ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 20, No. 1. 2014

Investigation of Shielding Properties of Yarns, Twisted with Metal Wire

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http://dx.doi.org/10.5755/j01.ms.20.1.2492

Received 24 September 2012; accepted 20 April 2013

The development level of the modern techniques and information technologies creates diverse nature electromagnetic fields and electric field accumulations in the human environment. Electrically conductive textiles that protect against electromagnetic waves and electric charge accumulations can be usable as protective covers for work in computer equipment rooms, measuring stands, air and gas filters and so on. One of the methods used in increase of electrical conductivity in textiles is the development of their specific structures (including the development of threads with the metal component).

In this paper, unlike the currently used in the world conductive material production method, where different metal fibres are used as an additives to the main fibre composition in order to create a variety of fibres and yarns, a spun yarn with metal wire was prototyped as samples for this research and the parameters of protective properties of these samples were investigated (such as surface resistivity, vertical resistance, etc.). The protective and shielding properties of woven network with prototyped twisted electro conductive thread with a wire (metal wire diameter of 15 microns) were investigated. During the investigation the influence of the following factors, such as conductive fibre composition, electrically conductive thread distribution frequency of the longitudinal and transverse direction, on the protective shielding properties of conductive network were analyzed.

The research enabled the assessment of influence of electrically conductive fibre yarn composition and its distribution in the woven mesh on protective shielding properties.

Keywords: conductive mesh, electrostatic properties, shielding effectiveness.

1. INTRODUCTION

In recent years with a wide development of technology, people use a various electrical and electronic devices, which radiate electromagnetic waves, and electric charges accumulate on their surfaces. Such phenomenon causes not only pollution to human health, but also sometimes it is a result of failure of electric devices. Different yarn with metal wire or metal core yarn fabrics offer a great opportunity to develop a new generation of multifunctional, protective and interactive textiles because of their structural order, ability to flex and conform to most desired shapes [1 – 4]. Metal wire has excellent permanent conductivity among all conductive fibres and exhibits electrostatic charging or discharging during various industrial processes because of friction, separation or conduction between objects [5]. The incorporation of metal wires and electroplating of metal is likely to affect the pliability of material and corrosion of these metals in hostile environment is likely to hamper their shielding properties [2].

The conductive threads are inserted into the fabric (mostly used in the materials for personal protective products) to limit surface potential [6, 7]. Low surface potential let to avoid risks of damage by direct electrostatic discharge and by indirect induction effects [7]. But, the spinning process of conductive yarn with metal wire is quite difficult and needs some experience [1, 5, 8].

Textiles with different levels of electrical conductivity could be used for a number of applications: electromagnetic (EM) shielding, electrostatic dissipation, for use in heating devices or for production of clothing where physical changes in the textile causes changes to electrical resistance that can be monitored [9, 10].

The aim of this study was to investigate the influence of metal wire on the electrostatic and shielding properties of conductive mesh structure textiles.

2. EXPERIMENTAL

Two different plain weave woven fabrics (polyester and flax) of a mesh structure were taken for the investigation. The warp and weft densities of these fabrics are 3 cm^{-1}. In order to ensure conductive properties of textiles, conductive yarns specially manufactured for this research work, were inserted in the mesh woven fabrics at different distances.

Four different yarns: polyamide monofilament yarn, polyethylene monofilament yarn, polyester multifilament yarn and polyester spun yarn were taken and twisted with stainless steel wire (type 304) of diameter of 15 microns (linear density of steel wire is 140 tex), supplied by Knight Precision Wire, United Kingdom. The conductive yarns were specially manufactured for this research work with PL-31A twisting machine. This twisting machine was chosen, because of its unique feed creel, which takes into account the packages, different in shape and application. Also, various types and fibre composition yarns can be

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twisted with this machine and it is possible to reach from 20 till 1000 twists in meter.

The conductive yarns were manufactured in such a way, that the synthetic yarns were used as cover materials and the steel wire was taken as core material. The twisting method was alike the conventional twist of yarns, but during the process the speed of feed roller of synthetic yarns was faster than of wire, therefore the plies of synthetic yarn covered the wire closely. The twist of such a formed conductive yarn is 100 m^{-1}, the twisting direction "S".

The linear density of yarns used in twisting operation was determined according to LST EN ISO 2060 and presented in Table 1. The detailed description of tested fabrics is also presented in Table 1.

