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Influence of Abrasion on Electrostatic Charge Decay of Woven Fabrics with Conductive Yarns

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Human body has quite low volume resistivity to act as a conductor and if insulated from earth it can accumulate electrostatic charge. The charge can be produced by contact electrification or by touching charged equipment or materials, which can cause hazardous, spark discharges. The aim of the research was to reveal the features of electrical charging and dissipation of charges in the woven fabrics containing conductive yarns after abrasion. All investigated fabrics were woven in Lithuanian Textile Institute as protective fabrics against incendiary discharges and electromagnetic radiation. Two groups of fabrics from polyester (PES) 16.7 tex f96 (as weft), PES 8.4 tex f72 (as warp) yarns and other two groups of fabrics from union polyester/cotton (65 % : 35 %) 15 tex × 2 (as warp and weft) yarns were manufactured for the study. Each group consisted of five fabrics differing by the fiber content. The conductive PES/INOX yarns were at different specified intervals inserted into one group of PES fabrics and one group of PES/cotton fabrics. Silver-plated yarns were correspondingly inserted into the other group of PES fabrics and other group of PES/cotton fabrics. The fabric surface resistivity, volume resistance, shielding factor and half decay time of fabrics were measured after abrasion for 5 000, 10 000, 15 000, 25 000, 35 000 and 45 000 rubs, and also with no abrasion. The values of surface and vertical resistances increased after abrasion. The half decay time became longer and values of shielding factor decreased. It was found that changes of surface after abrasion do have an influence to the tested fabrics. For fabrics, where surface fuzzing or pilling is seen, electrostatic characteristics are worse than for those with smooth surface. Therefore, it was found that while the number of conductive yarns inserted into the fabrics improved the fabric electrostatic properties, the abrasion led to the notable impairment of the protective power of the fabrics to incendiary discharges.

Keywords: charge dissipation, vertical resistance, surface resistivity, shielding factor, half decay time, abrasion.

INTRODUCTION

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 [1 – 3].

Recently, electrically conductive fabrics have found application as filters, de-electrifying coatings, electromagnetic interference shield materials, and special purpose clothing materials like dust-free and germ-free. Demand for these products has increased tremendously [4].

Textile fabrics are always in contact with the parts of machine devices during their manufacturing processes and with human bodies during their use [5 – 10]. The presence of a charged body and its associated field can also be sufficient to produce a potential across a device that can cause failure [10, 11].

The air in the vicinity of working devices is strongly ionized, and the charged yarn passing through this ionized air attracts ions of opposite sign and thus neutralizes it [12].

People use electrical equipment more frequently due to the progress of science and technology, which exposes humans to different frequencies of electromagnetic waves [13, 14]. 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 [15]. 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 [16].

The influence of washing on electrostatic properties of polyester woven fabrics containing S-Shield conductive yarns has been studied in [17]. The aim of the research was to reveal features of electrical charging and dissipation of charges in polyester fabric containing metal fibres appropriate for protective clothing in order to avoid incendiary discharges. It has been concluded that the shorter is the distance between conductive weft yarns the lower are values of surface and vertical resistances. Shorter half decay time results in the increase of shielding factor. The investigation of electrostatic properties of fabrics before and after washing has shown that although washing of fabrics impairs their anti-electrostatic properties the fabric with the biggest quantity of conductive PES/INOX weft yarns, washed and unwashed, met requirements of European standard EN 1149-5 and can be used in working clothing to prevent the static charges build-up [17].

Electromagnetic radiation barriers of nonwovens containing flax fibres and polypropylene fibres were also studied [18]. Thermal and electrical resistance in dry and wet conditions were measured. It was found that the insertion of flax fibres into polypropylene nonwoven structure at the amount of ~14 % resulted in 20 ÷ 100 times decrease of blend electrical resistance.

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Fabrics are always abraded during wearing, so the aim of this research was to reveal the features of electrical charging and dissipation of charges in woven fabrics containing conductive yarns after abrasion.

