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Functional Upholstery Materials for Protection Against Electrostatic Risk

Abstract
Textile products designed for areas protected against electrostatic discharge (ESD) should be characterised by a very low propensity to generate electrostatic charge. Functional pile knitted and woven textile upholstery materials for different purposes have been designed to meet electrostatic prevention requirements. A comprehensive evaluation of their electrostatic properties was based on the measurement of surface and volume resistance, R_s and R_v, as well as on the charge decay time tested by means of three different methods: triboelectric, induction and corona discharge. The propensity of these materials to charge was also analysed in model conditions simulating the use of a castor chair according to the new, so-called "chair method" developed especially for this purpose. The electrostatic voltage (V) was measured for an operator dressed in different clothing who used castor chairs covered with ordinary fabrics and with the textile upholstery materials designed. All the electrostatic tests were performed at 23 ± 1 °C and 25 ± 2% relative humidity. The materials designed are characterised by permanent antistatic properties: surface resistance $R_s = 10^3 – 10^{10}$ Ω; the charge decay half time t_{50} < 0.01 – 1.80 s and electrostatic voltage V = 0.1 – 0.6 kV. Flame retardant materials meet the requirements for furniture upholstery in public utility buildings and/or for car upholstery.

Key words: *textile upholstery material, ESD, permanent antistatic, charge decay time.*

Introduction

Nowadays, interest in protection against electrostatic discharge (ESD), regarded as an important issue, is still growing. ESD may lead to serious economic losses and can also be hazardous to humans. In zones where substances with low values of ignition energy occur, ESD may involve a high risk of fire or explosion [1]. In the age of 'the electronic civilization', ESD has become a problem not only for the electronics industry. High-tech electronic systems accompany us nearly everywhere, at work, in private places, modern cars, planes, ambulances with resuscitation equipment, etc. Occurrences of low level ESD from people have been reported to cause device failures and yield losses [2]. It was found that 60 – 90% of defective devices were damaged by ESD [3]. Angelopoulos [4] states that 15 billion dollars a year is attributed by the U.S. electronics industry to ESD damage alone. If there are no suitable conditions for charge dissipation, they accumulate on the material and the human body generating a static electricity voltage even at a level of several dozens of kV.

Antistatic textile upholstery materials are one of the key elements of comprehensive protection against the effects of static electricity. In numerous areas, their use is essential to secure the safety of people and infrastructures [5 - 7]. These materials must be adjusted to different functional applications and must protect against static electricity during their whole life cycle [7, 8]. The application of impermanent finishes using antistatic surfactants has been found not to be the best solution in view of the specificity of textile upholstery materials. Such chemicals are usually removed during conservation procedures, which nowadays involve vacuum cleaning, and their reapplication diminishes the aesthetics of seats and upholstered furniture, accelerating their wear out. Functional textile upholstery materials designed for areas protected against ESD (e.g., institutions of public utility) must also meet anti-fire requirements to ensure public safety. In general, these materials must combine such qualities as safety, comfort and aesthetics.

The major aim of this study was to design and produce new functional pile knitted and woven textile upholstery materials with the use of weaving and knitting techniques so that relevant selection of

Table 1. *Raw characteristics of pile knitted materials (plush).*

Sample	Pile warp	Pillar warp	Weft warp
P1	Antistatic flame retardant yarn composed of modified PAN Kanecaron with conductive staple polyamide fibres containing carbon inclusions side to side (1). Content of conductive fibres 2%.	PES DTY/PES Trevira CS + conductive twisted yarn composed of polyester filaments and conductive polyamide with carbon shell filaments (2). Content of conductive twisted yarn 25%.	PES DTY/PES Trevira CS
P2	PES DTY and pattern conductive threads composed of staple polyester fibres with an admixture of steel fibres (3). Content of conductive fibres 2.1%.	PES DTY/PES Trevira CS	PES DTY/PES Trevira CS

