the use of these specialized fabrics in creating specialized clothing with high comfort [1]. These materials can conduct electricity and can be used in a wide range of applications such as wearable technology [2], smart textiles [3], electromagnetic shielding [4], and electronic devices [5]. Researchers are exploring new materials and techniques for incorporating conductive materials into fabrics that are comfortable to wear for extended periods, and that can withstand stretching, bending, and washing without losing their conductivity or other properties [6]. As these technologies continue to evolve, we can expect to see more and more specialized clothing that takes advantage of the benefits of conductive fabrics. Conductive fabrics are fabrics that have been specially designed to conduct electricity, often using metallic fibers or coatings [7, 8].

Clothing made of conductive fabrics can experience mechanical stress during wearing, which can impact the electrical properties of the fabric. The wearing behavior of conductive fabrics depends on several factors, including the type of fibers or coatings used, the weave of the fabric, and the intended application [9]. In general, conductive fabrics can be quite durable and resistant to wear and tear, especially when compared to traditional fabrics. However, they can still experience some wear over time, especially if they are subjected to frequent use or stress [10]. One potential issue with conductive fabrics is that the conductive content can become damaged or degraded over time, leading to a loss of conductivity or other performance issues. This can happen due to factors such as exposure to moisture, high temperatures, or mechanical stress [11]. To minimize wear and tear on conductive fabrics, it is important to follow the manufacturer's guidelines for care and maintenance [12, 13]. Understanding the mechanical behavior of conductive fabrics is important for designing and engineering wearable electronics and smart textiles, where the fabrics are often subjected to a range of mechanical deformations during use [14].

Thus, in this paper, the mechanical behavior of two textile structures is presented and evaluated: a woven and a knitted structure, intended for professional underwear. Both structures have conductive textile threads in their composition. For the accuracy of the results, the values of the mechanical characteristics, obtained following the requests of the conductive textile materials, were compared with the simulation results with the Pattern Design Software (PDS) from OPTITEX.

2. MATERIALS AND METHOD

For the experiments, two different types of conductive textile yarns, with linear resistance of close values, were used, with the help of which two plain textile structures (woven and knitted fabrics), through classic/conventional technologies within INCDTP Bucharest.

The SEM and EDS analyses of the wires were carried out on the Auriga model workstation produced by Carl Zeiss SMT Germany FESEM FIB with field emission source with Gemini column for the electron beam. The SESI secondary electron detector of the Everhart Thomley type with the Faraday cup in the sample chamber was used at the acceleration voltage of 5 kV for sample visualization and 10 kV for EDS spectroscopy, as well as the energy dispersive spectrometer model X-MaxN with the acquisition software and Aztec processing.

The physical-mechanical characteristics of the analyzed textile structures highlighted: breaking force (N) and elongation at break (%), tear resistance (N), resistance to deformation (kPa), and deformation. Young's formula was applied to calculate the modulus of elasticity (N/cm^2). With these data, the anisotropy was calculated for the two structures.

For the simulation of the mechanical behaviour in dynamic conditions of the analyzed conductive textile structures, Optitex PDS was used, a 3D design/modelling/simulation software of personalized clothing items using human avatars and virtual models. Any change in the pattern size table is automatically transferred to the 3D virtual model.

3. RESULTS AND DISCUSSIONS

Table 1 shows the main characteristics of the conductive yarns used to make textile structures.

Aspects of the longitudinal sections of the yarns and the EDX diagrams highlight the main compositional specific elements (see. Fig. 1).

Table 1: Conductive yarns characteristics

No.	Type of conductive yarn	Fineness, dtex	Apparent diameter, µm	Linear electrical resistance, Ω/m
1.	INNOX/PES (aWv)	200X2	273	220
2.	STATEX Ag/PES (bKt)	296	228	200

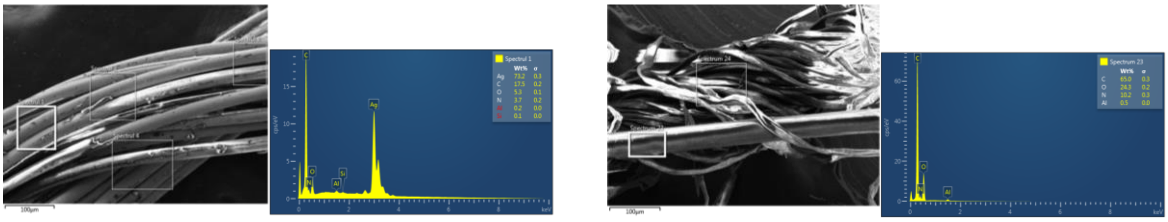

Fig. 1: SEM/EDX: a) STATEX Ag/PES yarn; b) INNOX/PES yarn

The woven structure - aWv (Fig. 2) and the knitted structure - bKt (Fig. 3) were subjected to mechanical tensile stresses, and the average values of the breaking force and elongation at break in the two orthogonal directions were recorded.

