ESD GARMENTS

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Abstract: *Protective equipment represents an alternative for the sustainable development of companies and for human health protection. The insertion of "invisible functionalities" in textile structures, the use of functional elements as part of the whole garment are just a few tools which define "freedom" of creation in the field of textiles. The electrical, chemical and mechanical properties of conductive textiles are crucial for intelligent textiles. ESD garments are used to protect sensitive devices from electrostatic discharges that can occur from the normal clothing of the human operators. ESD garments on the market don't solve all the problems raised by accidental electrostatic discharges. This is because the fabric, from which the garment is made, must fulfil at the same time two contradictory conditions: high resistivity, to limit the charging process and energy transfer in case of an eventual discharge, and high conductivity, to facilitate the dissipation process of charges, thus limiting the accumulation of charge on the fabric. To obtain an ESD garment with superior qualities, the present paper proposes the development of a bilayer structure using the integral knitting technique. The outer layer, which comes in contact with the working environment, is mainly dissipative (DL) which ensures the protection against short circuit and limitation of electrostatic energy transfer into the working environment, while the inner layer, which comes in contact with the human operator, is mainly conductive (CL), providing the controlled drainage of accumulated electrostatic charge.*

Key words: *electrical discharge, knitting, protective clothing*

1. INTRODUCTION

Electrostatic discharges are caused when a sufficiently amount of charge accumulated through different mechanisms (friction, induction or corona charging) [1-3] is suddenly released on a nearby object. The magnitude of these discharges depends on a number of parameters, such as: air gap between the charged object and the one to which the discharge will be made, humidity, resistivity of charged object, etc. [4-6]. Controlling these parameters can help minimize the risk of an electrostatic discharge.

When human operators are met on the production line of devices sensible to electrostatic discharge, a different protection measure is taken into consideration, namely ESD garments, which reduce the risk of an ESD from the operator's normal clothing to the sensitive device. ESD garments on the market don't solve all the problems raised by accidental electrostatic discharges. This is because the fabric, from which the garment is made, must fulfil at the same time two contradictory conditions: high resistivity, to limit the charging process and energy transfer in case of an eventual discharge, and high conductivity, to facilitate the dissipation process of charges, thus limiting the accumulation of charge on the fabric The protective garments must also have shielding properties, to prevent the electrostatic fields generated under the garment to induce charge to nearby objects [7] and good anti-static properties, so that they won't generate electric charge when making contact with other materials [8].

To satisfy the conditions for ESD garments (high resistivity and high conductivity), a bilayer structure of the fabric was developed. The bilayer structure offers both high resistivity and high conductivity, required for the ESD garments, while the integral knitting technique ensures the electrical conductivity throughout the fabric. An additional requirement for the inner layer is to ensure the user's comfort.

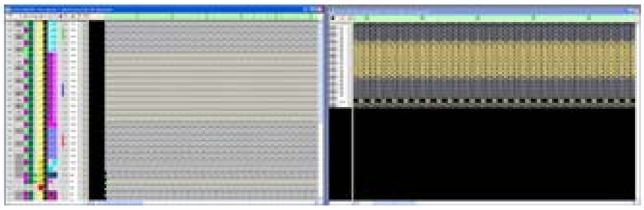
2. EXPERIMENTAL PART

Two-layer knit variants were made with plaited structures, with parallel evolution of two or more yarns with strictly determined relative position as a result of their submission at different angles (plaiting yarn V at an angle smaller than ground yarn F). The most used knitted structures are jersey and rib structure. In case of jersey structure, the plaiting yarn V appears on the foreground on the front and the ground yarn F, on the foreground on the back of the fabric. In case of rib structure due to alternating of front-back wales - both the plaiting yarn (at front aspect stitches) and the ground yarn (at rear aspect stitches) will be present on the foreground, on each side of the fabric.

Both types of fabric were made on STOLL knitting machines, from SC Tanex SRL, with a possibility to have a differentiated adjustment of yarn tension so as to ensure the correct plaiting of the fabric (Table 1 and 2).

