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The Use of Conductive Yarns in Woven Fabric for Protection Against Electrostatic Field

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The aim of the research was to assess the possibility of textile fabrics with conductive yarns to attenuate the value of electrostatic field strength. Nine groups of fabrics with conductive yarns were manufactured in Lithuanian Textile Institute for the study. Each group consisted of five fabrics differing by the fiber content. The conductive yarns were inserted into the fabrics at different specified intervals (only in weft direction or in weft and warp directions forming the grid). The electrostatic field strength was measured during the experiment using ESM-100 apparatus (measuring range of electrostatic field strength: 0.1 V/m – 100000 V/m). The electrostatic field strength of high voltage generating power supply was measured under fabrics with conductive yarns, with no conductive yarns and without any fabric. It was found that despite fibre content all tested fabrics decrease electrostatic field strength. Insertion of natural fibres into synthetic yarns decreases shielding effectiveness of the fabric. More conductive yarns and shorter are the distances between these yarns in the fabric, the better protection from electrostatic field is found. In order to have better shielding effectiveness; the porosity of the fabric should be as low as possible.

Keywords: conductive yarns, electrostatic field strength, shielding.

INTRODUCTION

The electricity is used everywhere, exposure to electromagnetic fields of extremely low frequency (50 Hz – 60 Hz) is unavoidable in our daily life [1 – 3]. Electrical current generates two types of fields oscillating at the same frequency. The first is an electric field; the other one is magnetic field. These fields decrease very quickly as one move away from the source. They both are an integral part of the electromagnetic spectrum [1].

Electromagnetic radiation can induce currents in external circuit elements that happen to be within effective range. Electromagnetic shielding material is one that attenuates radiated electromagnetic energy [4, 5]. It is increasingly needed to protect devices from interference problems and to avoid dangerous effects on human health due to electromagnetic radiation. Several shielding applications require solutions that textiles can suitably fulfill [5, 6].

Conducting threads are used for a long time to produce fabrics for electromagnetic shielding and electrostatic charge dissipation. Such threads and fabrics are increasingly used in applications where flexibility and conformability are important. Demand for these products has increased tremendously [7 – 11].

A number of experiments have been carried out to investigate the shielding effectiveness of antistatic fabrics [1 – 19]. Many authors characterize electromagnetic energy attenuation assessing shielding effectiveness (SE). The SE, is defined as the ratio of electromagnetic fields strengths E_0/E_1, where E_0, E_1 are the electric field intensities measured without (E_0) and with (E_1) the tested material separating field source and receptor. The authors in [16 – 18] concluded that the higher is the density of the fabric, the greater the amount of conductive element in the fabrics, which improves their EMSE (electromagnetic shielding effectiveness).

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MATERIALS AND EXPERIMENTAL METHODS

Two groups of fabrics (codes A and B) from polyester (PES) 16.7 tex f 96 (as weft) and PES 8.4 tex f 72 (as warp) yarns, one group of textured polyester (code C) 16.7 tex f 96 (as weft and warp), and other six groups of fabrics (codes D, E, F, G, H, K) from blended polyester/ /cotton (65 : 35 %) 15 tex × 2 (as warp and weft) yarns were manufactured in Lithuanian Textile Institute. Each group consisted of five fabrics differing by the fiber content. The PES/INOX (stainless steel/metal fibre) 20 tex blended yarn (80 : 20 %) known as S-Shield PES, produced by Schoeller GmbH & CoKG and Silver-plated yarn (Silverflex-170 yarns) (Z 300 m^{-1}), consisting of two twisted components: Polyester 11.3 tex (f 32) and Polyester silver-plated 4 tex (f 15), produced by Lantex A S were used as conductive yarns in the fabrics. The conductive yarn was inserted into each fabric at different specified intervals. The distribution of conductive yarns in the fabrics is defined in Table 1.

Warp density in the reed of polyester fabrics during weaving was 54 ends per cm, and the weft density in the reed was 25 picks per cm. Warp density in the reed of textured polyester fabrics was 25 ends per cm, and the weft density in the reed was 25 picks per cm. Warp density in the reed of PES/cotton fabrics was 22 ends per cm, and weft density in the reed was 22 picks per cm. The warp and weft densities, determined according to LST EN 1049-2: 1998 standard, method A are presented in Table 2.