Table 2. *Raw characteristics of woven materials.*

Sample	Warp	Weft
T4	PES DTY/PES Trevira CS and conductive threads composed of staple polyester fibres with admixture of steel fibres (3). Content of conductive threads 1.2%.	PES DTY/PES Trevira CS + PES Thermo-shrinkable thread TPE (4)
T5	PES DTY and conductive threads composed of staple polyester fibres with an admixture of steel fibres (3). The conductive threads create a pattern in the jacquard structure. Content of conductive threads 2.1%.	PES ATY/PES Trevira CS
T6	PES DTY and conductive threads composed of staple polyester fibres with an admixture of steel fibres. (3) The conductive threads are hidden in a harness structure. Content of conductive threads 2.1%.	PES ATY

the structure, type, involvement and arrangement of raw conductive materials ensure lasting protection against ESD hazards, fit for the conditions these materials are to be used in. In designing these materials, not only their anti-electrostatic but also flame retardant properties were taken into account. The new structure of fibre with relief designed was aimed at improving the comfort of seats used by persons who have been immobilised for a long period of time and are at risk of decubitus ulcer/bedsore. The authors made an attempt to combine all functions with an aesthetic appearance and attractive design, which is an essential aspect of the value of upholstery materials. To meet this objective, three modes were used: the applying of conductive elements to produce the design; the masking of these elements in the material structure and a solution combining these two ways. To develop a new method, the so-called "chair method", of investigating the propensity of upholstery materials to generate an electrostatic charge in the conditions of their use was another objective of this study.

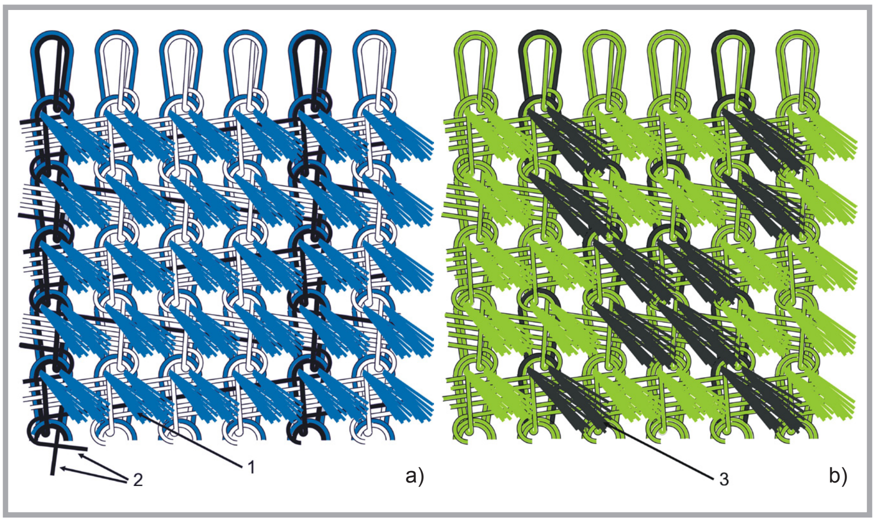
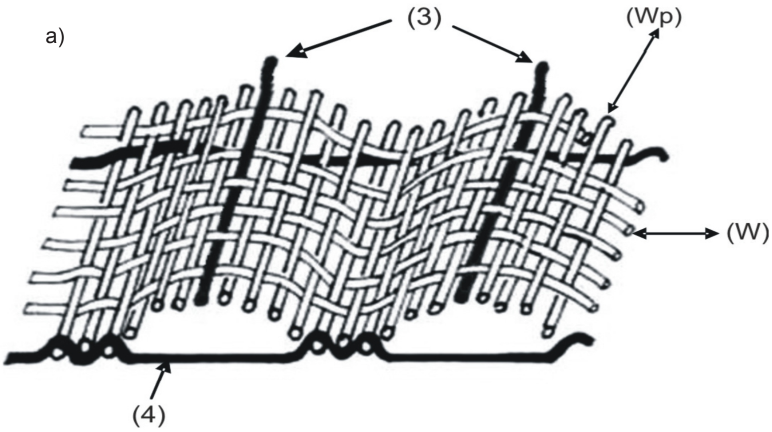


Figure 1. Distribution of conductive elements in a plush knitted structure: a) plain - P1; b) patterned - P2, where (1) - staple conductive fibres in all threads of the pile, (2) - threads with conductive filaments in bottom layer; and (3) - conductive threads with steel staple fibres creating the pattern.