MATERIALS AND EXPERIMENTAL METHODS

Two groups of fabrics from polyester (PES) 16.7 tex f96 (as weft), PES 8.4 tex f72 (as warp) yarns and other two groups of fabrics from union 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 fiber content. The conductive PES/INOX (stainless steel/metal fibre) 20 tex union yarn (80 % : 20 %) known as S-Shield PES, produced by Schoeller GmbH & CoKG yarns were at different specified intervals inserted into one group of PES fabrics and one group of PES/cotton fabrics. Silver-plated yarns (Silverflex-170 yarns) (Z 300 m^{-1}), consisting of two twisted components: Polyester 11.3 tex (f32) and Polyester silver-plated 4 tex (f15), produced by Lantex A S were correspondingly inserted into the other group of PES fabrics and other group of PES/cotton fabrics. These conductive yarns were inserted into each fabric at different specified intervals (Table 1). Warp density of polyester fabrics was 54 ends per cm, and the weft density was 25 picks per cm. Warp density of PES/cotton fabrics was 22 ends per cm, and weft density was 22 picks per cm.

Table 1. Distribution of conductive yarns in investigated fabrics

Number of non-conductive weft yarns between conductive ones	With PES non-conductive yarns	With PES/cotton non-conductive yarns
	71	55
	62	45
	49	33
	25	22
	13	12

Five circular specimens of 140 mm diameter of all types of fabrics were cut with the Heals Sample Cutter 230/140. Abrading test was performed by Nu-Martindale 406 apparatus applying the load of 12 kPa. The specimens of each fabric were in fives abraded for 5 000, 10 000, 15 000, 25 000, 35 000 and 45 000 rubs. Vertical electric resistance, surface resistivity, electric charge shielding factor and half decay time were measured for each of five abraded specimens as well as for the specimens of non-abraded fabrics. Prior the measurements the specimens were conditioned for more than 24 hours in the following atmosphere: air temperature (23 ±1) °C, relative humidity (25 ±5) %. The measurements were carried out in the same atmosphere.

The coefficient of variation of surface resistivity did not exceed 5.5 % and those of vertical resistance did not exceed 6.0 %.

The values of vertical and surface resistances at the potential of 250 V were determined with a Terra-Ohm-Meter 6206, produced by Eltex with a range of 10^5 Ω to 10^{14} Ω and an accuracy of ≤5 % for 10^{12} Ω. The device selects the voltage automatically to measure resistances depending on their magnitude. The values of resistances were taken after 15 s from the beginning of measuring. The difference between measurement methods of both resistances is that during the measurement of vertical resistance the specimen is placed on a base plate electrode, while during the measurement of surface resistance the specimen is placed on an insulating plate. In both cases the specimens are pressed by the load of about 10 N by an assembly of cylindrical and annular electrodes arranged concentrically with each other. The charge decay parameters were determined with the electric charge meter ICM-1 (induction charge method), produced by STFI. The instrument is controlled by a microprocessor and makes measurements with automatic calculations and display of the measured data.

Fabric specimen applied to measure half decay time and shielding factor was clamped between outer and inner rings over the field electrode.

The distance between the bottom of the field-measuring probe and the top of the ring was 50 mm. Resolution of an electronic electrometer is 0.05 pC, output voltage maximum ±20 V. The coefficient of variation of the values of half decay time was less than 5 %, while for the shielding factor it was less than 1 %.

The surface resistivity (ρ) of the fabrics was obtained from surface resistance measurement data using the equation [19]:

$$\rho = k \cdot R_s , \tag{1}$$

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

The factor k was calculated by the following equation [19]:

$$k = \frac{2\pi}{\ln(\frac{r_2}{r_1})} , \tag{2}$$

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

The geometrical factor (k) of the electrode used for the measurements was 19.8.

The charge decay characteristics were computed automatically. The value of the shielding factor (S) was obtained using equation [20]:

$$S = 1 - \frac{E_R}{E_{\max}} , \tag{3}$$

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.

RESULTS AND DISCUSSION

The experiments have shown that Polyester woven fabrics with silver plated conductive filaments have surface resistivity of the same magnitude as fabrics with stainless steel fibres. As it was found in the paper [17], the resistivity of fabrics definitely increases with the increase of the distances between conductive yarns in the fabrics.

The number of abrasion rubs does not have very distinct influence upon this value. For example, surface resistivity of fabric with 71 nonconductive yarns between conductive ones varies from $2.53 \times 10^{12}\ \Omega$ (before abrasion) till $2.90 \times 10^{12}\ \Omega$ (after 45 000 abrasion rubs). Figure 1 shows that surface reistivity of all tested fabrics increases for about $0.2 \times 10^{12}\ \Omega$ after each 5 000 abrasion rubs.