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Table 1. Set of conductive yarns in investigated fabrics

Code of fabric	No. of non-conductive warp yarns between conductive ones	No. of non-conductive weft yarns between conductive ones	Types of non-conductive and conductive yarns
A1	–	71	PES, S-Shield PES
A2	–	62	
A3	–	49	
A4	–	25	
A5	–	13	
B1	–	71	PES, Silverflex-170
B2	–	62	
B3	–	49	
B4	–	25	
B5	–	13	
C1	25	71	Textured PES, Silverflex-170
C2	25	62	
C3	25	49	
C4	25	25	
C5	25	13	
D1	–	55	PES/cotton, S-Shield PES
D2	–	45	
D3	–	33	
D4	–	22	
D5	–	12	
E1	–	55	PES/cotton, Silverflex-170
E2	–	45	
E3	–	33	
E4	–	22	
E5	–	12	
F1	11	55	PES/cotton, S-Shield PES
F2	11	45	
F3	11	33	
F4	11	22	
F5	11	12	
G1	22	55	PES/cotton, S-Shield PES
G2	22	45	
G3	22	33	
G4	22	22	
G5	22	12	
H1	11	55	PES/cotton, S-Shield PES – warp; Silverflex-170 – weft
H2	11	45	
H3	11	33	
H4	11	22	
H5	11	12	
K1	22	55	PES/cotton, S-Shield PES – warp; Silverflex-170 – weft
K2	22	45	
K3	22	33	
K4	22	22	
K5	22	12	

Table 2. Warp and weft densities of tested woven fabrics

	Codes of fabrics											
	A1 ÷A5	B1 ÷B2	C1 ÷C4	C5	D1 ÷D3	D4, D5	E1 ÷E3	E4, E5	F1 ÷F5	G1 ÷G2	H1 ÷H5	K1 ÷K5
Warp density, cm^{-1}	55	55	34	34	25	26	25	26	25	25	25	25
Weft density, cm^{-1}	29	29	32	34	23	23	23	23	23	23	23	23

The thickness of the fabrics was determined according to LST EN ISO 5084: 2000 standard with apparatus DM-teks.

The electrostatic field strength was determined with 3D H/E fieldmeter ESM-100 (see Fig. 1). The measuring range of apparatus is 100 mV/m – 100 kV/m, precision ±5 %. The measuring was performed with a specimen of (300 × 300) cm, which was stitched with white colour PES thread forming a pocket. The measurement time applied was 2 min, the readings was taken twice in a second.

Fig. 1. 3D H/E fieldmeter ESM-100

The electrostatic field strength of high voltage generating power supply (65 kV) was measured under fabrics with conductive yarns, with no conductive yarns and without any fabric. During the measurement the fabric specimen in form of pocket was pull on the antenna of the apparatus.

The measurements were carried out in the following atmosphere: air temperature (18 ±1) °C, relative humidity (34 ±1) %.

The coefficient of variation of electrostatic field strength varies from 1.0 % till 5.0 % for all tested fabrics.

RESULTS AND DISCUSSION

The experiments have shown that electrostatic field strength of high voltage generating power supply (65 kV) is 1198.98 V/m. Pure PES fabric with the thickness of about 0.35 mm decreases this value till 899.98 V/m, while PES/cotton fabric with thickness of about 0.65 mm – till 786.88 V/m. The decrease is due to the different thickness of fabrics and resistances of fibres. The vertical resistance of PES woven fabric is 2.82×10^{10} Ω [13], of PES/Cotton fabric – 2.3×10^{10} Ω [19].

