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THE INFLUENCE OF RELATIVE AIR HUMIDITY ON THE ELECTRICAL RESISTIVITY OF WOVEN FABRICS INTENDED FOR OUTERWEAR

Slađana Antić* ID, Suzana Đorđević ID, Sandra Stojanović ID, Tanja Nikolić ID, Svetomir Golubović ID
Academy of Applied Studies Southern Serbia, Department of Technology and Art Studies Leskovac, Leskovac, Serbia

The electrical resistance of woven fabrics is strongly influenced by the moisture content of the tested sample, which is largely determined by the relative humidity of the environment. Water molecules can become partially ionized, and the resulting water ions near the textile material help neutralize surface charges. Additionally, depending on their fibre composition, fabrics absorb varying amounts of moisture from the environment, which increases their electrical conductivity. This paper presents the results of the volume electrical resistivity testing of three fabrics with different fibre compositions intended for the production of women's blazers (F1 – 100% PES, F2 – 96.1% PES and 3.9% Elastane, F3 – 100% Silk). In blazers, certain pattern pieces require reinforcement with a fusible interlining, which created the need for two-layer samples. Tests were conducted for fusible interlining (I – 71.2% and 28.8% PES) and fabrics fixed to it frontally (F1I, F2I, and F3I). The electrical resistivity of samples was measured in both warp and weft directions, in an environmental chamber with humidity ranging from 40% to 65%, in 5% increments. At 40% humidity, the lowest electrical resistivity was recorded in F3, while the highest was in F2. At 65% humidity, F1 showed the lowest resistivity and F2 the highest. The silk fabric (F3) lost its initial advantage over the PES fabric, which may be explained by its structural characteristics. It can be concluded that lowering the relative humidity of the environment by 25% significantly increases the electrical resistivity of the textile materials by several times.

Keywords: woven fabric, raw material, electrical resistance.

* Author address: Slađana Antić, Academy of Applied Studies Southern Serbia, Department of Technology and Art Studies Leskovac Serbia, Partizanska 7, Leskovac, Serbia
e-mail address: sladjaantic61@gmail.com

INTRODUCTION

Clothing covers the human body, and beyond its functional role, it should enhance the body's shape, conceal imperfections, and provide a pleasant and comfortable wearing experience. The synthesis of appearance, functionality, and comfort is crucial from both physiological and health perspectives. Skin sensory comfort is influenced by the woven fabrics, where desirable properties include softness and smoothness, while undesirable and potentially harmful features include stiffness, roughness, allergic reactions, and clinging to the skin [1]. Garments clinging to the body are an especially unpleasant phenomenon caused by the accumulation of static electricity within the textile material. The effect is particularly pronounced in synthetic fibres; therefore, numerous authors have attempted to evaluate the quality of clothing fabrics through their electrophysical properties, one of which is volume electrical resistivity [2-5].

MATERIALS

The experimental material included three apparel fabrics with different fibre compositions: polyester (PES), a polyester/elastane (PES/EL) blend, silk, and fusible interlinings made from a cotton/ polyester (Co/PES) blend. The structural characteristics of the selected base fabrics before thermal fixation (labelled F1, F2, and F3) are presented in Table 1.

Table 1. Structural characteristics of base fabrics

Tested characteristic		**Unit of measurement**	**Test results**		
			F1	**F2**	**F3**
Fibre composition		(%)	100% PES	96,1% PES 3.9% EL	100% Silk
Weave type			Plain weave	Plain weave	Weft rib weave
Effective fabric width		(cm)	150	148	140
Fabric thickness		(mm)	0.450	0.580	0.680
Surface mass		(g/m^2)	179	264	226
Fabric density	warp	(threads/cm)	22.5	45	10
	weft	(threads/cm)	21	31	6.5
Yarn fineness	warp	(tex)	41.5	36	56
	weft	(tex)	41	33	weft 1 - 96.4 weft 2 - 448.4
Yarn insertion	Warp	(%)	10	21	7.75
	weft	(%)	10	17.1	3.61
Shrinkage	Warp	(%)	-0.8	-0.6	-0.39
	weft	(%)	-0.5	-0.5	+0.15

The structural characteristic of the selected fusible interlining is presented in Table 2.