Table 1. The description of fabrics used for investigation

Code of fabric	Composi-tion of mesh fabric	Composition of conductive yarns (linear density, tex)	The distance between conductive yarns in the fabric, cm	
			Warp	Weft
P1PA	Polyester	Polyamide monofilament (28 tex × 10) with steel wire	–	1
P2PA			–	2
P3PA			–	4
P4PA			1	1
P5PA			2	2
P6PA			4	4
F1PA	Flax	Polyamide monofilament (28 tex × 10) with steel wire	–	1
F2PA			–	2
F3PA			–	4
F4PA			1	1
F5PA			2	2
F6PA			4	4
P1PE	Polyester	Polyethylene monofilament (68 tex × 4) with steel wire	–	1
P2PE			–	2
P3PE			–	4
P4PE			1	1
P5PE			2	2
P6PE			4	4
F1PS	Flax	Polyester fibre (spun yarn) (50 tex × 5) with steel wire	–	1
F2PS			–	2
F3PS			–	4
F4PS			1	1
F5PS			2	2
F6PS			4	4
F1P	Flax	Polyester multifilament (30 tex × 9) with steel wire	–	1
F2P			–	2
F3P			–	4
F4P			1	1
F5P			2	2
F6P			4	4

Before measurements all fabrics were conditioned in dry conditions, i. e. the relative humidity 25 % and temperature 23 °C, for 24 hours.

The shielding effectiveness of tested fabrics was determined by measuring shielding factor and half decay time according to LST EN 1149-3, 2^{nd} method (induction charging) in dry conditions. These parameters were taken with the electric charge meter ICM-1, produced by STFI. Arrangement of equipment ICM-1 for induction charging test method is presented in Fig. 1. The instrument is controlled by a microprocessor and makes measurements with automatic calculations and display of the measured data.

The value of the shielding factor (S) is obtained by equation:

$$S = 1 - \frac{E_R}{E_{\max}}, \tag{1}$$

where E_R is the maximum electric field strength indicated on the recording device with the test specimen in the measuring position, and $E_{\max}$ is electric field strength indicated on the recording device with no test specimen present.

The half decay time is the time taken for the indicated field strength to decay to $E_{\max}/2$.

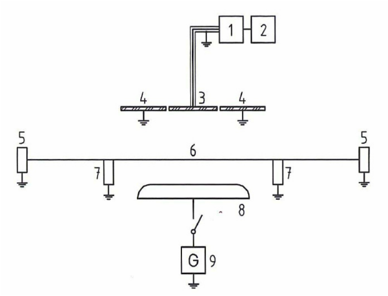


Fig. 1. Arrangement of electric charge meter ICM-1, where 1 – charge amplifier, 2 – recording device, 3 – field-measuring probe (a metal disc, surrounded by an earthed guard ring and connected to the charge amplifier), 4 – guard ring, 5 – specimen clamping ring, 6 – test specimen, 7 – support ring, 8 – field-electrode, 9 – voltage generator

The standard deviation of the values of shielding factor was less than 0.36 and of values of half decay time – less than 0.04.

Vertical and surface resistances were measured according to LST EN 1149-2 and LST EN 1149-1 standards respectively, with Terra-Ohm-Meter 6206 (produced by Eltex), connected with an assembly of stainless steel electrodes (see Fig. 2).

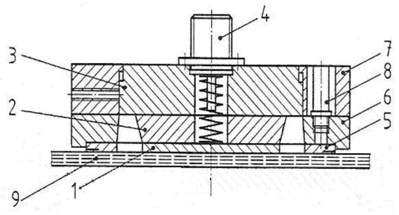
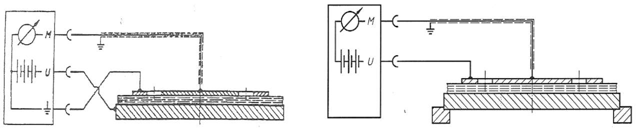


Fig. 2. Assembly of electrodes, where 1 – test electrode, 2 – insulating disc, 3 – guard plate, 4 – coaxial plug-in connection, 5 – annular electrode, 6 – insulating ring, 7 – sucreening ring, 8 – connector, 9 – sample

In order to determine vertical resistance the sample is placed between the assembly of electrodes (see Fig. 2) and the disc of base plate electrode, while during measurement of surface resistance the specimen is placed between the assembly of electrodes and insulating plate.