As we can see from the Fig. 2, the value of electrostatic field strength increases increasing number of non-conductive yarns between the conductive ones. For

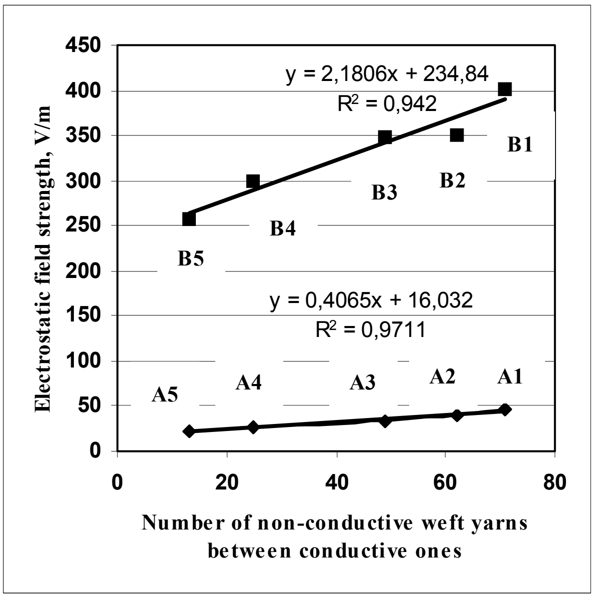

Fig. 2. Electrostatic field strength of PES fabrics versus the number of non-conductive weft yarns between conductive ones

example, the electrostatic field strength of A3 fabric with 49 non-conductive yarns between S-Shield PES yarns is 33.57 V/m, of A5 fabric – 22.58 V/m. The electrostatic field strength of B1 fabric with 71 non-conductive yarns between Silverflex-170 yarns is 401.53 V/m and of fabric with the shortest distance between conductive yarns is 256.96 V/m.

The surface resistivity of PES fabrics with yarns containing stainless steel fibres in their structure is higher than of PES fabrics with silver-plated yarns [20]. It results in higher values of electrostatic field strength of fabrics with silver-plated yarns comparing to values of fabrics with metal fibres in their structure. It means that the protection is better of fabrics with S-Shield PES yarns than of fabrics with Silverflex-170 yarns (see Fig. 2).

K. B. Cheng with other authors [9] investigated an electromagnetic shielding effectiveness of the twill copper woven fabrics. They conclude that in order to have a better shield, the porosity of the fabric should be as low as possible and more conductive material should be available.

In this case, the densities in warp and weft directions are not the same; warp yarns are thinner than weft ones, so the porosity of all fabrics of groups A and B are similar (the pores are so small, that look invisible).

The coefficient of determination of linear curve for test results of A group of fabrics is equal to 0.97, and of B group of fabrics – 0.94, i. e. it is sufficiently high.

The insertion of conductive warp yarns in fabrics gives very low values of electrostatic field strength and obviously high shielding factor, comparing to measured values of fabrics of group B (see Figs. 2 and 3).

The measured values of electrostatic field strength is almost the same of C2, C3 and C4 fabrics, it varies from 15.41 V/m till 15.87 V/m. The best electrostatic properties and the lowest values of electrostatic field strength are of fabric with 13 non-conductive PES weft yarns and 25 PES warp yarns between conductive Silverflex-170 yarns (see Fig. 3). The structure of fabric C5 forms an effective conduction grid network with the smallest pores between yarns in the fabric. It results bigger weft density comparing to densities of other woven fabrics, of group C. The other fabrics from group C have wider pores in the fabrics, which are seen visually. That is why; the value of electrostatic field strength is conspicuous from other experimental results of group C.

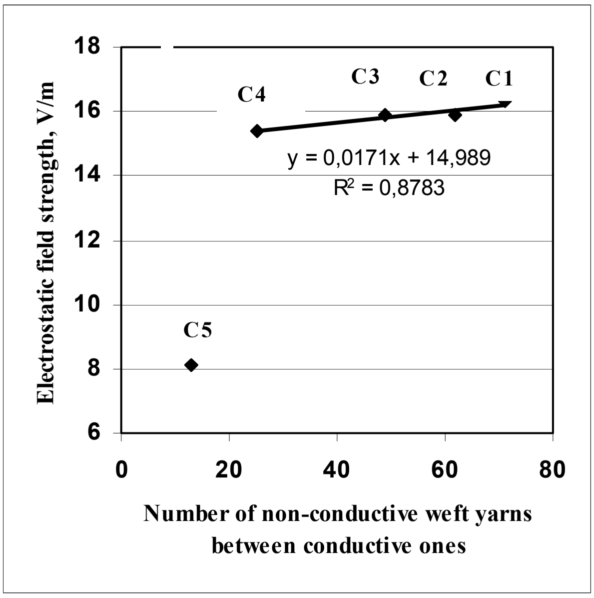

Fig. 3. Electrostatic field strength of PES fabrics versus the number of non-conductive weft yarns between conductive ones

