ELECTRICAL PROPERTIES OF THE TEXTILE FABRICS

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Abstract
The frequent demand placed recently for clothing, furnishing and technical textiles made of synthetic polymers is evaluation the electrical properties in accordance with application intentions. These textile fabrics are evaluated by methods of measuring the surface resistance and the electrical resistance. Given methods have sufficient ability to express conducting and transferring of the electrostatic charge on their surface. There are evaluations of electrical and thermal resistance are presented in publication. The results obtained from two types of nonconductive woven fabrics from different material composition were discussed in this paper as well. The aim was to compare non-homogeneous textile materials and evaluated the influence of electrical properties on thermal insulation properties.

Keywords: Specific electrical conductivity, specific electrical resistance, resistivity, thermal resistance, thermal conductivity

1 Introduction

1.1 Electrical properties

Is known that clothing made of synthetic fibers during use may generated electrostatic charge. Potencial spark discharge especially in working clothes creates a significant security risk. Equally unpleasant effects created by electrostatic charge in wearing when the clothes stick, spark and have an increased ability to get dirty. Electrical properties of textile materials depend on their sort, structure and climatic conditions of environment in which they are located. Electrical properties are indicated by the size of electrostatic charge that is directly related to the size of the electrical resistance and thermal resistance of textile fabrics**.**

1.1.1 Electrical conductivity and electrical resistance

Non-metallic textile materials located in an electric field behave as an insulators, because most of the compounds consist of (mainly carbon, hydrogen, nitrogen and oxygen) have electrons as charge carriers hard bound to the atom core [1]. Conductivity of the fabric depends on the number of free movable electrons.
For the movement of electrons is a need for some energy sources such as thermal energy. The moisture contained in the fiber significantly increases its conductivity. For definition the specific conductivity σ_E of the polymer fibers of length l_v(m) and cross-sectional surface S_v (m) as the ratio of surface current density I / S_v and electric field strength U / l_v is used this relation [3]:

$$\sigma_E = \frac{I \cdot l_v}{U \cdot s_v} = \frac{G.l_v}{s_v} \qquad \left[S \cdot m^{-1}\right] \tag{1}$$

Where U-voltage (V), I-current (A), R-resistance (V/A), G-conductivity (S=A/V). Reciprocal value of specific conductivity is a specific electrical resistance R_E (2). This characterizes the resistance of the conductor unit length and unit cross-section. It also respect the fact that the various materials put different electrical current resistance, because they have different structure.

$$R_E = 1/\sigma_E \left[S^{-1} \cdot m = \Omega \cdot m\right] \tag{2}$$

The materials are separated according to the electrical specific resistance of the conductors $R_E = 10^{-8}$-10^{-2} [Ω.m], semiconductors $R_E = 10^{-2}$-10^{0} [Ω.m] and isolants $R_E = 10^{0}$-10^{16} [Ω.m]. Conventional synthetic fibers have a specific electrical resistance $R_E = 10^{12}$-10^{14} [Ω.m] [2]. Antistatic fibers have a specific electrical resistance R_E = 10^{6}-10^{10}. Electrically conductive fibers have a specific electrical resistance for about $R_E = 10^{-5}$ [Ω.m].

1.1.2 Electrostatic change

Creation of static electricity occurs on textiles the following changes: static attraction, repulsion, discharging and physiological changes [3]. Eelectrostatic charge causes problems during processing and use of textile fibers.

It is produced on textile fibers by friction, tension and pressure. Created temperature difference causes the movement of electrons passing from warmer to cooler places. If one material has electrically charged layer on its surface, this may in contact with other material pass on this other material. Especially low conductivity in synthetic fiberes gets worse removal of charge.

1.1.3 Transfer heat of the textile fabric

Textile materials transmit or receive (exchange) energy through the heat and thus perform the work. This energy exchange process is called heat transfer [8]. There are known three basic mechanisms of heat transfer: transfer of heat by conduction, convection and radiation. The heat is often transmitted by combination of all three mechanisms. Alternatively, it is combined with the change of water vapor and gases as well [9] . The heat is spontaneously spred from place with higher temperature to place with lower temperature, from the skin through clothing to the environment (for the conditions when the skin temperature is higher than the ambient temperature).It is expressed by the value of thermal conductivity or thermal resistance. Characteristics of textile insulators is that the electrical resistance decreases with increasing temperature (electrical resistance increases with encreasing temperature in the metal fibers). The textil fabric can be divided into good and bad conductors of heat based on values of thermal conductivity and thermal resistance. The same is true for the electrical current. Transfer of heat is the function of textile fiber material and structural parameters (porosity,surface weight and bulk weight). The presence of moisture and other additives decreases the electrical and thermal resistance of fibers.