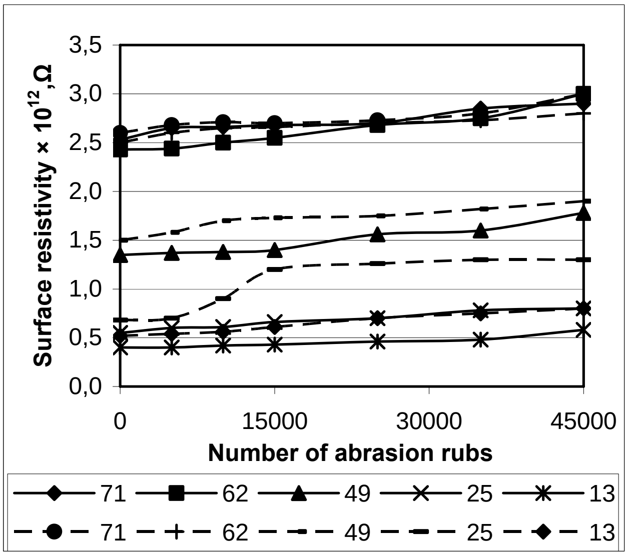

Fig. 1. Surface resistivity of PES fabrics versus the number of abrasion rubs (——— fabrics with S-Shield PES yarns; — — — fabrics with Silverflex-170 yarns) (the legend shows the number of weft yarns between conductive ones)

The values of surface resistivity before abrasion of fabrics with different conductive yarns were very close, e. g., the surface resistivities of fabrics with 13 PES weft yarns between conductive ones are – $0.52 \times 10^{12}\ \Omega$ (for fabrics with S- Shield PES yarns), $0.55 \times 10^{12}\ \Omega$ (for fabrics with Silverflex-170 yarns).

For fabrics with silver plated filaments this measured value becomes higher increasing abrasion rubs than for fabrics with stainless steel fibres (see Figure 1).

Surface resistivity of fabrics with longest distances between conductive yarns (71 and 62 nonconductive yarns between conductive ones) of both types of fabrics are almost the same after each abrasion period.

The magnitude of vertical resistance is at a scale of $10^3\ \Omega$ for the Polyester fabrics with S-Shield PES yarns (see Figure 2). Test results have shown that the shorter is the distances between conductive yarns, the more obvious changes of vertical resistances are seen increasing the number of abrasion rubs. The magnitude of vertical resistance of PES fabrics with silver plated filaments is in some orders higher than for fabrics with metal fibres (see Figure 3). The fabrics with S-Shield PES yarns the same as fabrics with Silverflex-170 yarns became more porous after 15 000 abrasion rubs. Certain fabric zones looked like frameworks after 45 000 abrasion rubs. The resistance increases about 20 Ω comparing values of fabrics before with fabrics after 45 000 abrasion rubs.

It is also obvious that vertical resistance of fabrics of both groups highly decreases with shortening the distances between the conductive yarns. The same dependence was described in study [17] for Polyester fabrics with conductive yarns before and after washing.

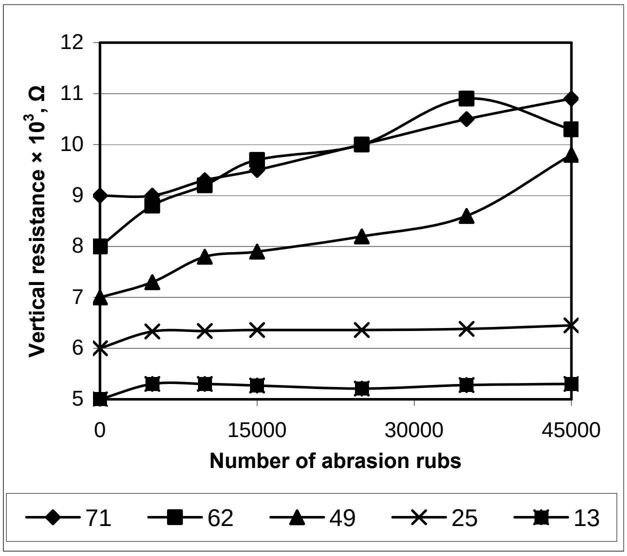

Fig. 2. Vertical resistance of PES fabrics with S-Shield PES yarns versus the number of abrasion rubs (the legend shows the number of weft yarns between conductive ones)