Materials

The selection of textile raw materials and conductive elements, as well as their arrangement in the structure of upholstery materials should provide optimum conditions for electrostatic charge dissipation [9, 10] and ensure compliance with fundamental endurance and utility requirements, which have been set for upholstery materials used in interior and car outfits. The design aspect is less impor-



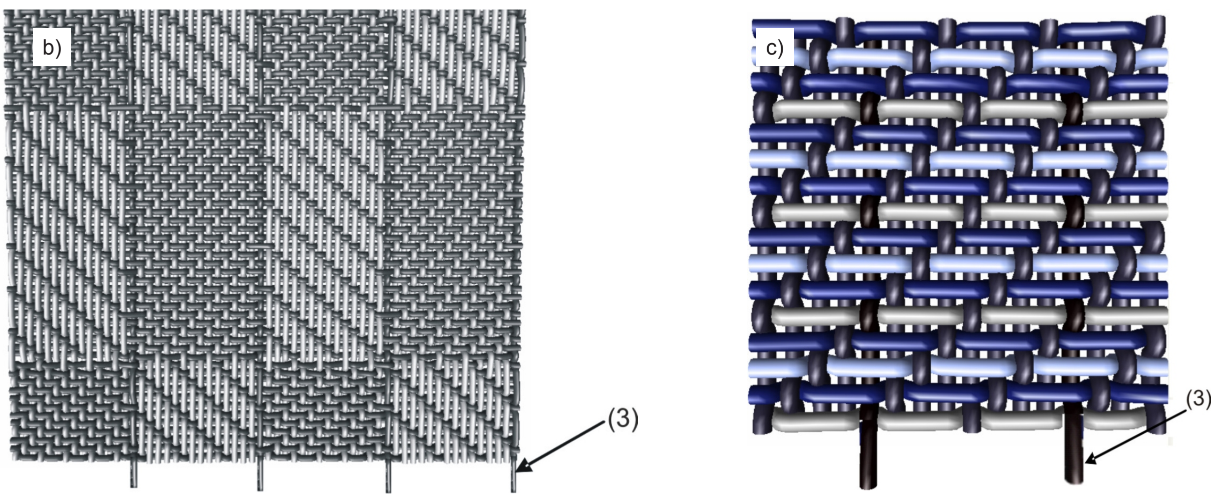


Figure 2. Schematic diagrams of woven fabric structures; a) elastic harness woven fabric with relief - T4; b) patterned jacquard structure – T5; c) plain harness structure – T6, where (3) - conductive threads, (4) - thermo-shrinkable, elastic monofilament.

tant in protective clothing, but antistatic functional upholstery materials must be characterised by attractive designs and colours fitting nicely into the environment in which they are to be used. Therefore, their structure should be designed in such a way that allows to mask conductive elements as well as create decorative elements. In the developed structures of knitted and woven upholstery materials, a diversified arrangement of three types of conductive elements (filaments with a carbon shell, staple hybrid fibres with carbon inclusions side to side, and steel staple fibres) was applied. Polyester yarn, ATY and DTY, and flame retardant yarn - Kanecaron and Trevira CS were the major textile raw materials used.

Upholstery materials with pile (plush)

The raw characteristics of pile knitted plush produced using the technique of double knitting with binding warp are presented in ***Table 1***. ***Figure 1*** presents two examples of knitted plush: plain (a) – P1 and patterned (b) – P2.

In the P1 structure, staple conductive fibres with the "side to side" carbon component are placed in all threads (1) which make the pile. Conductive twisted yarn with carbon shell filaments (2) were applied in the structure of warps, creating the plush bottom layers; which may vary in their distribution in warp and weft arrangements depending on the level of electrostatic properties required. P2 represents another example of warp knitted plush. The pile of this patterned knitted plush was made of textured polyester yarn. In the structure of patterned plush P2, conductive threads of polyester staple fibres with an admixture of steel fibres (3) distributed in the pile created the pattern of a particular design

Harness and jacquard woven fabrics

The raw characteristics of woven fabrics produced using the harness and jacquard technique are presented in ***Table 2***.

Elastic harness woven fabric with relief

The T4 fabric with a relief structure presented in ***Figure 2.a***), characterised by an enhanced elasticity towards the weft, was produced with the use of the harness weaving technique. In the arrangement of polyester weft (W), threads, thermo-shrinkable elastic monofilaments (4) and conductive threads with staple steel fibres (3) were used and arranged in the polyester warp (Wp) structure at an appropriate distance with interweaves. Conductive and elastic threads of the same colour scheme distinguished them from other ones, which formed the background and created an element of a given pattern.

Flat jacquard and harness woven fabrics used in cars

Colourfully woven antistatic fabrics, T5 and T6, presented in ***Figures 2.b*** and ***2.c*** respectively, were produced with the use of conductive threads with steel fibres (3) in the warp structure. Due to appropriate colouring, arrangement, pattern and interweave designing, conductive threads represent a pattern element (T5) or remain invisible (T6).