1.2 Methods for evaluation of electrical and thermal properties of textile fabrics

The methods for evaluation electrical properties of various materials can be divided into two groups [4]:

Measurement of electrical resistance as:

- electrical resistance of such surface for example to protect electronic components and equipment
- surface and specific surface resistance for example as a protection against discharge ignition
- internal electrical resistance such as the contact resistance

Measuring of ability of materials and products to take out an electrostatic charge as a speed decrease of electrostatic charge :

- after charging by corona discharge
- after inductive charging
- after triboelectric charging

1.2.1 Method of measuring electrical resistance

For the evaluation of electrical properties is used measurement of surface resistivity and resistance in current textile practice. On the samples of textiles is possible to measure the surface and vertical resistivity. Measuring equipment is shown in Fig. 1 and consists of three circle electrodes. Electrical resistance measurement was done on a measuring device 4339B High Resistance Meter as shown in Fig.2 [7].

Surface resistivity ρ_s [Ω]: $\rho_s = R_s \cdot o / l$ (3)

where is Rs -surface resistance [Ω], o - mean circumference (resp. length of electrodes) [m], l - electrodes distance[m].

Fig. 1 *Three-electrod system for measuring surface resistivity [4]*

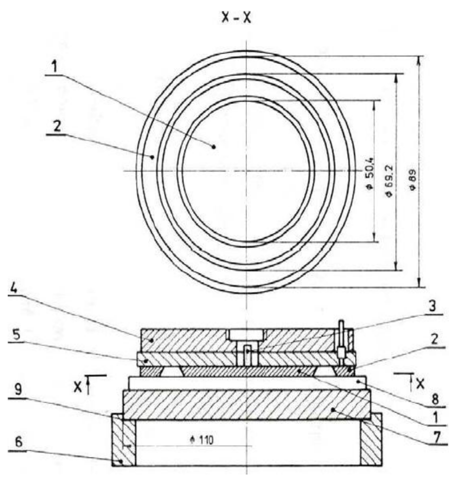

Fig. 2 *Three-electrode concentric system for measuring surface resistivity and resistance[7]*

Surface resistivity was measured between electrodes 1 and 2. For surface resistivity measurement of textile fabric is necessary to know the value of mean circumference of the electrodes and distance between electrodes. Given values are for measuring surface resistivity given into the measuring device . The values of surface resistivity and resistance can be then deducted from the device without conversion of measured data.

1.2.2 Triboelectric method

The basis for triboelectric measurement method is to generation electrostatics charge on standardized sample fabrics. Electric charge is generated by friction of fabrics between two rods, where each is made of different materials (aluminum, HDPE) [4]. This is measured in one single location of the sample using electric voltmeter, and expressed in units intensity of electric field (kV.m). Measuring output is value of max. intensity electric field under standardized conditions of friction as the intensity field after 2 seconds and gradually to 30 seconds measurement.

Fig. 3 *Certification panel measuring accurary device Tribotest [4]*

1.2.3 Measurements of thermal resistance

Thermal resistance Measurements was done on the Alambeta device. It is an indirect measurement method, which simulates and objectively evaluate the thermal contact between the wet skin and dry textile fabric during the short contact [10]. Model of wet human skin is replaced by knitted fabric COOLMAX FX-205, which is wetted in1 ml solution with addition of detergent 1:50. The function of device see Fig. 4 is described as follows: Specimen 5 is placed on the base device 6 heated to ambient temperature. Head 1 heated to a temperature of approx. 10° C higher than the ambient temperature (about 33° C, what is the skin temperature) runs down. Heat flow sensor 4 and 7 measured heat flows between the surfaces 9**.** Part of the head 1 is a thermometer 8, heating elements 3, thermostat 2 and thermal insulation. Measured data are processed by computer and shown on the device display.

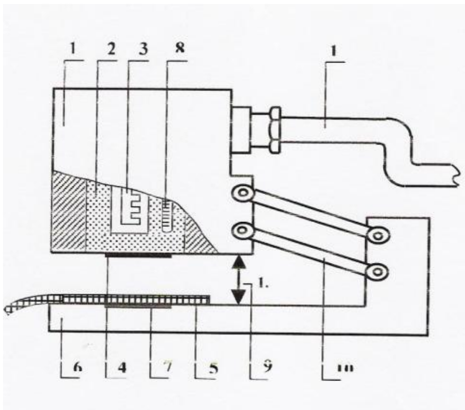

Fig. 4 *Measuring device Alambeta [10]*

2 Experimental part

2.1 Used materials

Measurements of electrical properties were performed on samples of woven fabrics with similar parameters, but with a different material structure. Images of fabrics were scanned via image analysis Nis Element (Fig. 5, 6) [5]. Fabrics were made of the same yarns interrelated plain weave. There are irregular air holes between the binding points in the fabric called - pores.. In Tab. 1 are shown the basic parameters of measured woven fabrics.