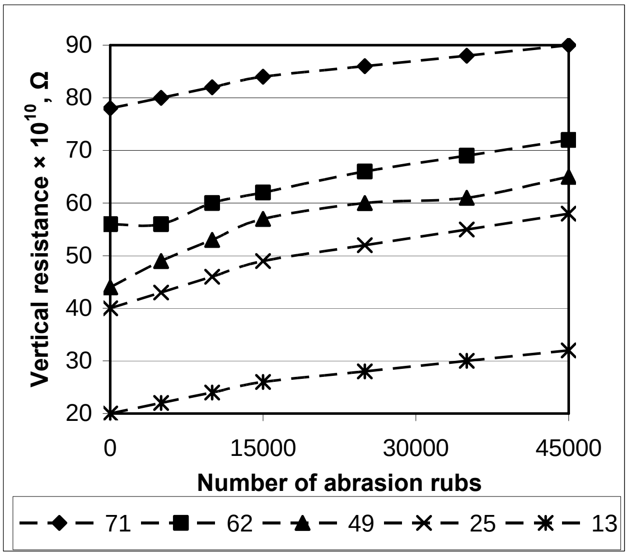

Fig. 3. Vertical resistance of PES fabrics with Silverflex-170 yarns versus the number of abrasion rubs (the legend shows the number of weft yarns between conductive ones)

The vertical resistance studied in [21], at air temperature (22 ±2) °C and relative humidity (41 ±2) %, of polypropylene, polyamide and polyethylenterephtalate woven fabrics reached the level of $2.4 \times 10^{14}\ \Omega\text{m} - 1.7 \times 10^{15}\ \Omega\text{m}$. As we can see from Figures 2 and 3, the vertical resistance of PES woven fabrics with S-Shield PES yarns is at a scale of magnitude $10^3\ \Omega$, with Silverflex-170 yarns – $10^{10}\ \Omega$. The vertical resistances of these investigated fabrics are lesser than of fabrics with nonconductive woven fabrics, examined in [21].

Shielding factor of PES woven fabrics with metal fibres and silver plated yarns depends on the intensiveness of abrasion. The values of shielding factor increases with increase of conductive yarns in the fabrics. It drops depending on the level of damage done during abrasion. As we can see from Figure 4, the most obvious chops of shielding factor is for PES fabric with 25 S-Shield PES yarns after 35 000 abrasion rubs and for fabric with 49 S-Shield PES yarns – after 5 000 rubs. This is because the fabric was damaged the most in abrasion (i. e. the fabric became more porous).

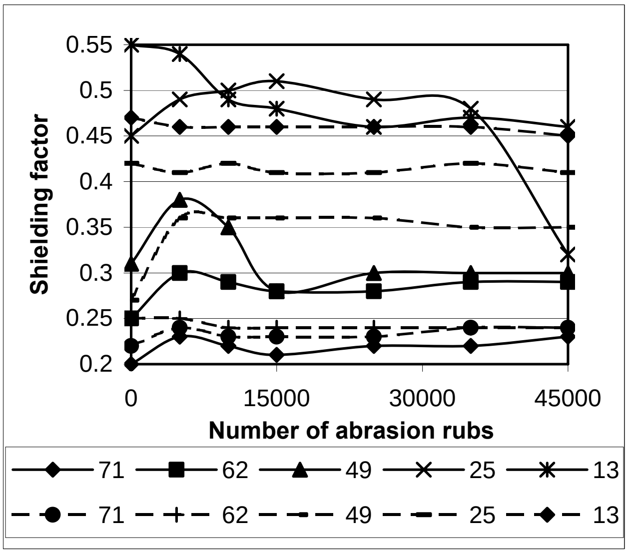

Fig. 4. Shielding factor of PES fabrics versus the number of abrasion rubs (——— fabrics with S-Shield PES yarns; — — — fabrics with Silverflex-170 yarns) (the legend shows the number of weft yarns between conductive ones)

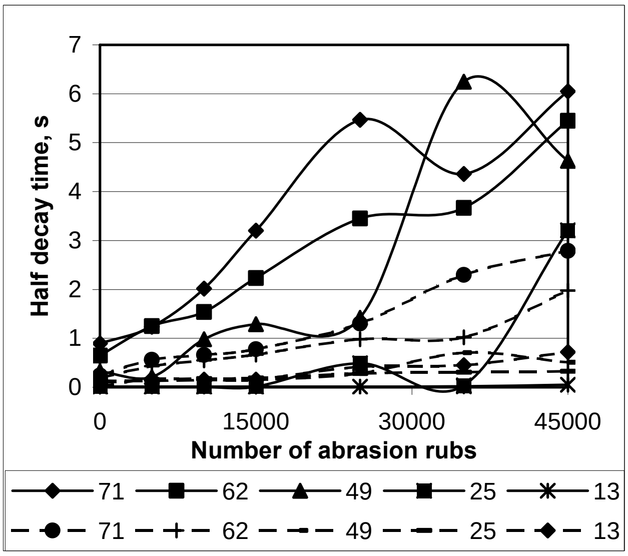

Fig. 5. Half decay time of PES fabrics versus the number of abrasion rubs (——— fabrics with S-Shield PES yarns; — — — fabrics with Silverflex-170 yarns) (the legend shows the number of weft yarns between conductive ones)