Methods of assessing electrostatic properties

Surface and volume resistance as well as the charge decay time were defined for the knitted and woven textile upholstery materials designed. Owing to the fact that an electric charge can be generated on materials by different ways/mechanisms, all materials designed were tested using three different methods: triboelectric, induction and corona discharge, to measure the charge decay time [11 - 13]. Using the newly developed "chair method" for assessing upholstery materials, their propensity to static electrification was also analysed [14].

Electrical resistance

The surface resistance was measured according to Standard EN 1149–1:2008 and the volume resistance according to Standard PN EN 1149–2:1999 by applying an appropriate arrangement of electrodes and a teraohmeter 6206 (ELTEX, Germany).

The charge decay time

Corona discharge method

Measurements were taken as specified in Standard PN EN 61340–2–1:2004. The material surface was charged by corona discharge from the electrode shifting between the field sensor and material surface. The measurements were performed at a charge voltage of 10 kV for a charge time of 0.02 s. During these measurements, the following parameters were recorded:

- maximum surface voltage U_{max} (maximum voltage obtained for the sample at an inflicted voltage for a defined charge time);
- half-decay time t_{50} (time from U_{max} to 50% of this value);
- time $t_{1/e}$ (time from U_{max} to $1/e$ of this value);
- time t_{10} (time from U_{max} to 10% of this value).

The measurements were performed on the ungrounded bottom side of the material.

Induction method

The principle of this method, which is consistent with Standard PN EN 1149–3:2007, is that the field electrode stepwise, supplied with high voltage of 1200 V for 30 µs, generates a charge directly under the surface of the sample tested. The measurement specimen placed above the material tested registers the following field intensity alterations induced by the presence of the sample:

- half-decay time t_{50} (after which the value of field intensity, E_R, reaches 50% of the initial value);
- shielding factor, $S = 1 - E_R/E_{max}$

where: E_R is the maximum voltage value of the field with a sample and E_{max} is the maximum voltage value of the field without a sample.

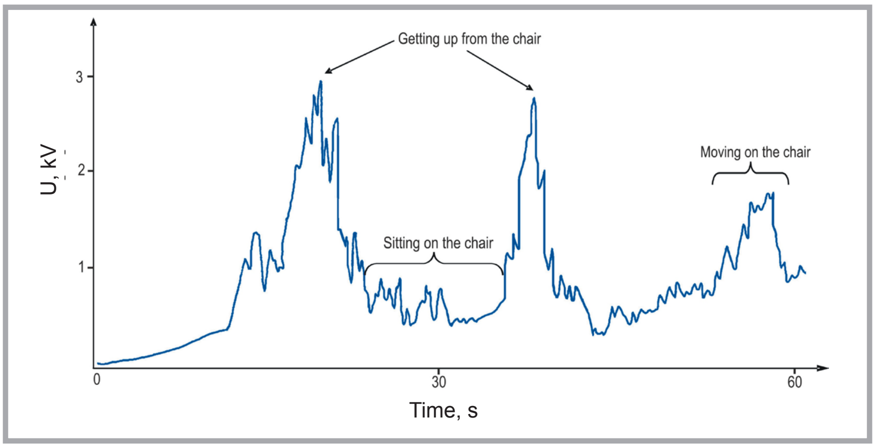


Figure 3. *Example of the voltage registration on an operator's body while using a chair.*

Triboelectric method

The triboelectric method, which is consistent with Standard PN EN 1149–3:2007, involves discharge ignition on the material under test by rubbing with cylindrical rods made of conductive polyethylene or aluminum. In this technique, the following parameters are registered:

- maximum voltage of the electrostatic field, E_0 in kV/m;
- field voltage, E_{30} in kV/m (voltage 30 s after reaching the E_0 value);
- half-decay time, t_{50} (time from reaching the E_0 value to 50% of this value).