Fig.2: Woven fabric – aWv

Fig. 3: Knitted fabric - bKt

In the case of aWv, the average breaking force in the weft direction is about 37% of the average breaking force in the warp direction. In the case of bKt, the difference is smaller, the average breaking force in the horizontal direction being only ~54% of that in the vertical direction. The value of the average elongation at break, inversely proportional to the breaking force, in the case of aWv, is ~45.7% of that in the direction of the beam, while in the case of bKt, the value in the vertical direction is ~55% of that in the horizontal direction. It is found that the deformation resistance values (KPa) of bKt are ~51% lower than those of aWv, with the relative deformation values (mm) close (Table 2).

Table 2: Conductive woven and knitted fabrics.

Characteristics/Variant		aWv	bKt
Mass, g/m^2		151	115
Length of metallic yarn, cm/10 cm		10,5	35
Density, nr./10cm	H	75	280
	V	40 (metallic yarn)	46 (metallic yarn)
		50 (cotton yarn)	92 (cotton yarn)
Breaking strength, N	H	431,54	1665,81
	V	234,40	610,16
Elongation at break, %	H	94,14	32,19
	V	171,64	14,88
Thickness, mm		0,44	0,96
Deformation resistance	KPa	303,1	586,35
	mm	36,7	32,1
Tear resistance, N	H (Wa)	31,86	76,57
	V (Wf)	55,68	88,34
Water vapor permeability, %		29,9	21,5
Air permeability, l/m^2/s		307	5241

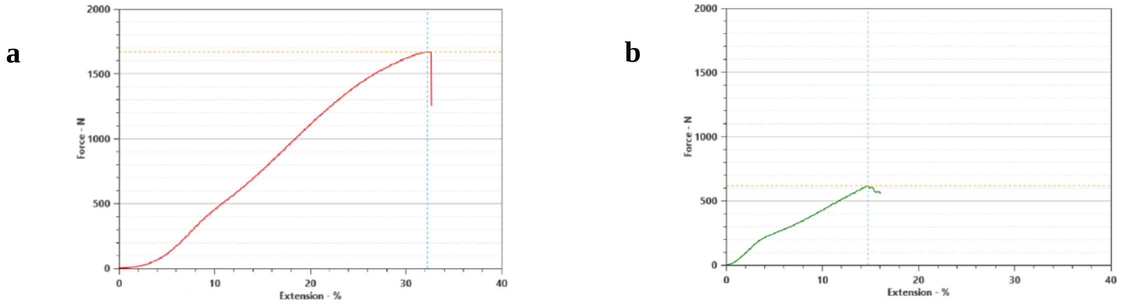

Fig. 4: Stretching behavior - aWv: a): warp direction; b): weft direction

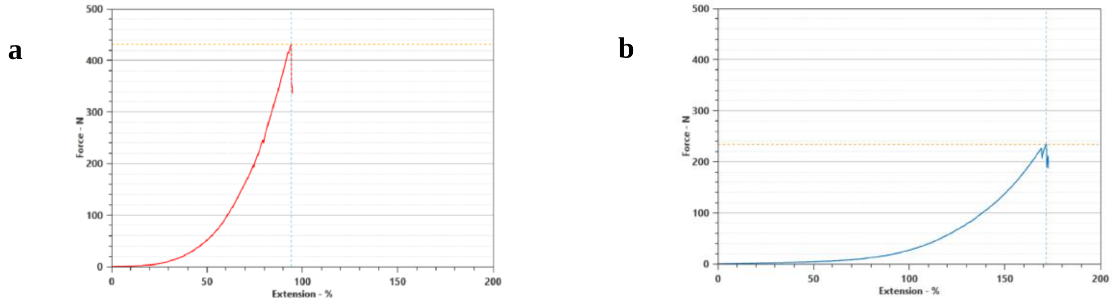

Fig. 5: Stretching behavior - bKt: a): vertical direction; b): horizontal direction

For the structures under analysis, the modulus of elasticity (Young's) was calculated as a measure of the stiffness of a material that describes the relationship between stress and strain in the material.