The electrostatic field strength of only PES/cotton fabric is 786.88 V/m. As we can see from Fig. 4, the values of electrostatic field strength of both types of fabrics (of fabric with S-Shield PES yarns and of fabric with Silverfex-170 yarns) with the longest intervals between conductive yarns is lower than of control PES/cotton fabric. Also we can see that electrostatic field strength is higher of PES fabric than of PES/cotton fabric. It means that pure PES decreases electrostatic field strength more than mixture of PES/cotton. In this case cotton impairs electrostatic properties of fabric.

The values of electrostatic field strength increases with increase in distances between conductive yarns. The shielding effect is better of fabrics with metal fibers, because the resistance of silver is higher comparing to resistance of stainless steel.

The increase in shielding effectiveness of the woven fabrics was due to the presence of increased conductive material content per square meter of the fabric. The porosity of fabrics E1, E2, E3 and D1, D2, D3 is bigger than of fabrics E4, E5 and D4, D5. The pores in the fabrics with longer distances between conductive ones are seen visually, their weft densities are a little bit bigger.

The difference in values of electrostatic field strength of fabrics with 12 and 22 non-conductive yarns between S-Shield PES yarns (D4 and D5) is about 10 V/m. The difference of these measured vales for fabrics with the shortest distances between Silverflex-170 yarns is about 20 V/m (see Fig. 4).

As we can see from Fig. 5, the values of electrostatic field strength of fabrics with 22 warp yarns between conductive ones and stainless steel weft yarns inserted into fabric at specified intervals (group of G fabrics) are bigger than for fabrics with 11 warp yarns between yarns with metal fibres (group of F fabrics). The electrostatic field strength is 138.73 V/m of fabric with the shortest distance between conductive weft yarns and with 22 non-conductive warp yarns; 123.65 V/m of fabric with the shortest distance between conductive weft yarns and with 11 non-conductive warp yarns (see Fig. 5).

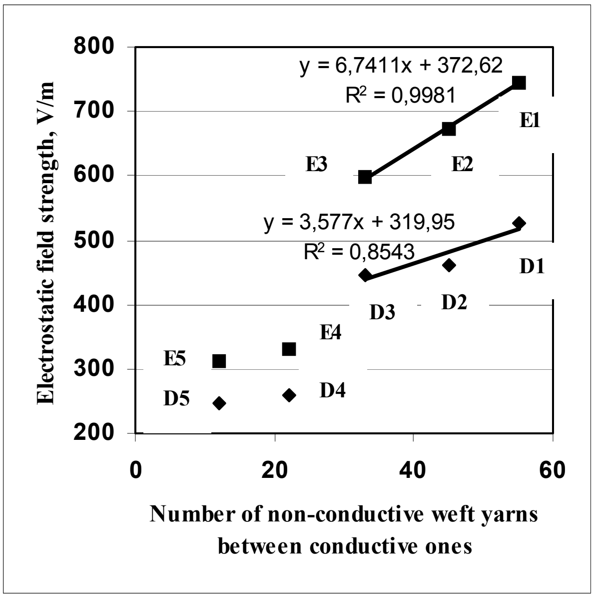

Fig. 4. Electrostatic field strength of PES/cotton fabrics versus the number of non-conductive weft yarns between conductive ones