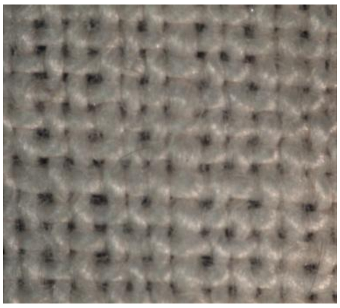

Fig. 5 *Cotton woven fabric*

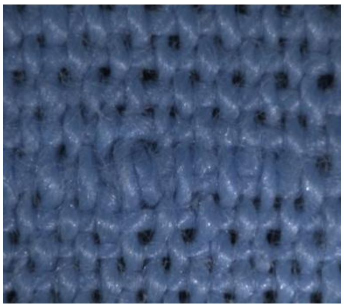

Fig. 6 *Polypropylen woven fabric*

Table 1 *Parameters of woven fabrics: linear density T, sett warp and weft Do, Du, strength in the warp and weft F, elongation in the warp and weft ε*

Sample	T [tex]	ρ_s [g.m^{-2}]	Do [100 mm]	Dú [100 mm]	F [N] warp/veft	ϵ [%] warp/veft
Cotton fabric	48	205	201	184	834/883	6,98/7,11
Polypropylen fabric	48	190	196	186	939/817	15,74/16,62

2.2 Measurement of electrical resistivity and resistance of woven fabric

Measurement of electrical resistivity and resistance of woven fabrics were made on a device described in section 1.2.1 under the following conditions: -test voltage 100V, relative humidity 65%, temperature 21 ° C (samples were prepared by air-conditioning for 24 hours), number of measurements 20.

Table 2*: Results of measurements of surface resistivity and resistance R_E [Ω] woven fabrics*

Sample	R_E [Ω] PP-warp	R_E [Ω] PP-veft	R_E [Ω] cotton- warp	R_E [Ω] cotton -veft
Average	$6,286.10^{12}$	$10,5.10^{12}$	$4,275.10^{11}$	$3,463.10^{11}$
Standard deviation	$2,500.10^{12}$	$8,374.10^{12}$	$1,053.10^{11}$	$0,3929.10^{11}$

2.3 Measurement of thermal resistance of woven fabrics

Measurements of thermal resistance were made on the Alambeta device to the following conditions: relative humidity 65%, temperature 21 ° C (samples were prepared by air-conditioning for 24 hours). Twenty measurements were made in total and the resulting statistic characteristics are shown in tab. 3. The Alambeta device evaluates more indicators, but for our contribution has been selected only values of thermal conductivity, thermal resistance and thickness of woven fabric.

Table 3 *Results of measuring thermal conductivity K [W.m^{-1}.K^{-1}] and thermal resistance R [W^{-1}.m^{2}. K] woven fabrics*

Measured values	Cotton fabrics	Polypropylene fabrics
Mean specific heat conductivity K	0,0633	0,0691
Standard deviation heat conductivity K	0,008	0,005
Confidence interval for mean value K	0,0596-0,0670	0,06740-0,0699
Mean thickness of the fabric h [mm]	0,548	0,697
Mean value resistance of heat conduction R	0,0087	0,0115

3 Results and discussion

Experimental measurements were tested using QC Expert, (whether it is a normal data distribution, homogeneous and independent) [6]. It was found that all measured data correspond to given parameters**.** The results of measurements show that electrical resistivity and resistance measured parallely in the warp direction is not the same as in the weft direction. This difference is shown in figures 7 and 8. Even the measurements made by electrodes deposited in parallel way with the warp have bigger anisotropy than those in the weft direction. A relatively important component of anisotropy measurements electrical resistivity presents air that is located between the binding points of woven fabric.