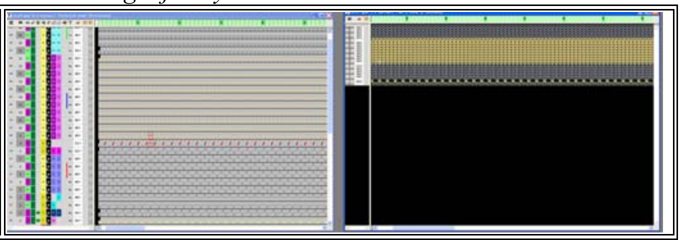
1. Rib1x1

Table 1: *Rib structure*

MSEC	Value	Description	
MSEC 3	0.55	Transfer speed	
MSEC 4	0.60	Knitting speed	

2. Single jersey

Table 2: *Single jersey structure*

MSEC	Value	Description	
			

Yarn used:

- ground yarn: Nm 50/3, 100% cotton;
- ground yarn: Nm 30/2, 100% wool;
- plaiting yarn: conductive yarn type 2: 75% cotton + 25% epitropic yarn (Nm 34/1 carbon coated polyester);
- plaiting yarn: conductive yarn type 3: Nega-Stat P210, 112 dtex 12 f, polyester filament with trilobal core and carbon outer layer;
- plaiting yarn - conductive type 4, Nega-Stat P190, 155 dtex, 24f, polyester filament with trilobal carbon inner core;
- plaiting yarn - conductive type 5, nylon filament superficially saturated with carbon particles.

Table 3: *Samples resulted after experiments*

Sample No.	Structure	F1/Front	F2/Rear	Conductive yarn percentage
1	plaited jersey	one cotton yarn + one yarn type 2	one cotton yarn + three yarns type 4	6%
2	plaited rib	one cotton yarn + one yarn type 2	one cotton yarn+two yarns type 3	5%
3	plaited jersey	one cotton yarn + one yarn type 2	one cotton yarn +two yarns type 3	5%
4	plaited rib	one cotton yarn + one yarn type 2	one cotton yarn + three yarns type 3	6%
5	plaited jersey	one cotton yarn + one yarn type 2	one cotton yarn +one yarns type 3	4%
6	plaited jersey	one cotton yarn + one yarn type 2	one cotton yarn +two yarns type 4	6%

7	plaited jersey	one cotton yarn + one yarn type 2	one cotton yarn +one yarns type 4	5%
8	plaited rib	one cotton yarn + one yarn type 2	one cotton yarn +one yarns type 4	4,5%
9	plaited rib	one cotton yarn + one yarn type 2	one cotton yarn +two yarns type 4	6%
10	plaited jersey	one cotton yarn + one yarn type 2	one cotton yarn +one yarn type 5	4,5%
11	plaited jersey	one cotton yarn + one yarn type 2	one cotton yarn +two yarns type 5	6%
12	plaited jersey	one cotton yarn + one yarn type 2	one cotton yarn + three yarns type 5	7,5%
13	plaited rib	one cotton yarn + one yarn type 2	one cotton yarn + three yarns type 5	7,5%
14	plaited rib	one cotton yarn + one yarn type 2	one cotton yarn +two yarns type 5	6%
15	plaited rib	one cotton yarn + one yarn type 2	one cotton yarn +one yarn type 5	4,5%
16	plaited rib	one wool yarn + one yarn type 2	one wool yarn +one yarn type 5	4,5%
17	plaited rib	one wool yarn + one yarn type 2	one wool yarn +two yarns type 5	6%
18	plaited rib	one wool yarn + one yarn type 2	one wool yarn +two yarns type 5	7,5%
19	plaited jersey	one wool yarn + one yarn type 2	one wool yarn + three yarns type 5	7,5%
20	plaited jersey	one wool yarn + one yarn type 2	one wool yarn +two yarns type 5	6%
21	plaited jersey	one wool yarn + one yarn type 2	one wool yarn +one yarn type 5	4,5%

3. RESULTS

In order to characterize the 21 knitted fabric samples (table 3), complete sets of tests were conducted for the following parameters: weight [g/m^2], thickness: density (wales/10cm, rows/10cm), thickness (mm), air permeability (l/m^2/s), water vapour permeability (%), thermal conductivity (mW/mK), thermal resistance (m^{2}KW), shielding factor (S), discharge time (s) (Table 4a and 4b).

Table 4a: *Characteristics of knitted samples*

Sample no.	Bilayer structure	Type of yarns combination	F1 yarns combination	F2 yarns combination	Weight [g/m2]	Density		Thichness, [mm]
						rows/10cm	wales/10cm	
5	Plaited jersey	Cotton yarns combination	1 cotton yarn +1 yarn type 2	one cotton yarn +one yarn type 3	470	43	92	1,58
3				one cotton yarn +two yarns type 3	495	41	90	1,63
7				one cotton yarn +one yarn type 4	487	44	86	1,63
6				one cotton yarn +two yarns type 4	508	44	79	1,69
1				one cotton yarn +three yarns type 4	525	43	84	1,62
10				one cotton yarn +one yarn type 5	597	47	81	1,62
11				one cotton yarn +two yarns type 5	589	47	82	1,66
12				one cotton yarn +three yarns type 5	634	47	75	1,74
21		Wool yarns combination	1 wool yarn +1 yarn type 2	one wool yarn +one yarn type 5	521	47	71	1,65
20				one wool yarn +two yarns type 5	562	47	69	1,65
19				one wool	603	46	69	1,66