Propensity to static electrification investigated by means of the 'chair method'

Measurements of the charge decay time and resistance provide a certain piece of basic information about electrostatic properties shown by different materials. However, having obtained this information, it is not always possible to predict the behaviour of materials in a real-life situation in general with respect to triboelectric mechanisms and protection against electrostatic hazards in particular. Current researches are ardently seeking a methodology and theoretical models that would broaden this branch of knowledge [9, 14 – 18]. Propensity to static electrification was investigated by means of the 'chair method', following the method developed specially for assessing the upholstery materials designed [14]. The basic principle of this method is to illustrate the conditions in which a typical castor chair is used. The study procedures are based on a preliminary analysis of the voltage generated on the body of the chair user during typical computer operation activities (***Figure 3***). A defined series of these activities comprised the following: sitting down on the chair, sitting at rest, putting the back against the back of the chair, moving on the chair, getting up from the chair and sitting down again. A castor chair with a leakage to the ground resistance of $R_U \geq 10^{14}$ Ω was placed on an insulating mat with an electrical volume resistance of $R_V \geq 10^{13}$ Ω. Before starting the test, the computer operator (capacity of 150 pF), in footwear (volume resistance of $R_V \geq 10^{13}$ Ω) and dressed in underwear and bottom cotton clothing (surface resistance of 10^{11} Ω), put on specific outerwear made of different homogeneous textiles and textiles with added conductive threads with electrostatic characteristics, as given in ***Table 3***.

Table 3. *Electrostatic properties of clothing and fabric from the chair tested.*

Outerwear	Resistance		Charge decay – induction method	
	Surface R_S, W	Volume R_V, W	t_{50}, s	S
CO	5.3×10^{11}	6.8×10^{10}	5.280	0
WO	8.4×10^{12}	1.0×10^{12}	> 30	0
PA	1.1×10^{13}	1.6×10^{12}	> 30	0
VI	4.0×10^{11}	3.0×10^{10}	4.867	0
PES	1.1×10^{13}	1.8×10^{12}	> 30	0
PES 1 - with conductive threads along the warp, every 2 cm	1.3×10^{6}	1.3×10^{5}	> 30	0.260
PES 2 - with a net arrangement of conductive threads, coated on one side	1.1×10^{6}	8.0×10^{5}	< 0.01	0.687
S – ordinary polyester fabric from the test chair	7.4×10^{12}	8.5×10^{11}	9.94	0

Table 4. *Results of the tests performed and utility property requirements according to Standard PN EN 14465.*

Characteristics			Unit	Sample/ Requirements				
				P1	P2	T4	T5	T6
Tensile strength	Mean of max. force	along	N	600	610	1700/A	1200/A	1100/A
		across		350	340	1900/A	1400/A	1300/A
	Mean of elongation at max. force	along	%	35.5	36.5	40	44	41.5
		across		44.0	44.0	75	49	27.5
Tear strength		along	N	64/A	63/A	76/A	124/A	139/A
		across		50/A	48/A	103/A	123/A	181/A
Abrasion resistant			stroke number	16000/C	35000/A	10000/C	18000/B	60000/A
Colour fastness to artificial light			degree	5/B	7/A	4/C	7/A	6/A
Colour fastness to rubbing	dry	along.	degree	4 - 5/A	5/A	4 - 5/A	5/A	4 - 5/A
		across		4 - 5/A	5/A	4 - 5/A	5/A	4 - 5/A
	wet	along		4/A	4 - 5/A	4 - 5/A	5/A	4 - 5/A
		across		4/A	4 - 5/A	4 - 5/A	5/A	4 - 5/A
Mass per unit area			g/m2	390	406	417	336	346

Table 5. *Results for the electrical resistance and resistivity.*

Sample	Surface resistance R_S, Ω		Volume resistance R_V, Ω	Surface resistivity r_S, Ω	Volume resistivity r_V, Ω
	top	bottom			
P1	3.8×10^{9}	3.1×10^{9}	3.8×10^{6}	7.5×10^{10}	4.6×10^{6}
P2	6.3×10^{10}	2.9×10^{10}	2.9×10^{10}	1.2×10^{12}	1.9×10^{10}
T4	$< 2.0 \times 10^{3}$	1.2×10^{12}	1.5×10^{11}	$< 4.0 \times 10^{4}$	1.7×10^{12}
T5	$< 2.0 \times 10^{3}$	$< 2.0 \times 10^{3}$	$< 2.0 \times 10^{3}$	$< 4.0 \times 10^{4}$	$< 7.8 \times 10^{3}$
T6	$< 2.0 \times 10^{3}$	$< 2.0 \times 10^{3}$	$< 2.0 \times 10^{3}$	$< 4.0 \times 10^{4}$	$< 7.1 \times 10^{3}$

First, the charge was neutralised on the body of the operator standing on the mat and holding a hand electrode connected to a voltmeter to ensure that the potential of the charge equalled zero. Then the operator sat down on the chair and repeated a series of activities for 60 s. In the meantime, the voltage generated on the operator's body was recorded. Following each single test, the chair and clothing were neutralised with an ioniser. Five measurements were taken for each version — castor chair upholstery/outerwear.