The measuring circuits of electrodes during measurements of resistances are presented in Fig. 3.



a b

Fig. 3. Measuring circuit: a – vertical resistance, b – surface resistance

The surface resistivity (ρ) was calculated according to equation:

$$\rho = k \cdot R_s , \tag{2}$$

where R_s is the measured surface resistance, k is the geometrical factor of the electrode.

The geometrical factor of the electrode is calculated according to equation:

$$k = \frac{2 \cdot \pi}{\log_e \left(\frac{r_2}{r_1} \right)} = \frac{2 \cdot 3.14}{\log_e \left(\frac{34.6}{25.2} \right)} = \frac{6.28}{0.317} = 19.8 , \tag{3}$$

where r_1 is the radius of the inner electrode, r_2 is the inner radius of the outer electrode.

For presentation of surface resistivity and vertical resistance values in Figs. 7÷10, the random absolute error was calculated using equation:

$$\Delta_\alpha = \frac{t_n \cdot s}{\sqrt{n}} , \tag{4}$$

where t_n is Student's coefficient (equal to 2.78, when confidence level is 95 %), s is standard deviation, n – number of specimens.

The data presented in this paper is mean result, calculated out of five specimens for each fabric. The dimensions of specimens, used in measurements, was (150 × 150) mm. The conditioning for 24 hours and tests were carried out in dry conditions.

The area of conductive mesh grid was calculated by multiplying the width times the length of the mesh grid.

3. RESULTS AND DISCUSSION

In the beginning of the whole research work experiments with control (fabric without threads with steel wire) polyester and flax woven mesh fabrics were carried out. It was determined that these fabrics do not exhibit any shielding properties, i. e. the shielding factor of synthetic fabric was equal to zero, and of flax mesh fabric – 0.03. The half decay time of these control textiles were: for synthetic fabric 0.77 s, for flax fabric 0.10 s. It is seen from the test results that charge decay characteristics of flax fabric are a little bit better than of synthetic fabric. The electric charges accumulated on the flax fabric's surface decay quicker than from the surface of polyester fabric. This can be explained by the nature of fibres. The similar test results that the electric charges decay from the surface of synthetic fabrics slower than from the natural fabrics were determined in previous papers [11 – 13].

The results of shielding factor and half decay time of fabrics with different conductive yarns are presented in Fig. 4, Fig. 5 and Table 2.

The test results of shielding factor have showed that this parameter is very conductive additive dependent. Shielding factor of control fabrics was very similar and equal to zero, but after insertion of conductive yarns in the control meshes, it increases distinctly. The investigation of polyester and flax fabrics with conductive yarns inserted in the fabrics proved this conclusion. The values of shielding factor of tested fabrics with distances between conductive yarns of 4 cm show that even if the quantity of conductive yarns in the fabric is quite small, but still their shielding factor is bigger than of control fabrics.

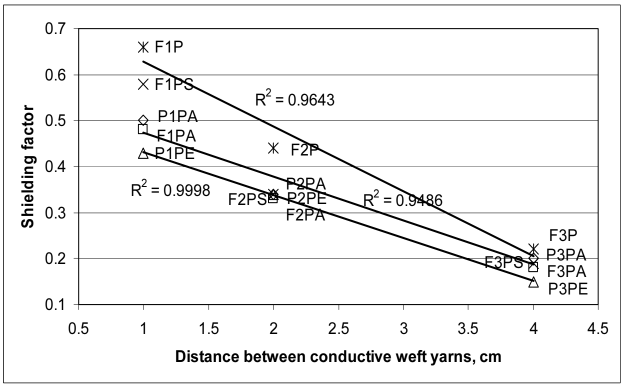


Fig. 4. The shielding factor vs distance between conductive yarns of investigated fabrics

It is seen from the Fig. 4 that there is no such a big difference among values of shielding factor of fabrics, differ in conductive yarns inserted, but with the same distance between them. The noticeable difference in these values is seen when conductive yarns are inserted into the fabric in a distance of 1 cm. But, still it can be excluded that the highest shielding factor and the best shielding efficiency have flax fabrics with steel core polyester multifilament yarns, i. e. shielding factor of F1P is 0.66, of fabric F3P – 0.22. And the lowest shielding properties have polyester fabrics with polyethylene monofilament conductive yarns, i. e. shielding factor varies from 0.43 till 0.15 for fabrics P1PE and P3PE respectively. It is also seen from values presented in Fig. 4 that there is a linear correlation between shielding factor and distance between conductive weft yarns because of sufficient high correlation coefficients (the smallest correlation coefficient of all five fabric groups is 0.90).