Shielding factor of fabrics also depends on the distance between conductive yarns. It increases with shorter distances between antistatic (conductive) yarns. This parameter is better for fabrics with stainless steel fibres, because their values are a little higher and close to unity, than for fabrics with silver plated filaments.

Figure 5 shows that the charge decays faster in less damaged fabrics with shorter distances between antistatic yarns. Charge decay time is less than 0.01 s for fabric with 13 PES yarns between yarns with metal fibres. The same value is obtained for the fabric with 25 PES yarns between conductive (S-Shield PES) yarns (only for fabrics abraded less than 25 000 rubs). The other fabrics with metal fibres have quite long charge decay time and it increases increasing abrasion intensiveness.

Half decay time of fabrics having silver plated filaments in their structure is shorter compared to fabrics with S-Shield PES yarns. Silver plated filaments did not break or were not damaged in some other way, so charge decay time depends only on the distances between conductive yarns and the state of non-conductive yarns in the fabrics after abrasion. The shorter is this distance, the quicker charge decays from the fabric.

R. Kacprzyk and W. Mišta were carried out measurements on plain weave fabrics made of polypropylene, polyamide and polyethylenterephtalate fibres. The values of the half decay time of these fabrics were measured for fabrics as produced (without any pretreatment). The measurement was taken by the field-window method; the obtained values of half decay time fell within the range of 4 s to 10 s [21]. As we can see from the Figure 5, the half decay time of non-pretreated PES woven fabrics with conductive yarns is less than 1 s and increases increasing the abrasion rubs, but does not exceed 7 s.

The electrostatic properties of polyester wale-knitted fabrics with carbon compounds were investigated in [22]. In this case, the distances between electro-conductive bands were 10 mm. Surface and through (vertical) resistances, times of half-decay and screening coefficient (shielding factor) were investigated in this study. The same as in our study, the neutralization of the charge accumulated on the sample starts very quickly and then proceeds slowly. Rapid accumulation is result of carbon compound (in our case – conductive yarns) and it becomes slower because of polyester. The analysis also indicates that the electrostatic properties depend on the structural features of the background too.

The magnitude of the surface resistivity of PES/cotton fabrics with conductive S-Shield PES yarns is at a scale of 10^{11} Ω (see Figure 6). It is at one order lower than for PES fabrics with the same conductive yarns (Figure 1). The value of investigated parameter increases with the increase in abrasion rubs. The increase is very distinct.

Fabrics with 12 and 22 non-conductive yarns between conductive ones in the fabrics have the same surface resistivity during the whole experiment – the values of both fabrics coincident with values of fabrics before and after 35 000 abrasion rubs. The influence of abrasion rubs upon the surface resistivity of fabrics with longer distances between yarns with metal fibres is very distinct.

Small pills are covering a big part of specimen surface after 5 000 abrasion rubs. Increasing number of abrasion rubs on the fabrics results in the vanishing of pills, but appearing of surface fuzzing. More fabrics are abraded more surface fuzzing is observed. Surface resistivity increases with the increase of surface fuzzing in the fabrics.

Surface resistivity is the lowest for the fabric with 12 PES/Cotton yarns between Silverflex-170 conductive yarns

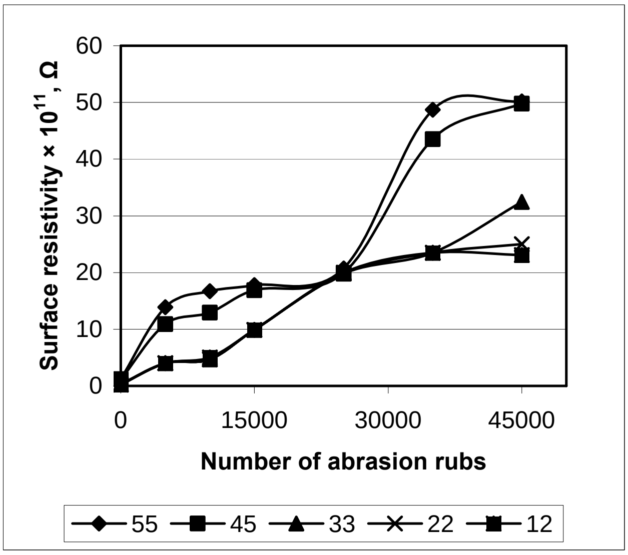

Fig. 6. Surface resistivity of PES/cotton fabrics with S-Shield PES yarns versus the number of abrasion rubs (the legend shows the number of weft yarns between conductive ones)