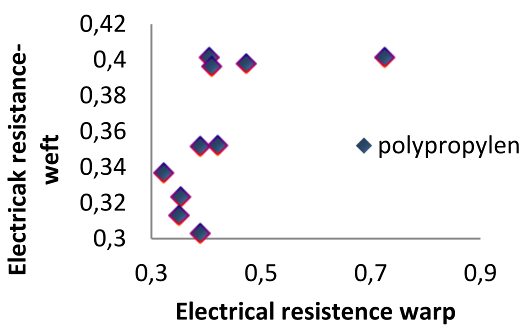

Fig. 7 *Electrical resistance of polypropylene woven fabrics*

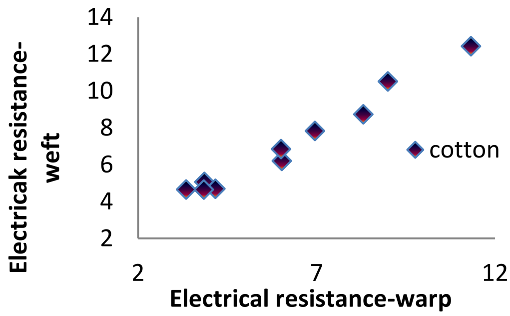

Fig. 8 *Electrical resistance of cotton woven fabric*

Electrical characteristics are quite closely related to the thermal properties. Characteristics of textile insulators is that the electrical resistance decreases with increasing temperature [8]. Correlation was calculated between the electrical resistivity and resistance and heat resistance for both types of woven fabrics and shows a simple linear correlation. However, as the approaching r = 0 we may say that the measurements of thermal and electrical resistance are independent.

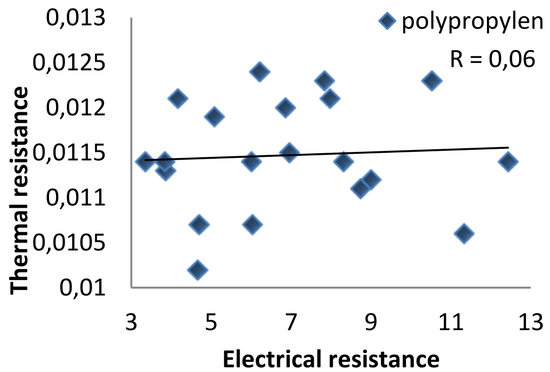

Fig. 9 *Correlation dependence polypropylene woven fabric*

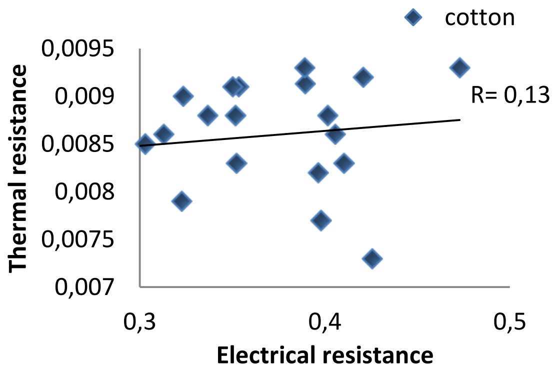

Fig. 10 *Correlation dependence cotton woven fabric*

Electrical properties of two types of materials were evaluated in this paper. Cotton fabric has negligible electrical properties on the basis of literary knowledge. This fact was not confirmed by experimental measurements. For the polypropylene woven fabric was measured the average resistance value from 6,286 to 10,5 $.10^{12}$. Polypropylene woven fabric is close cotton woven fabric results of the measurement of electrical resistance (the lower limit of the theoretical resistance which is from.10^{12} to 10^{14})**.** Validated method of measuring of electrical resistivity and resistance appears to be insufficient from our point of view. It inadequately reveals the difference between the formation of electrostatic charges on the cotton and polypropylene woven fabric.To show the difference would be more appropriate method based on measuring of decreasing speed and ability to take out electrostatic charge after triboelektric charging. It was thought that the electrical resistance is closely related to thermal resistance. Our experimental measurements could not prove that fact**.** Bigger impact on the electrical properties will have environment, structure and type of material. These effects will be observed in our next contributions.

4 Conclusion

This work dealt with the evaluation of electrical properties of woven fabrics made of cellulosic and synthetic fibers. Measurements of surface resistivity and resistance were made on the set of woven fabrics appear the same surface weighing, sett in a direction parallel to the warp and weft (voltage up to 100V). Measurements were to the following conclusions:

1. Measurements showed significant variability and anisotropy of electrical properties of polypropylene woven fabric. From our poin of view the variability of measurement is caused by different sett of the warp and weft.
2. Measurements did not confirm significant difference of electrical properties between given measured woven fabrics.
3. Measurements confirmed that the resistance method is insufficient for measuring of electrical properties of woven fabrics, therefore needs to be complemented by the triboelektrickou method.
4. The measured results confirmed that polypropylene woven fabric is better heat insulator. Polypropylene will be better resistant towards heat transfer passing from the skin through clothing to the environment.
5. The rate of narrownnes of the statistical dependence between the electrical and thermal resistance was expressed by the regression line (fig.9,10) and correlation coefficient. The correlation coefficient showed that there is not dependency between the variables being monitored.
6. Anisotropy of both measured values was caused by a significant component of air porosity of fabric, which affected aspecially the measurement of electrical resistivity and resistance.

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