So, from data, presented in Fig. 4, it was determined that the shorter is the distance between conductive weft yarns, the better is the shielding efficiency of fabrics. The same conclusions were obtained in previous papers [11 – 13]. It is also can be concluded that the best values of shielding factor have fabrics with only 1 cm between conductive yarns, and the visible difference in values of tested parameter is seen only comparing these fabrics.

It is seen from Fig. 5 that shielding factor depends on the area of conductive mesh grid. The smaller is the area of the grid, the higher is the overall shielding effectiveness. Summarizing results of fabrics with conductive yarns inserted only in one direction to fabrics with conductive mesh formed, we can conclude that the area of the grids affects shielding efficiency of fabrics more considerably compared to the quantity of conductive yarns.

Analysing data given in Fig. 5, it can be stated that the best shielding properties have polyester fabrics with conductive mesh formed by polyethylene yarns with steel wire. This is because polyethylene yarns with steel wire form a better electrical conducting net comparing to other fabrics. The shielding factor of P4PE fabric is equal to unity, and of P5PE – 0.71.

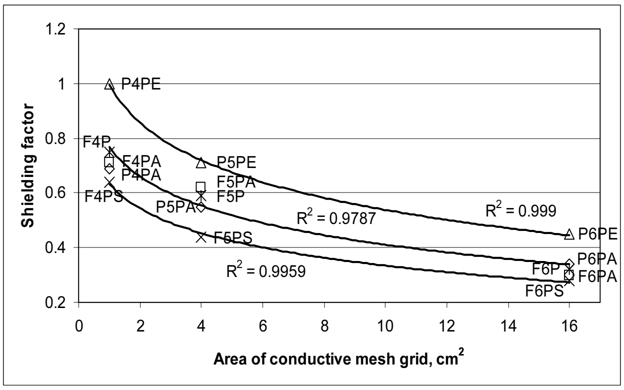


Fig. 5. The shielding factor vs area of conductive yarns grid of investigated fabrics

Table 2. The half decay time of tested fabrics

Code of fabric	Half decay time, s
P1PA	<0.01
P2PA	0.05
P3PA	0.36
P4PA	<0.01
P5PA	<0.01
P6PA	0.16
F1PA	<0.01
F2PA	0.06
F3PA	0.23
F4PA	<0.01
F5PA	<0.01
F6PA	0.13
P1PE	<0.01
P2PE	0.05
P3PE	0.17
P4PE	<0.01
P5PE	<0.01
P6PE	0.02
F1PS	<0.01
F2PS	0.03
F3PS	0.15
F4PS	<0.01
F5PS	<0.01
F6PS	0.14
F1P	<0.01
F2P	<0.01
F3P	0.04
F4P	<0.01
F5P	<0.01
F6P	0.02

The experiments have showed (see Fig. 5) that when area of conductive mesh grid is more than 4 cm^2, the values of shielding factor of tested fabrics are closer and there is no such a big difference what kind of conductive yarn (polyethylene or polyamide) is presented in the fabric. It is also seen from the Fig. 5 that there exists a correlation between shielding factor and area of conductive mesh grid in the fabrics, because the correlation coefficient of logarithmic function is very close to unity.

As it was mentioned earlier half decay times of control textiles is: for polyester fabric 0.77 s, for flax fabric 0.10 s. It means that the electric charge accumulates on the polyester fabric longer than on the flax fabrics. It is seen from the Table 2, that insertion of conductive yarns results in shorter half decay times.

The investigations have showed that comparing polyester background conductive fabrics among themselves, the fabrics with conductive polyamide yarns have better shielding efficiency than polyester fabrics with conductive polyethylene yarns. In some literature sources it can be find that the conductivity of polyamide is better that of polyethylene [2, 14]. This is the reason why two groups of fabrics with the same background, quantity and distribution of conductive yarns have different shielding properties.

It is also seen from Fig. 4 and Fig. 5 that the values of shielding factor of flax fabrics with polyester multifibre yarns with a steel wire is better than of flax fabrics with polyester spun yarns with a steel wire. It can be explained by the difference of polyester yarns. Multifilament yarns are slicker and their form is smoother and they cover steel wire more closely than spun yarn.