				yarn +three yarns type 5				
2				one cotton yarn +two yarns type 3	728	38	60	3,41
4				one cotton yarn +three yarns type 3	825	37	63	3,34
8				one cotton yarn +one yarn type 4	705	37	61	3,52
9		Cotton yarns combination	1 cotton yarn +1 yarn type 2	one cotton yarn +two yarn type 4	834	37	65	3,32
15	Plaited rib			one cotton yarn +one yarn type 5	785	37	61	3,39
14				one cotton yarn +two yarn type 5	828	36	59	3,58
13				one cotton yarn +three yarn type 5	878	36	59	3,61
16				one wool yarn +one yarn type 5	766	36	57	3,33
17		Wool yarns combination	1 wool yarn +1 yarn type 2	one wool yarn +two yarn type 5	802	34	60	3,53
18				one wool yarn +two yarn type 5	846	33	59	3,57

Table 4b: *Characteristics of knitted samples*

Sample no.	**Air permeability l/m2/s**	**Water Vapor permeability %**	**Thermal resistence m2K/W**	**Thermal conductivity, mW/m·K**	**Shielding factor [S]**	**Discharging time t1/2 (F1)**	**Discharging time t1/2 (F2)**	**Conductive yarn percent %**
5	593,4	39,1	0,03913	40,25	0,84	0,0227	0,0228	4%
3	646	41,6	0,03901	41,65	0,92	0,0251	0,0228	5%
7	484,6	42,5	0,03354	48,65	0,82	0,0274	0,0246	5%
6	475,8	40,9	0,03447	49,05	0,83	0,025	0,0232	6%
1	539	38,3	0,03869	41,85	0,9	0,0249	0,0268	6%
10	374,4	36,2	0,03269	49,55	0,72	0,0258	0,0273	4,5%
11	395	35,9	0,04444	37,35	0,70	0,0252	0,0258	6%
12	401,4	34	0,03395	51,25	0,81	0,0235	0,0263	7,5%
21	643	34,2	0,04291	37,45	0,80	0,0253	0,0282	4,5%
20	601	34,8	0,04099	40,25	0,73	0,0227	0,024	6%
19	647,6	30,06	0,03567	46,55	0,80	0,0251	0,0255	7,5%
2	667,8	37,6	0,04950	69,05	0,82	0,0245	0,0245	5%
4	581,2	40,8	0,04805	69,45	0,82	0,027	0,0238	6%
8	654,8	38,1	0,05052	69,75	0,78	0,026	0,0268	4,5%
9	495,8	35,8	0,04664	71,15	0,90	0,0234	0,0241	6%
15	454,2	30,1	0,05481	61,85	0,81	0,0238	0,0274	4,5%
14	576,6	28,5	0,05732	62,45	0,83	0,0255	0,0248	6%
13	609,8	32,4	0,05726	63,05	0,7	0,0241	0,0228	7,5%
16	593,6	29,3	0,07881	42,25	0,86	0,0252	0,0244	4,5%
17	800,8	29,5	0,07801	45,25	0,80	0,0236	0,0269	6%
18	872,2	28,6	0,07786	45,85	0,82	0,0227	0,0241	7,5%

When using a rib structure, voluminousness of the fabric will be higher due to the spatial arrangement of the stitch elements, due to an increased amount of incorporated air into the knitted structure. These aspects favour on the one hand a very high thermal comfort and on the other hand an effective air flow, respectively perspiration vapours between body and environment.

From way in which statistical events are distributed can be mention the following aspects:

- electrostatic shielding factor hasn't significant differences for the analyzed samples, sample 9 from rib structure group and sample 3 from jersey structure group shows the best possible attenuation of the electrical load (fig. 1);
- the presence of the yarn type 2 on the front face 1 determine the performance improvement by using the yarns 3, 4 and 5 for all knitting configuration, knitting structure does not significantly influence the ability of electrostatic discharge (fig. 2);
- the limits of variation for water vapor permeability is between 28.5% and 42.5%, statistical events that agglomerates into optimal zone indicate the presence of the cotton yarn, in patent structure (fig. 3).
- air permeability causes sensations of warm and cool of clothing products, the best value being obtained by the samples 10, 11, 12 (374 - 400 l/m^2/s), characterized by the presence of cotton yarn and conductive yarn element from nylon filament surface saturated with carbon particles (fig.4).