Table 2. The structural characteristic of the selected fusible interlining

Tested characteristic		Unit of measurement	Test results
			I
Fibre composition		(%)	71.2% Co 28.8% PES
Weave type			Plain weave
Effective fabric width		(cm)	90
Fabric thickness		(mm)	0.435
Surface mass		(g/m^2)	99
Fabric density	warp	(threads/cm)	16
	weft	(threads/cm)	9
Yarn fineness	warp	(tex)	40
	weft	(tex)	39
Yarn insertion	warp	(%)	2.6
	weft	(%)	5.8
Shrinkage	warp	(%)	0
	weft	(%)	0

By applying thermal bonding of the frontal side (face side) of base fabrics with the fusible interlining, a so-called "double-layer textile material" is obtained. The properties of these composite materials are presented in Table 3 [6].

Table 3. Investigated properties of the double-layer textile material

Tested characteristic	Unit of measurement	Test results		
		F1I	F2I	F3I
Layer thickness	(mm)	0.754	0.899	0.889
Fabric mass per layer	(g/m^2)	273	360	319

All tested samples were conditioned for 24 hours under standard atmospheric conditions at a temperature of 20 ± 2 °C and relative humidity (RH) of 65 ± 2%.

METHODS

To determine the volume electrical resistivity (Rx, GΩ) of the selected materials, a measuring device developed at the Department of Textile Engineering, Faculty of Technology and Metallurgy, University of Belgrade, was used [7, 8]. Measurements were conducted in both warp and weft directions using the stationary voltage method, i.e,. the volume electrical resistivity method [9, 10].
A schematic representation of the apparatus is shown in Figure 1.

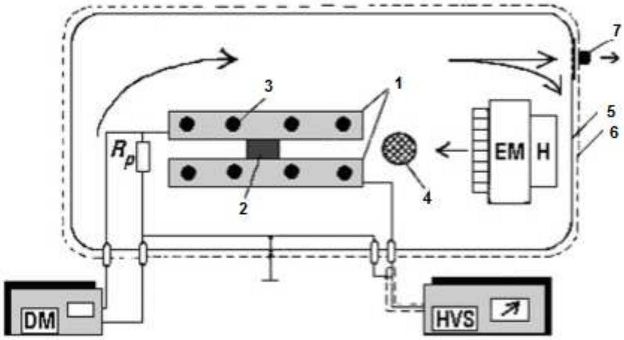

Figure 1. Schematic representation of the apparatus for determining the volume electrical resistivity of fabrics.

The fabric sample (2), with unknown electrical resistivity (Rx), is placed between the electrode plates (1) and fixed in position using tightening screws (3). The silver-coated electrode plates (1) are connected to a high-voltage source (HVS). Air humidity and temperature inside the chamber are monitored via a digital measuring device (4). The entire sample holding system is enclosed within a transparent chamber (5), which is externally covered with a metallic mesh (6), forming a Faraday cage. Humidity variation within the chamber is regulated using a humidifier (H), as well as by adjusting the aperture opening (7), which connects the chamber to the surrounding atmosphere where the measurements are conducted. Air circulation is achieved using an electric motor with a turbine wheel (EM). Voltage measurements are carried out using a digital measuring device (DM), Philips PM 2528 model.
The voltage method is based on measuring the voltage (Um) across a resistor with known resistance (Rp). This Rp is connected in series with the fabric sample of unknown electrical resistivity (Rx). The volume electrical resistivity (Rx) of the fabric sample is calculated using the following equation [5]:

$$R_x \approx \frac{R_p R_i}{R_p + R_i} \cdot \frac{E}{U_m} \tag{1}$$

where: E = 1200 V,
R_p = 1,64 MΩ i
R_i = 10 MΩ.

RESULTS AND DISCUSSION

The results of sample preparation indicated that both the thickness and mass of the bonded fabrics were lower than the sum of the individual layers' thickness and surface masses. The reduction of surface mass after frontal bonding usually resulted from heat- and pressure-induced densification, volatilization of moisture/finishes, fiber shrinkage or melting, and fiber loss from the surface. This can be observed by comparing the measurement results presented in Tables 1, 2, and 3. The thickness of the frontally bonded fabric F1I was 0.131 mm less than the combined thickness of fabrics F1 and interlining I. Similarly, the thickness of F2I was 0.116 mm less than the sum of F2 and I, and the thickness of F3I was 0.146 mm less than the sum of F3 and I. The difference in thickness observed after frontal bonding of fabrics F1, F2, and F3 can be attributed to the specific bonding conditions applied during the process.