Testing conditions

The tests were conducted in a bulky, air conditioned chamber (HERAUS, Germany), at 23 ± 1 °C and 25 ± 2% relative humidity after a 48-h acclimatisation of the textiles, clothing and test unit in the same conditions.

Flammable properties

The materials designed to be used as car upholstery were assessed for their fire resistance according to Standard PN-ISO-3795:1996. Combustibility level B,

Table 6. Results for the charge decay time.

Sample	Method											
	Corona				Induction		Triboelectric					
							Aluminum			Polyethylene		
	U_{max}, V	t_{10}, s	$t_{1/e}$, s	t_{50}, s	t_{50}, s	S	E_{max}, kV	E_{30}, kV	t_{50}, s	E_{max}, kV	E_{30}, kV	t_{50}, s
P1	- 439	0.39	0.12	0.07	< 0.01	0.79	0	0	0	+2.0	0	0
P2	- 1939	0.83	0.24	0.15	1.80	0	+10.0	0	2.7	+176.6	0	2.8
T4	- 619	0.88	0.23	0.14	< 0.01	0.61	0	0	0	+12.7	+2.7	5.9
T5	- 75	0.17	0.05	0.03	0.02	0.39	0	0	0	+1.8	0	0
T6	- 56	0.18	0.06	0.04	0.03	0.36	0	0	0	+1.3	0	0

measured by the relation between the length of burns in the ample and the time of its burning in mm/min was determined. The combustibility of the materials designed for chair upholstery in public utility buildings was assessed using the methods described in Standards PN-EN 1021-1:2006 and PN-EN 1021–2:2006. The following criteria were adopted:

1. Smouldering
   - unsafe escalating combustion
   - test assembly burnt
   - smoulders to extremities or through thickness
   - smoulders more than 1 h or more than 100 mm from the ignition source
2. Flammability
   - unsafe escalating combustion
   - test assembly burnt
   - burns extremities or through thickness
   - burns longer than 120 seconds.

The materials were positively assessed as satisfying the requirements set in the two aforesaid Standards if neither smouldering nor flames occurred.

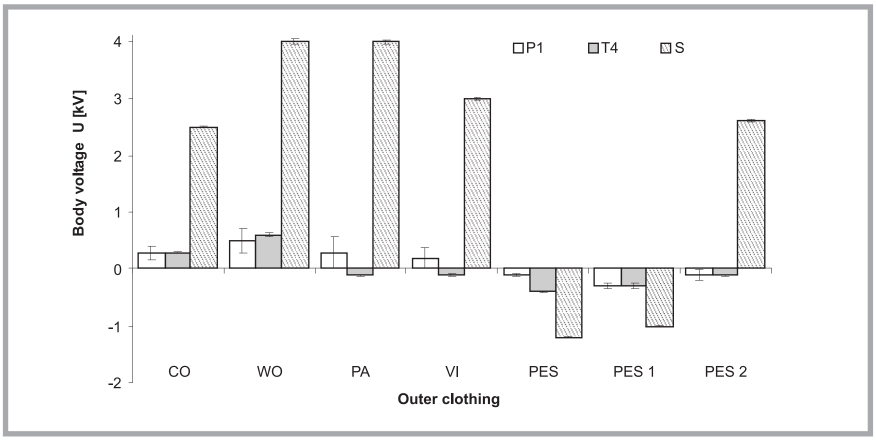


Figure 4. Means of maximum values of the operator's body voltage while using a chair covered with different textile upholstery materials.

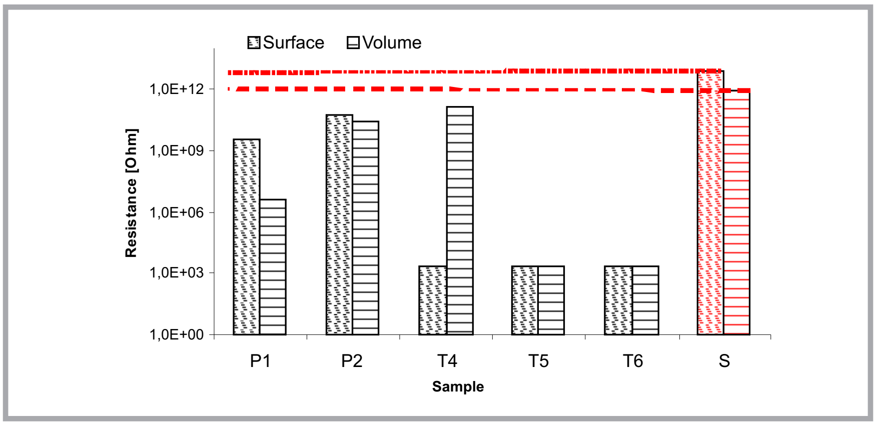


Figure 5. Comparison of resistance values for the materials developed and the ordinary test chair fabric S.