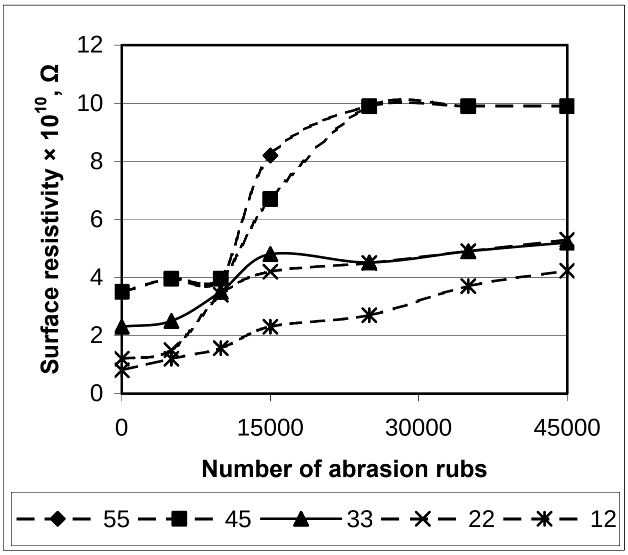

Fig. 7. Surface resistivity of PES/cotton fabrics with Silverflex-170 yarns versus the number of abrasion rubs (the legend shows the number of weft yarns between conductive ones)

(see Figure 7). The value increases from 0.8×10^{10} Ω (for fabrics as received) up to 4.23×10^{10} Ω (after 45 000 rubs) increasing the number of abrasion rubs on the fabric. The fabrics with 22 and 33 non-conductive weft yarns between conductive ones have very close surface resistivity.

Fabrics as received with longer distances between yarns with silver plated filaments have lower surface resistivity comparing to the same fabrics with 22 and 33 non-conductive weft yarns, but the resistances increase very distinctly increasing the number of abrasion rubs. As it was seen with PES/cotton fabrics, after 5 000 rubs, small pills were seen on the surface of the fabrics. Increasing the number of abrasion rubs, slight surface fuzzing without pills is observed and it increases with the intensiveness of abrasion.

Vertical resistance of PES/cotton fabrics with PES/INOX yarns in their structure is at a scale of 10^5 Ω. For fabrics with the same conductive yarns, but with PES instead of PES/Cotton yarns it is at a scale of 10^3 Ω (see Figure 2 and Figure 8). The resistance of the fabric with the shortest distance between conductive yarns is quite low. It increases very slightly with the increase of abrasion rubs and varies from 0.1×10^5 Ω till 0.3×10^5 Ω. Vertical resistance of the other woven fabrics increases distinctly with the increase of abrasion intensiveness.

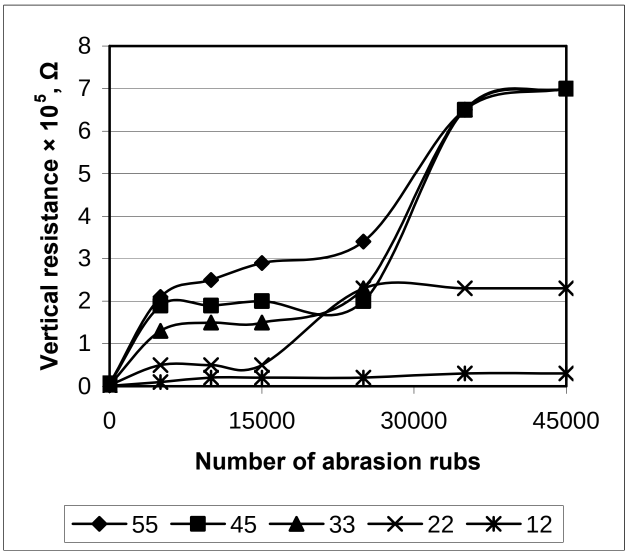

Fig. 8. Vertical resistance of PES/cotton fabrics with S-Shield PES yarns versus the number of abrasion rubs (the legend shows the number of weft yarns between conductive ones)