The principle view of charge decay curve of tested fabrics, received with apparatus ICM-1 is presented in Fig. 6.

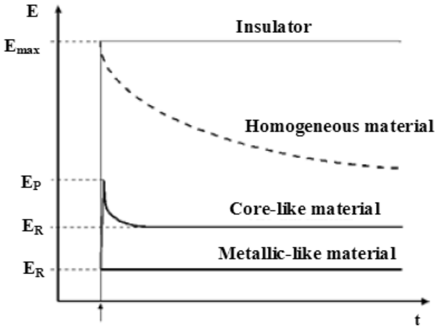


Fig. 6. The principle view of charge decay curve, received with apparatus ICM-1 [15]

It can be concluded that according to [15, 16] and the shape of the curve of our tested fabrics with specially designed and manufactured conductive yarns represents core like materials, i. e. conductive yarns may be assigned as steel core conductive yarns. The neutralization of the charge accumulated on the conductive fabric surface begins with a rapid decrease caused by discharging initiated by steel wire content and then proceeds slowly because of the high resistive synthetic yarns (in this case polyester, polyethylene or polyamide) [16]. More conductive yarns are inserted in the fabric or smaller the area of conductive mesh grid in the fabric, the shorter is the values of half decay time.

The further investigation of electrostatic properties of tested fabrics just confirmed conclusions mentioned above. The surface resistivity and half decay are two parameters that characterize the electrostatic properties of fabric's surface. It is seen from the presented data in Figs. 7, 8 and Table 2 that the smaller is the surface resistance, the shorter is the half decay time. The results of surface resistivity also showed the same dependence as test results of shielding factor. It showed that the more conductive

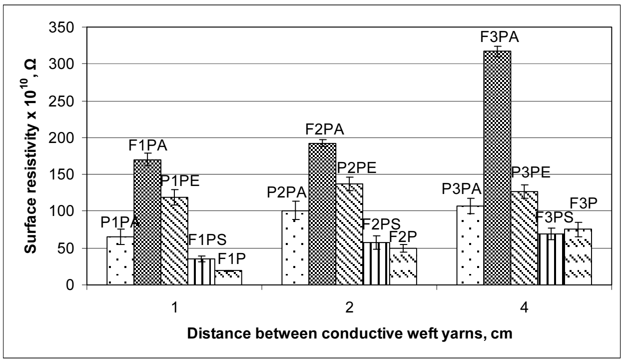


Fig. 7. The surface resistivity vs distance between conductive yarns of investigated fabrics

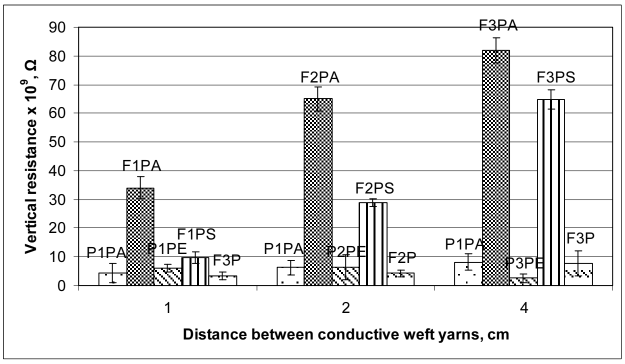


Fig. 8. The surface resistivity vs area of conductive yarns grid of investigated fabrics

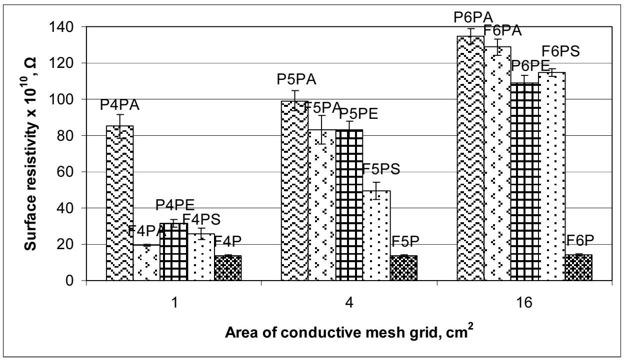


Fig. 9. The vertical resistance vs distance between conductive yarns of investigated fabrics