Results and discussion

Physicochemical and usefulness tests

The textile materials designed were subjected to standardised tests to assess a set of properties of textile upholstery materials intended for various purposes. The results of these tests are summarised in ***Table 4***. On account of the specific properties of relief elastic fabric T4, an elongation analysis was also performed, yielding the following results in %: permanent elongation (length-wise direction 1, cross-wise direction 2.5), elastic elongation (length-wise direction 6.4, cross-wise direction 19.6), and total elongation (length-wise direction.7.4, cross-wise direction 22.1). The textile upholstery materials designed meet the requirements defined for textiles intended to be used for upholstered furniture and car seats.

Electrostatic properties

The results of electrical resistance tests and resistivity determinations are given in ***Table 5***, and those of the charge decay time measurements in ***Table 6. Figure 4*** shows the results of voltage generated on the operator's body when using a castor chair covered with typical fabric S and two designed textile materials of completely different structure, raw material composition and the way in which conductive elements are arranged - plush P1 and relief woven fabric T4. The data are expressed as a mean of maximum voltages recorded in each test ± standard deviation. The means reported are for five measurements performed for each upholstery/clothing set.

Analysis of ***Figures 4*** & ***5*** shows that the diversified mode of introducing conductive elements into knitted and woven structures shapes the value of surface and volume resistance differently, but with regard to upholstery utility, it is essential that this kind of fabric be characterised by a particularly low surface resistance value. This is evidenced especially by the results obtained for fabric T4, which, despite a high value of volume resistance,

***Table 7.** Results of flammability tests.*

Sample	Possible application	Test method	Requirements	Result
P1	Upholstery materials for furniture in public utility buildings	PN-EN 1021-1:2006 PN-EN 1021-2:2006	Standard criteria must be fulfilled	Meets standard criteria
P2	Upholstery materials for cars	PN- ISO 3795:1996	B ≤ 100	Combustibility level B; along – 83.3 across – 63.5
T4	Upholstery materials for furniture in public utility buildings	PN-EN 1021-1:2006 PN-EN 1021-2:2006	Standard criteria must be fulfilled	Meets standard criteria
	Upholstery materials for cars	PN- ISO 3795:1996	B ≤ 100	Combustibility level B =0
T5	Upholstery materials for cars	PN- ISO 3795:1996	B ≤ 100	Combustibility level B; along - 81 across - 82

shows a low propensity to generate electrostatic charge when analysed with the use of the chair method. Fabric S, with a volume resistance value close to that of T4 but with high a surface resistance value, demonstrated undoubtedly the highest propensity to generate electrostatic charge. These are important observations since in a part of the criteria for assessing electrostatic properties, surface and volume resistance are considered interchangeably. Therefore, it appears that the kind of resistance studied should be specified precisely and linked with the purpose for which the material is to be used.

According to Standard EN 1149–5:2008, dissipative electrostatic material is that in which the half decay time is $t_{50} < 4$ s or the shielding factor $S > 0.2$ (tested using the induction method) or the surface resistance $\leq 2.5 \times 10^9\ \Omega$ on one surface at least. The literature standard values of the charge decay time measured with use of the corona discharge method apply to time $t_{l/e}$ or t_{10} as follows:

- a charge decay time from U_{max} to l/e of this value lower than 0.5 s,
- as charge decay time lower than 0.5 s for a surface voltage of 5000 V to 500 V.

A time $t_{l/e}$ not exceeding the standard value was obtained for all textile materials designed. The charge decay time values obtained for individual textile materials by means of the all three methods differed from each other; however, a certain dependence was retained. Using all the three methods, the lowest time t_{50} values were obtained for textile materials P1, T5 and T6. Using the induction method, time t_{50} met the criterion $t_{50} < 4$ s in all textile materials tested. The worst albeit positive result, 1.8 s, was obtained for plush P2. All the materials except for this plush met the criterion based on the shielding factor. Using the triboelectric method, plush P2 also showed the worst results. However, this method has no officially attributed evaluation criteria, but like the castor chair method it may be used in comparative studies of the propensity of materials to generate electrical charge.