Frontal bonding is a process of adhering the fusible interlining to the base fabric. The essence of this process lies in selecting an appropriate interlayer, i.e., a compatible thermoplastic, based on the fibre composition of the base fabric, and experimentally determining optimal bonding conditions such as temperature, pressure, and dwell time in the press. Under the influence of temperature, the thermoplastic melted and penetrated the pores of the fabrics, yarns, and fibres, and then solidified upon cooling over a specified period.

These process parameters must be properly maintained; otherwise, an inadequate bond may occur, manifesting as thermoplastic penetration onto the face side of the fabric's insufficient adhesion. This process reduces the pore size within the textile structure and decreases the thickness, affecting the resulting stability of the fabrics. A reduction in the fabric's pore size can influence air and moisture permeability, which is an important factor in determining the volume electrical resistivity.

Differences in the electrical resistivity of fabrics with the same fibre composition, measured in the warp and weft directions, originate from the structural and physical-mechanical properties of the fabric and the yarns used in its construction.

Lower electrical resistivity measured in the warp direction, compared to the values measured in the weft direction, can be partially attributed to a greater number of parallel threads acting as charge carriers along the direction of the applied voltage.

Table 4. Volume electrical resistivity values of the tested fabrics

R, GΩ									
Sample		**Surface mass (gm^{-2})**	**Fabric thickness (mm)**	**φ, (%) (Humidity in the chamber)**					
				40	**45**	**50**	**55**	**60**	**65**
F1	Warp	179	0.450	6040	4640	3600	2780	2380	1850
	Weft			6700	4980	3980	3220	2730	2000
F2	Warp	264	0.580	16900	11480	9300	7550	6400	5170
	Weft			17560	12130	9760	8310	7180	5560
F3	Warp	226	0.680	5120	3390	2910	2580	2370	2160
	Weft			8460	5040	4400	4050	3770	3350
I	Warp	99	0.435	209	73.8	47.4	38.0	32.7	27.0
	Weft			293	115	74.2	56.9	47.9	39.6
F1I	Warp	273	0.754	302	113	91.1	71.3	59.8	52.8
	Weft			431	206	160	137	116	96.6
F2I	Warp	360	0.899	890	394	318	221	176	139
	Weft			1130	461	356	242	193	156
F3I	Warp	319	0.889	535	293	239	206	184	168
	Weft			851	548	449	387	359	321

The results of the average volume resistivity values of the fabrics are presented. At RH of 40%, the lowest electrical resistivity was obtained in the base fabrics made from raw silk (F3), while the highest was found in the fabrics composed of synthetic and El fibres (F2). At 65% RH, fabric F1 exhibited the lowest resistivity, whereas F2 remained the fabric with the highest value. The raw silk fabric (F3) lost its advantage over the PES fabric (F1), which can be explained by the approximately twice lower density of the warp and weft of the silk fabric compared to the PES fabric (Table 1).
Frontal bonding reduces the resistivity by an order of magnitude, approximately to the level of the fusible interlining, which improves wearing comfort by reducing the tendency to accumulate static electricity. This can be attributed to the fusible interlining (71.2% Co and 28.8% PES), which, as a conductive component, assumes the role of charge transfer medium in the bond structure.
Based on the results presented in Table 4, the influence of fibre composition on the volume electrical resistivity of the tested fabrics is evident. Fabrics made from cellulose-based fibres exhibited the lowest resistivity, followed by the frontally bonded base fabrics, then those made from protein-based fibres (silk), while the highest was measured in fabrics composed of synthetic and elastane fibre blends.
The amount of moisture a textile material can absorb depends on its fibre composition. Due to their high content of hydroxyl groups, natural cellulose fibres behave as highly hydrophilic substances that form hydrogen bonds with water molecules. As water penetrates the cellulose structure, limited swelling and volumetric contraction occur, which can be explained by the dipole field in which negatively charged OH groups in cellulose attract the positively charged parts of water molecules [11, 12].
Protein fibres also possess good sorption capacities. Although silk exhibits a strong tendency to generate static electricity (comparable to PES) under dry conditions, its main protein component – fibroin rapidly absorbs moisture from the air due to high sorption ability, especially at higher RH levels. This leads to fibre swelling and a corresponding decrease in resistivity. Nevertheless, PES fabric (F1) still shows lower resistivity values, primarily due to its higher structural density.
Figures 2 to 8 illustrate the volume electrical resistivity of the base fabrics, fusible interlining, and frontally bonded fabrics as a function of RH within the testing chamber.