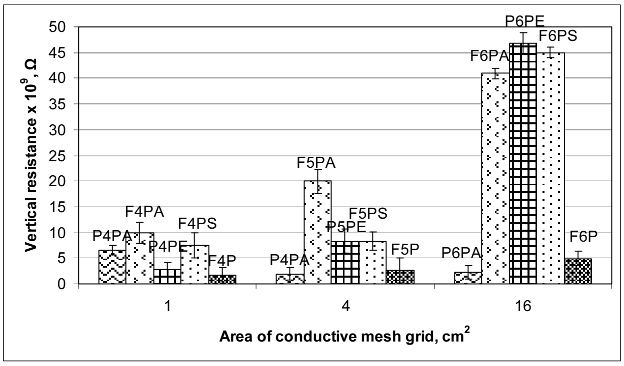


Fig. 10. The vertical resistance vs area between conductive yarns of investigated fabrics

yarns are in the structure of fabrics, the better are values of surface resistivity.

Zimnevska with other co-authors in their work [17] determined that the surface resistance of flax fabric is less than in 10^{10} Ω order of magnitude and the surface resistance of polyester fabric is approximately 1.4×10^{11} Ω. In our research work we estimated that surface resistance of flax mesh fabric is 1.7×10^{11} Ω (surface resistivity – 3.4×10^{12} Ω) and the resistance of polyester mesh fabric – 9.5×10^{10} Ω (surface resistivity – 1.9×10^{12} Ω). Hence the results are very similar.

The parameters of vertical resistance are important for fabrics that are used as inner layer, because the charge migration to ground is designed to happen on the garment surface. The results of vertical resistance of investigated fabrics are presented in Fig. 9 and Fig. 10.

The investigation has showed that vertical resistance of tested fabrics is also very sensitive to metal additives, as other parameters investigated in this work.

It is seen from the Figs. 9 and 10 that vertical resistance is 10^9 Ω order of magnitude. The smaller is the distance between conductive yarns or the smaller is the area of conductive mesh grid, the smaller is the vertical resistance. The same dependence was done for the surface resistivity and charge decay parameters.

It is also seen from the experimental data that the best electrostatic and shielding properties have flax fabrics with polyester multifibre yarns and steel wire, when conductive yarns are inserted only in one direction and polyester fabrics with polyethylene yarns with steel wire, when conductive yarns are inserted in to the mesh in longitudinal and cross direction and forms the conductive grid.

The random absolute error of values of vertical resistance and surface resistivity was on the average of 9 %, so the experimental results are reliable.

4. CONCLUSIONS

Samples with specially twisted various kinds of synthetic yarns with steel wire was manufactured and investigated.

It was concluded that the nonconductive background materials do not have any impact on shielding factor. Only conductive additives influence this parameter. Summarizing results of fabrics with conductive yarns inserted only in one direction to fabrics with conductive mesh formed, we can conclude that the area of the grids affects shielding efficiency of fabrics more considerably compared to the quantity of conductive yarns. The best shielding properties have polyester fabrics with conductive mesh formed by polyethylene yarns with steel wire. This is because polyethylene yarns with steel wire form a better electrical conducting net comparing to other fabrics, i. e., shielding factor of P4PE fabric is equal to unity, of P5PE – 0.71.

By decreasing the distance between conductive weft yarns in the samples, shielding factor increases, and results of these two parameters are linearly correlated (the smallest correlation coefficient of all five fabric groups is 0.90). Also, a correlation between shielding factor and area of conductive mesh grid in the fabrics exists, because the correlation coefficient of logarithmic function is very close to unity.

The surface resistivity and half decay are two parameters that characterize the electrostatic properties of fabric's surface. The smaller is the surface resistance, the shorter is the half decay time. More conductive yarns are inserted in the fabrics, more quickly electric charges decay from the surface. The results of surface resistivity showed the same dependence as test results of shielding factor.

The parameters of vertical resistance are important for fabrics that are used as inner layer, because the charge migration to ground is designed to happen on the garment surface. The investigation has showed that vertical resistance of tested fabrics is also very sensitive to metal additives, as other parameters investigated in this work. The smaller is the distance between conductive yarns or the smaller is the area of conductive mesh grid, the smaller is the vertical resistance. The same dependence was done for the surface resistivity and charge decay parameters.

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Presented at the National Conference "Materials Engineering 2012"
(Kaunas, Lithuania, November 16, 2012)