For textile materials P1 and T4, the "chair method" yielded distinctly lower values of voltage on the operator's body for each type of outer clothing tested as compared with fabric S covering the test chair. The maximum voltage on the operator's body ranged from 1.0 to 4.0 kV when the chair covered with this material was used, whereas it was 0.1 ÷ 0.5 kV for plush P1 and 0.1 ÷ 0.6 kV for textile material T4, depending on the type of outer clothing. Similar voltage values were observed for textile materials P1 and T4, whose basic raw textile materials were differently placed in a triboelectric series [19], which indicates that in both cases, the conductive elements had been arranged in a manner that ensured efficient dispersion of electrostatic discharges generated during chair usage. Moreover, it should be stressed that this phenomenon occurs in conditions unfavourable to this process, when the value of leakage to the ground resistance of the chair tested is characteristic of an insulator, when the operator is insulated from the ground by footwear and an insulating mat, and when relative humidity is low [17, 20]. This is essential from a practical point of view, since textile upholstery materials during their usage are in contact with garments of a very diversified composition and structure of raw materials and specific contact surface. In common practice it is rather impossible to prevent the generation of discharges through the selection of textile upholstery materials and clothing. This approach can be applied in special zones/workplaces. Grant and Crown [17] suggest that prior to its use, a possible material combination should be tested in model conditions simulating typical activities in such zones. All the more so because the induction of electrostatic voltage in triboelectric processes is determined not only by the type of materials in contact with each other but also by numerous determinants, which is confirmed in observations made by Gonzales and Holdstock et al. [9, 21]. As shown by the results of theoretical and experimental studies carried out by Tappura and Nurmi [10], the kind of conductive elements should be properly selected and their distribution well controlled to obtain regular dissipation of electrostatic charges.

Analysis of the results obtained and literature data shows the necessity of comprehensive electrostatic tests of upholstery materials. Von Pidoll established that there are no standard methods and assessment criteria for these materials [22] in contrast to e.g. floor coverings, despite both these materials constituting a hazard to electrostatic safety.

Flammability tests

The results of flammability tests of the materials developed as flame retardants are given in ***Table 7***. The assessment of flammable properties of the materials designed depended on the utility purpose they were intended for. Plush P1 meets the criteria set for materials to be used in public utility buildings; plush P2 and fabric T5 satisfy the car upholstery requirements most frequently posed by car producers; and textile material T4 can be applied in both areas of utility, whose high safety standard plays a crucial role as it is designed for seat covers to be used by persons immobilised for long period of time.

Summary

The functional textile upholstery materials designed are characterised by permanent electrostatic and/or flame retardant properties. Electrostatic parameters for individual materials may differ depending on the way they are intended to be used, as well as on the resulting level of protection against electrostatic discharge, which at the same time involves economic aspects of their manufacture.

The materials designed fulfil the requirements set for electrostatic-dissipative materials, all of which are characterised by the charge decay time $t_{50} < 4$ s. These materials also meet the charge decay time criterion $t_{1/e} < 0.5$ s, linked with the corona discharge method. The materials designed yield much lower voltage values on the operator's body than standard ones commonly used for chair upholstery.

The structure of anti-electrostatic upholstery materials, both knitted and woven, should be designed in such a way as to obtain a low surface resistance value for the top/use side, as well as the charge decay time and/or the shielding factor required by the standard criterion.

Upholstery materials should be characterised by a level of protection against electrostatic discharges that has been proved to be effective enough for each kind of user clothing.

Anti-electrostatic clothing does not always ensure sufficient protection especially if the upholstery material used shows adverse electrostatic properties.

The method developed for the evaluation of an upholstery's propensity to generate an electrostatic charge when used on a chair renders it possible to assess the effect of upholstery and clothing materials on the voltage generated on the chair user but can be used as a tool to design a means of protection against ESD by verifying in practice whether upholstery and garment materials are properly selected for a given purpose. Bearing in mind the safety and comfort of users, as well as the protection of electronic devices, it is recommended that the functional textile upholstery materials designed be used in public utility institutions, means of transport, post servicing electronic devices and other settings sensitive to ESD.

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