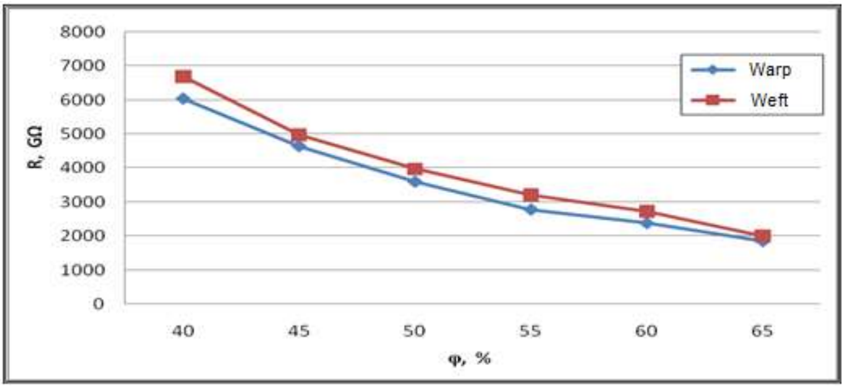

Figure 2. Dependence of the volume electrical resistivity of fabric F1 (100% PES) on air humidity

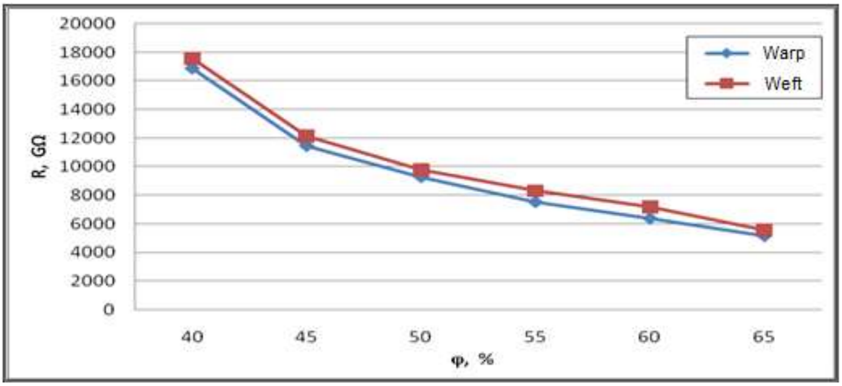

Figure 3. Dependence of the volume electrical resistivity of fabric F2 (96.1% PES and 3.9% elastane) on air humidity

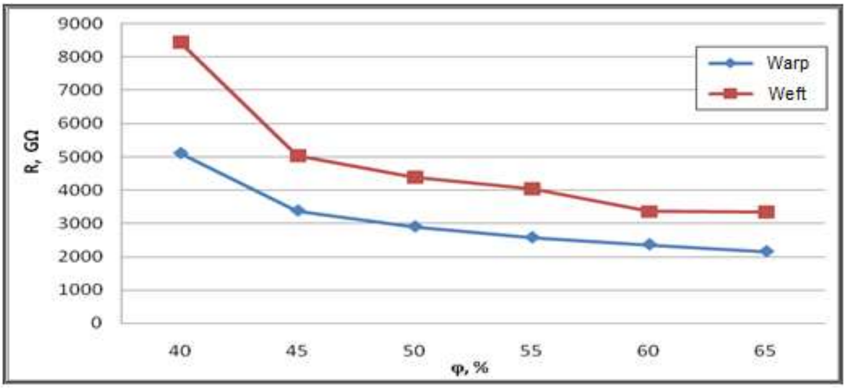

Figure 4. Dependence of the volume electrical resistivity of fabric F3 (100% silk) on air humidity