Table 3: Conductive woven and knitted fabrics

Variants		Force, N	L_0, cm	L_1, cm	ΔL	A, cm^2	Thickness, cm	Young modulus		Anisotropy
								N/cm^2	gf/cm	
aWv	H	200	20	20,6	0,6	202	0,044	16,6	1733,5	0,83
	V	100	20	21,0	1,0	201	0,044	20,0	2039,5	
bKt	H	80	20	21,6	11,6	204,8	0,096	0,766	77,36	2,89
	V	65	20	44,0	24	204,8	0,096	0,265	26,81	

To visualize and confirm the degree of deformation of the aWv and bKt structures during banding of the arms and legs, two comparative maps were selected: one map showing the simulated deformation in the upper area (fig 6) and one in the lower area (fig. 7). In the case of both structures, the simulation of mechanical stress during bending, on the avatar reveals areas of maximum stress in certain anatomical topographic regions:

- the cervical and thoracic area, including elbows breasts, armpits, and shoulders (upper area) (fig 6);
- the legs areas, including hips, knees, and calves (lower area) (fig. 7).

For a more accurate estimation of the stress behavior, the previously obtained values of strength and elongation of the material and approximate values for bending and shearing stress, which was estimated and selected from a proprietary database were used.

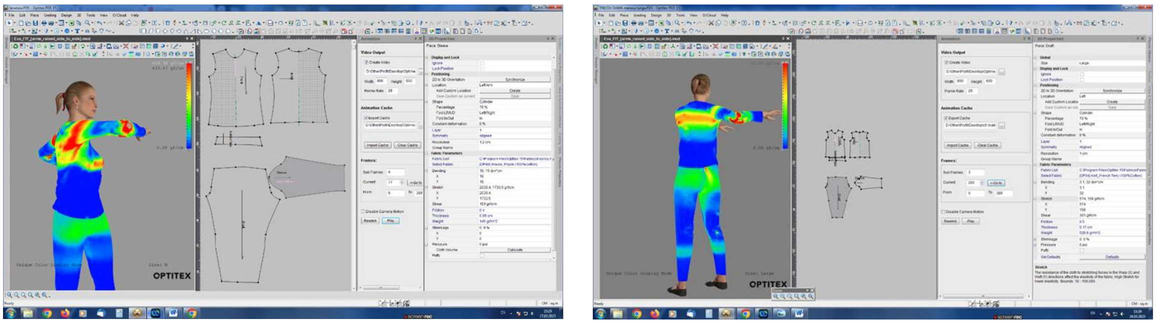

Fig. 6: Upper zone mechanical stress (red areas – maximum effort): a) aWv; b) bKt

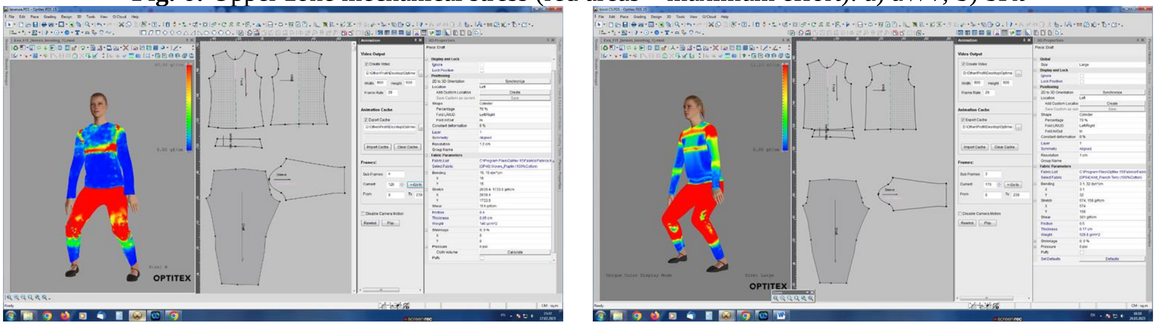

Fig. 7: Mechanical stress lower area (red areas – maximum effort): a) aWv; b) bKt

It is estimated that in the lower body area, the stress at exertion is much higher than in the upper area, according to figures 6 and 7. According to Figures 6 and 7, any variation in stress, during wear, appears colored other than blue on the dressed avatar. The higher the stress, the closer the colors of the respective areas are to orange. The maximum stress on the avatar map is colored in red. While a piece of professional underwear equipment for military use is desired to be developed using the two fabrics, both functionality, and comfort have to be high.

Comparing the upper and lower areas for both simulations shows that the widest red areas are presented at lower areas for both textile fabrics. Comparing the two situations and lower areas, higher stress was reported for the woven structure, which means an adjustment of the size in critical areas has to be done. Anyway, the maximum values of the stress obtained by simulation are lower than the calculated young modulus in both situations. In the case of aWv, the maximum stress obtained by human avatar simulation is ~4 times lower than the calculated one, while in the case of bKt, the maximum simulated stress is ~2 times lower.