Especially it is seen for fabrics with more PES/Cotton yarns between conductive ones. The resistance depends not only on the distance between nonconductive yarns, but also on the fibre content of used yarns. Each fibre has different conductivity and different resistance. The changes on the surfaces of fabrics after abrasion determine the values of vertical resistance. Fuzzier in the surface of the fabric, the higher is the vertical resistance. More non-conductive yarns are in the fabric, the bigger is surface fuzzing (see Figure 8).

The vertical resistance of PES/cotton fabrics with silver plated filaments in their structure is at a scale of 10^9 Ω. The resistance increases after each 5 000 rubs by $0.1\ \Omega \div 0.2\ \Omega$. The more fabrics are abraded, the higher is the vertical resistance. The unevenness of the fabric surface influences this value (see Figure 9).

The vertical resistance of the webs (all from viscose raw materials), prepared by dry-laying and wet-laying and later carbonized and activated with the aim of obtaining carbon and active nonwovens were studied in [23]. The experiments were carried out at the same conditions as indicated in our research work. The resistance of viscose is 8.27×10^8 Ω. It was found that the best active carbon nonwoven was obtained from precursors, manufactured by the needling technique (the active nonwoven's resistivity obtained equaled 0.27 Ωm).

The best electrostatic properties in our research work we received for samples with the biggest amount of conductive yarns in their structure.

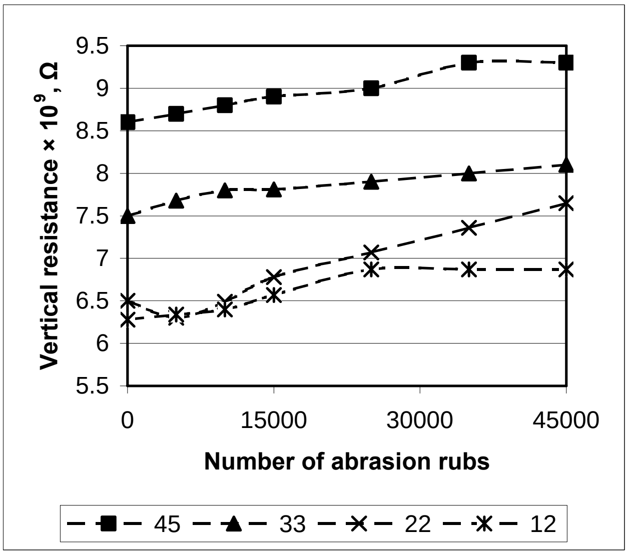

Fig. 9. Vertical resistance of PES/cotton fabrics with Silverflex-170 yarns versus the number of abrasion rubs (number the legend shows the number of weft yarns between conductive ones)

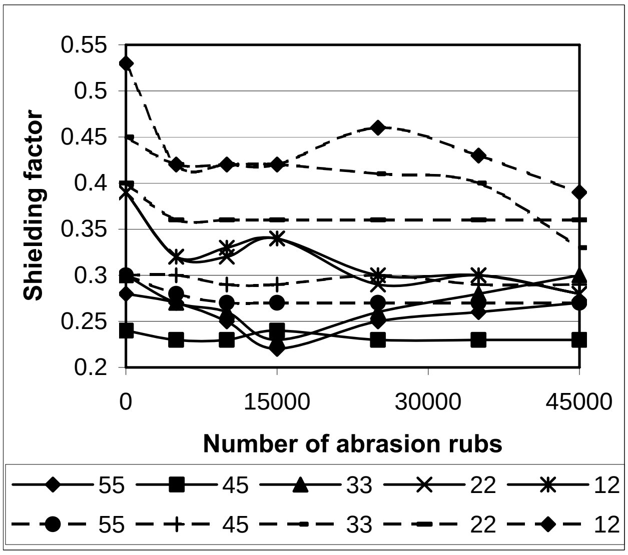

Fig. 10. Shielding factor of PES/cotton fabrics versus the number of abrasion rubs (——— fabrics with S-Shield PES yarns; — — — fabrics with Silverflex-170 yarns) (the legend shows the number of weft yarns between conductive ones)

Shielding factor is very sensitive to fabrics abrasion intensiveness. The more damage is made to the fabric lower is this parameter. Fabrics with 55 and 33 non-conductive yarns between PES/INOX yarns after 15 000 rubs have the smallest shielding factor. The best shielding effect have the fabrics with the smallest amount of antistatic yarns in their structure. The smallest shielding factor is for fabric with 45 PES/cotton yarns between conductive ones.