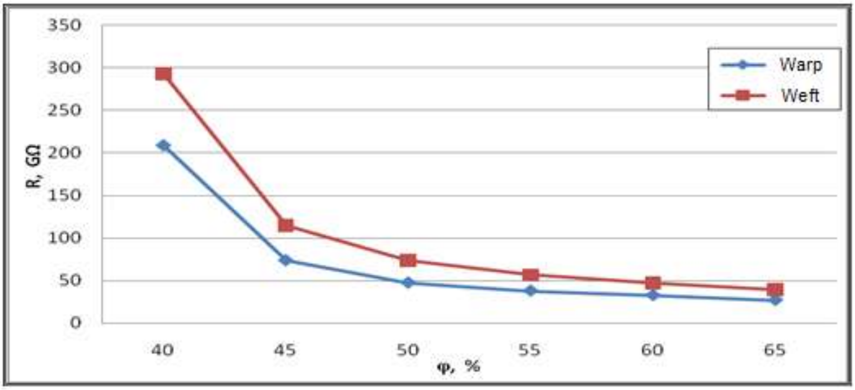

Figure 5. Dependence of the volume electrical resistivity of fabric I (71.2% cotton and 28.8% PES) on air humidity

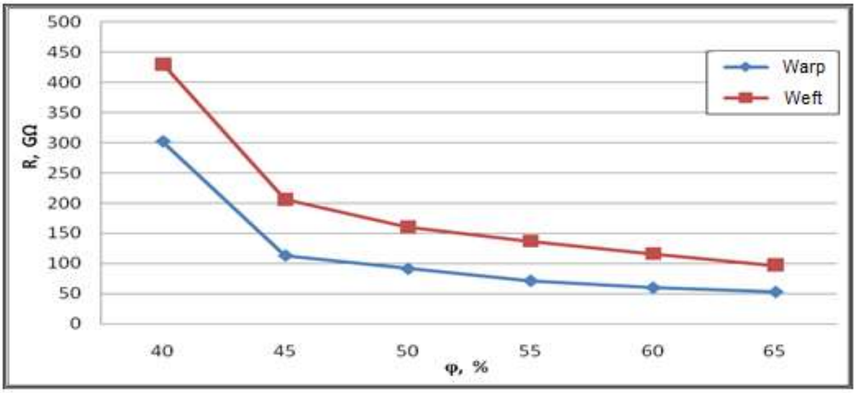

Figure 6. Dependence of the volume electrical resistivity of frontally bonded fabric F1I on air humidity

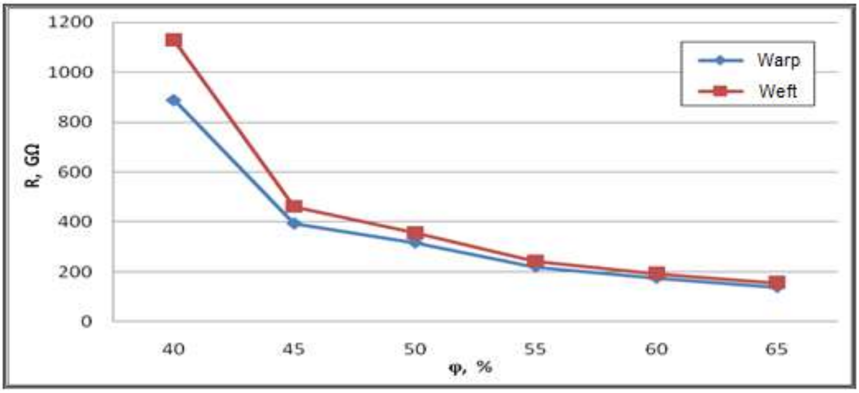

Figure 7. Dependence of the volume electrical resistivity of frontally bonded fabric F2I on air humidity

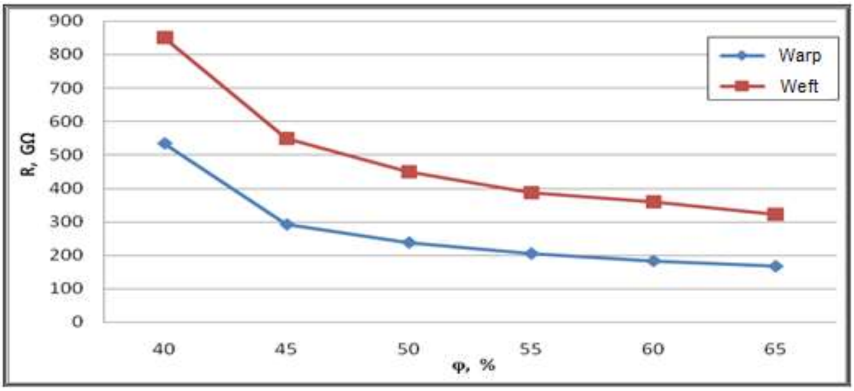

Figure 8. Dependence of the volume electrical resistivity of frontally bonded fabric F3I on air humidity

Observing figures 2 to 4, which depict the volume electrical resistivity of base fabrics as a function of air humidity, the silk F3 exhibits the largest difference between warp and weft resistivity values. This is attributed to the significant difference in fineness of these yarns. This discrepancy persists at humidity levels and is also evident in frontally bonded silk fabric F3I, as shown in Figure 8.