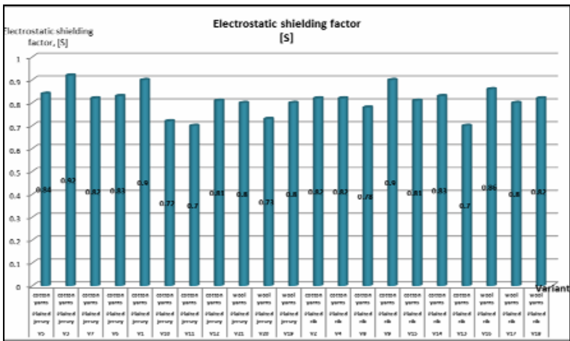


Fig. 1: *Electrostatic shielding factor*

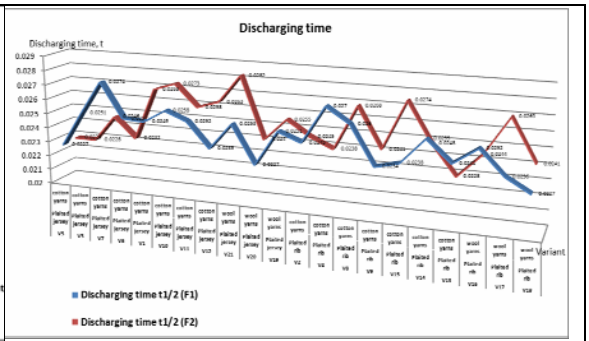


Fig. 2: *Discharging time*

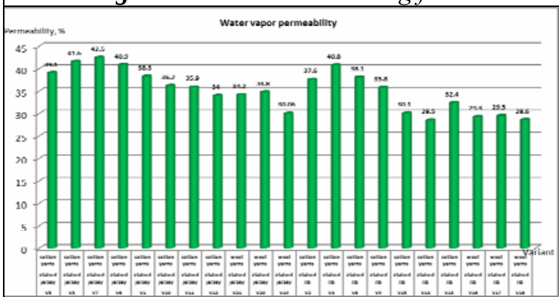


Fig. 3: *Water vapor permeability*

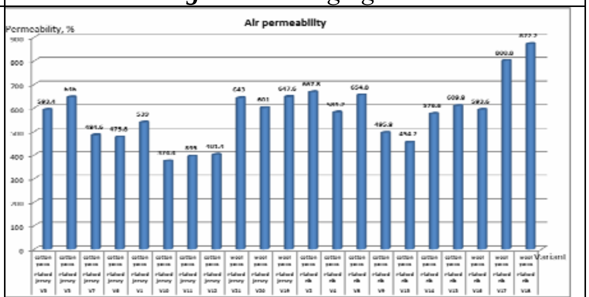


Fig. 4: *Air permeability*

4. CONCLUSIONS

A number of 21 samples made by integral knitting technique with different types of conductive fibres, which can be used in ESD applications, were tested for their ESD properties. The dielectric properties of the same samples were analyzed to see if there is a correspondence between them and ESD properties. Analysing the results, it was found that bilayer structure satisfy the two conditions for the ESD garments (high resistivity and high conductivity).

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REFERENCES

[1] G. Schmeer-Lioe, Anwendungsorientierte Prufung des elektrostatischen Verhaltens vonTextilien, Technische Textilien 43 (2000) 182.

[2] J.N. Chubb, Comments on methods for charge decay measurement, J. Electrostat. 62 (2004) 73-80.

[3] M. Cieslak, S. Wrobel, Assessment of Textiles Based on Three Test Methods of Charge DecayTime, 7th International Symposium EL-TEX 2006 (2006) 16-17.

[4] F. Marchini, Advanced Applications of Mettalized Fibres for Electrostatic Discharge and Radiation Shielding, J. Ind. Text. 20 (1991) 153-166.

[5] N. Wilson, The Nature and Incendiary Behaviour of Spark Discharges from Textile Sufraces, J.Electrostat. 16 (1985) 231-245.

[6] J.L. Davidson, T.J. Williams, A.G. Bailey and G.L. Hearn, Characterisation of electrostatic discharges from insulating surfaces, J. Electrostat 51-52 (2001) 374-480.

[7] A.S. Ardeleanu, A. Verejan and C. Donciu, Study Regarding the Knitting Parameters in 3D Textiles Shields Implementation, Acta Electrotehnica 51 (2010) 128-131.

[8] G. Baumgartner, Consideration for developing ESD garment specifications, ESD TR 05-00 Report, ESD Association (2000).