As it is seen in the Figure 10, the shielding factor of PES/cotton fabrics with 55 and 45 weft yarns between S-Shield PES yarns is very low. It is from 0.27 till 0.3. For other fabrics this parameter decreases with the increase of the number of abrasion rubs.

The best shielding effect has woven fabric with 12 non-conductive weft yarns between conductive ones, but the more this fabric is abraded, the lower is the value of shielding factor. As we can see from the Figure 10, woven fabrics with metal fibres in their structure have lower shielding factor than fabrics with silver plated yarns.

The half decay time parameter is very sensitive to the unevenness of woven fabrics surfaces. The shortest time is for fabric with 22 weft non-conductive yarns between conductive S-Shield PES yarns.

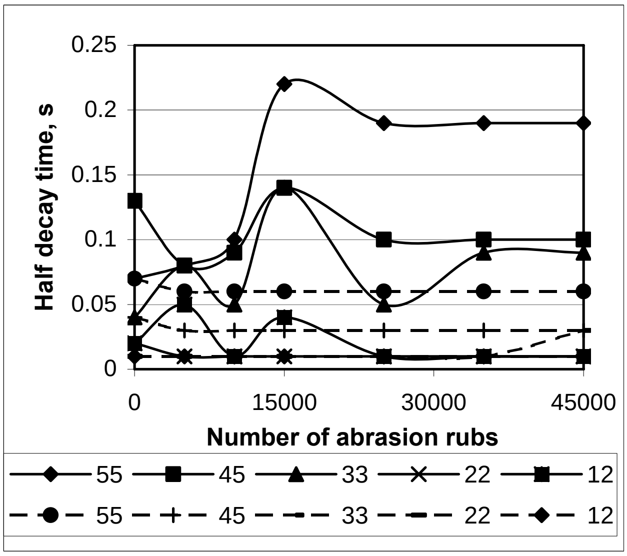

Fig. 11. Half decay time of PES/cotton fabrics versus the number of abrasion rubs (——— fabrics with S-Shield PES yarns; — — — fabrics with Silverflex-170 yarns) (the legend shows the number of weft yarns between conductive ones)

For fabric with 12 PES/cotton yarns between conductive yarns half decay time varies from less than 0.01 s till 0.09 s, increasing the number of abrasion rubs till 45 000. The longest half decay time of PES/cotton fabrics with PES/INOX yarns is for fabrics with longer non-conductive distances between conductive yarns and the parameter increases with the increase of abrasion rubs. The half decay time is very sensitive to the unevenness of fabric surface. More fibres slipped from the yarns is on the surface after abrasion, longer are half decay time.

The shortest half decay time is of fabrics with 12, 22 and 33 PES/Cotton yarns between Silverflex-170 ones, i. e. it is less than 0.01 s The half decay time distinctly increases after 35 000 abrasion rubs for the last woven fabric (see Figure 11). Other fabrics, with more non-conductive yarns in their structure, have longer half decay time. This time remains almost the same, despite the number of abrasion rubs. Here unevenness does not have very big influence, because silver plated filaments do not broke. All surface fuzzing or pills rise from staple yarns.

CONCLUSIONS

Vertical resistance and surface resistivity of fabrics with conductive yarns increase with the increase in number of abrasion rubs. The longer are the intervals between conductive yarns, the higher are measured resistance values. Vertical resistances are lower for the fabrics with S-Shield PES yarns in their structure.

Distinct surface fuzzing on the PES/cotton fabrics is seen after abrasion, because ends of staple fibers slide from the yarns. This results in worse electrostatic characteristics of fabrics, i. e. high surface and vertical resistances and long charge decay time.

Shielding factor decreases with the increase in abrasion rubs. Due to surface fuzzing the shielding factor of woven fabrics with PES/INOX yarns a decrease more than of fabrics with Silverflex-170, increasing the intensiveness of abrasion.

Half decay time increases with the increase in the number of abrasion rubs. It is sensitive to the level of surface fuzzing.

Therefore, it was found that while the number of conductive yarns inserted into the fabrics improved fabrics electrostatic properties, the abrasion led to the notable impairment of the protective power of the fabrics to incendiary discharges.

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