CONCLUSION

The obtained results demonstrated that the volume electrical resistivity primarily depends on the fibre composition and structural characteristics of the fabric. When the RH is reduced from 50% to 40%, the smallest increase in resistivity is observed in fabric F3 (100% silk). However, when RH is increased to 65%, the largest reduction in resistivity occurs in fabric T1 (PES), which can be attributed to the fact that fabric has approximately half the warp and weft density compared to the PES fabric. The highest electrical resistivity was measured in fabric F2, composed of synthetics and El fibres. The lowest resistivity was observed in the fusible interlining I (Co/PES), made of cellulose-based fibres. Frontal bonding of basic fabrics significantly reduced electrical resistance at 65% humidity, most notably in fabrics F2 (37 times in the warp direction and 35 times in the weft direction). At 40% humidity, the most significant reduction was seen in fabric F1 (20 times in the warp direction and 15 times in the weft direction).
Based on these results, it can be concluded that frontal bonding with a fusible interlining significantly improves the performance of PES fabrics. Lowering the relative humidity of the environment in which the textile material is located by 25% increases the electrical resistance of the textile material sample several times. This highlights the importance of conditioning textile samples in an environment of precisely controlled humidity before measurement, to ensure accurate and reproducible results.

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Izvod

UTICAJ RELATIVNE VLAŽNOSTI VAZDUHA NA ZAPREMINSKE ELEKTRIČNE OTPORNOSTI TKANINA NAMENJENIH ZA GORNJU ODEĆU

Slađana Antić ID, Suzana Đorđević ID, Sandra Stojanović ID, Tanja Nikolić ID, Svetomir Golubović ID
Akademija strukovnih studija Južna Srbija, Odsek Visoka tehnološko umetnička škola, Leskovac, Srbija

Električna otpornost tekstilnih tkanina intenzivno zavisi od sadržaja vlage u ispitivanom uzorku, što u velikoj meri opredeljuje relativna vlažnost sredine u kojoj se nalazi. Molekuli vode su u izvesnom stepenu jonizovani, tako da joni vode koji se nalaze oko tekstilnog materijala neutralizuju naelektrisanje na njegovoj površini. Sa druge strane zavisno od sirovinskog sastava, vlakna sorbuju različitu količinu vlage iz sredine koja ih okružuje što utiče na povećanje njihove elektroprovodnosti. Ovaj rad prikazuje rezultate ispitivanja zapreminske električne otpornosti za tri tkanine različitog sirovinskog sastava namenjenih za izradu ženskog blejzera (F1 - 100% PES, F2 – 96.1% PES i 3.9% Elastan, F3 -100% Svila). Kod blejzera neki krojevi trebaju biti ojačani lepljivom međupostavom, tako da je iskazana potreba za dvoslojnim uzorcima. Ispitivanja su izvršena na lepljivu međupostavu (I – 71.2% Pamuk i 28.8% PES) i frontalno fiksiranim tkaninama (F1I, F2I i F3I). Električne otpornosti uzoraka merene su u pravcu osnove i potke, kod vlažnosti u komori od 40 do 65% u razmacima po 5 jedinica. Najmanju električnu otpornost kod vlažnosti od 40% poseduje F3, dok najveću F2. Kod vlažnosti od 65% najmanju otpornost pokazuje F1, a najvišu F2, tkanina od svile gubi prednost nad tkaninom od PES-a, što se može objasniti njenim konstruktivnim svojstvima. Može se zaključiti, da sniženje relativne vlažnosti sredine u kojoj se nalazi tekstilni materijal za 25% povećava njegovu električnu otpornost nekoliko puta.

Ključne reči: tkanina, sirovinski sastav, elektična otpornost.