5. CONCLUSIONS

The paper presents a comparative analysis of the wearing behavior of two textile conductive fabrics, designed to be used for professional underwear use in the military area. The physical and mechanical characteristics of the fabrics were used to calculate the anisotropy and Young modulus. Both values were compared with the bending behavior simulation on a human avatar using PDS 3D software. The map of the simulated bending stress reveals the high peaks at elbows, hips, knees, thoracic, and armpit areas. All the highest values obtained by simulation are lower than the calculated ones, which means that at maximum stress the fabrics will not be damaged.

ACKNOWLEDGEMENTS

This work was carried out through the Core Programme within the National Research Development and Innovation Plan 2022-2027, carried out with the support of MCID, project no. 6N/2023, PN 23 26, project title "Intelligent equipment to ensure the survival of combatants in operational conditions" Acronym: IRHEM.

REFERENCES

[1] Venkatraman, P. D. "Fabric properties and their characteristics." Materials and technology for sportswear and performance apparel (2015): 53-86.

[2] G. B. Tseghai, B. Malengier, K. A. Fante, A. B. Nigusse, L. Van Langenhove, *Integration of Conductive Materials with Textile Structures*, an Overview. in Sensors 2020, 20, 6910. https://doi.org/10.3390/s20236910;

[3] C. K. Kan, Y. L. Lam, F*uture Trend in Wearable Electronics in the Textile Industry*. Appl. Sci. 2021, 11, 3914. https://doi.org/10.3390/app11093914

[4] R. R. Ruckdashel, N. Khadse, J. K. Park, Smart E-Textiles: Overview of Components and Outlook. Sensors, 2022, 22, 6055. https://doi.org/10.3390/s22166055

[5] I. R. Radulescu, L. Surdu, E. Visileanu, R. Scarlat, C. Constantin, C. Morari, B. Mitu, *Influence of plasma coated woven fabrics yarn's Density on electromagnetic shielding effectiveness*, Annals of the University of Oradea, Fascicle of Textiles, Leatherwork, vol 21, issue 1, 2020, 97-102

[6] J. Ren, C. Wang, X. Zhang, T. Carey, K. Chen,Y.F. Torrisi, *Environmentally-friendly conductive cotton fabric as flexible strain sensor based on hot press reduced graphene oxide*. Carbon, 111, 2017, 622-630.

[7] S. Lee, *Analysis of electrical and comfort properties of conductive knitted fabrics based on blending ratio of silver-coated yarns for smart clothing*. Journal of Engineered Fibers and Fabrics. 2022;17. doi:10.1177/15589250221104474

[8] C. Wang, M. Zhang, K. Xia, X. Gong, H. Wang, Z. Yin, B. Guan, Y. Zhang, *Intrinsically Stretchable and Conductive Textile by a Scalable Process for Elastic Wearable Electronics*, ACS Applied Materials & Interfaces 2017 9 (15), 13331-13338, DOI: 10.1021/acsami.7b02985

[9] Repon, Md, Ginta Laureckiene, and Daiva Mikucioniene. "Effect of stretching on thermal behavior of electro-conductive weft-knitted composite fabrics." Polymers 14.2 (2022): 249.

[10] W. Liu, D. Shangguan and J. C. Lee, "Evaluation of Launderability of Electrically Conductive Fabrics for E-Textile Applications," in IEEE Transactions on Components, Packaging and Manufacturing Technology, vol. 10, no. 5, pp. 763-769, May 2020, doi: 10.1109/TCPMT.2020.2981902.

[11] Kim, J., Jeon, Y., Kim, J., Park, M., & Lee, J. (2019). Effect of bending on the electrical conductivity of conductive fabrics. Textile Research Journal, 89(12), 2444-2454.

[12] Li, C., Li, Y., Li, L., Wang, X., & Zhang, H. (2018). Effects of stretching deformation on electrical properties of conductive fabric. Materials Research Express, 5(7), 076401.

[13] Wu, J., Zhou, H., & Zhang, H. (2020). Effect of compression on the electrical conductivity of conductive fabrics. Journal of Textile Research, 41(4), 1-6.

[14] G. Popescu, S. Olaru, C. Grosu, I. Badea, *Development of jacket patterns for teenagers using Optitex flattening module*, TEXTEH Proceedings 2021:334-341, DOI: 10.35530/TT.2021.52