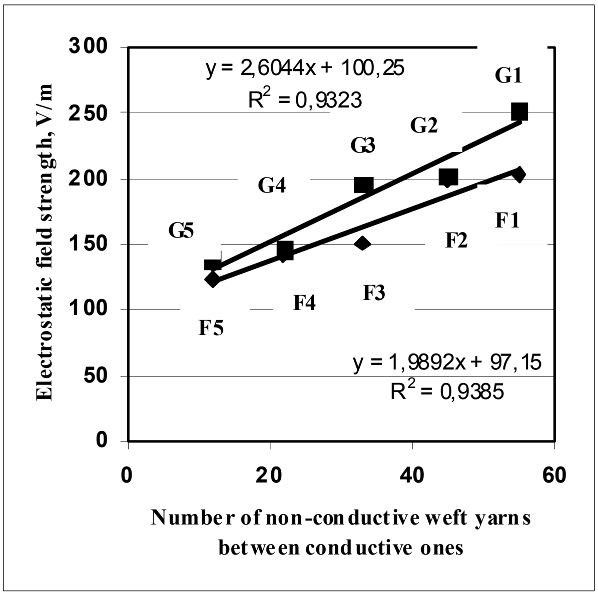

Fig. 5. Electrostatic field strength of PES/cotton fabrics versus the number of non-conductive weft yarns between conductive ones

Jung-Sim Roh with other authors [21] investigated an electromagnetic shielding effectiveness of metal composites fabrics, where metal component yarns were inserted in certain intervals to obtain different open grid structures of metal within the fabrics. They found out that the overall electromagnetic shielding effectiveness (EMSE) increases with metal content, but different frequency dependence relates to the aspect ratio of metal grid structure. Also it was found that the EMSE of the metal composite fabrics could be tailored by modifying the metal grid size and geometry [21].

For example, the electrostatic field strength of fabric with 12 non-conductive weft yarns and 11 PES/cotton warp yarns between conductive ones (fabric H4) is 153.76 V/m, of fabric with the same distance in weft direction between yarns with silver plated filaments, but with 22 non-conductive warp yarns between S-Shield PES yarns (fabric K4) is 200.36 V/m.

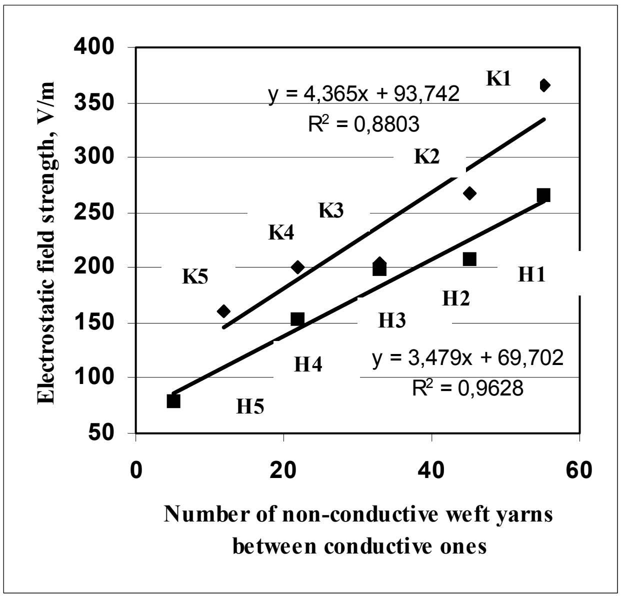

Fig. 6. Electrostatic field strength of PES/cotton fabrics versus the number of non-conductive weft yarns between conductive ones

The value of electrostatic field strength depends on the area of the grid square. The values of electrostatic field strength of fabrics which square takes almost the same area are very similar, i. e. the electrostatic field strength of H4 fabric is 153.76 V/m, while K5 fabric it is 160.94 V/m (see Fig. 6).

CONCLUSIONS

All tested fabrics decrease electrostatic field strength. The shielding effect of tested PES/cotton fabric is better than that of PES fabric. It means that natural fibres increase shielding effectiveness of fabrics.

Fabrics with conductive yarns in their structure decrease investigated parameter very distinctly. The best shielding effect is of fabrics with conductive yarns in both weft and warp directions.

More conductive yarns and shorter are the distances between these yarns in the fabric, the better protection from electrostatic field is seen.

The fabrics with S-Shield PES yarns decrease electrostatic field strength more, than fabrics with conductive Silverflex-170 yarns.

The best test results have showed the PES fabric with Silvereflex-170 yarns, inserted into fabric at specified intervals in weft and warp directions.

The porosity of fabrics has very big influence on the shielding factor. Lesser are pores of the fabric, bigger is weft densities of the fabrics, lesser are values of electrostatic field strength. Dense fabrics and fabrics with shortest distances between conductive yarns have smaller pores than fabrics with longer distances between conductive yarns.

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