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Electrical Resistivity of Conductive Leather and Influence of Air Temperature and Humidity

Električna upornost prevodnega usnja ter vpliv temperature in vlažnosti zraka

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Abstract

Leather is a material that has been used in different applications for centuries. Today, living in the era of high-technology, we are surrounded by smart products. For this reason, traditional products must be changed or improved in order to support and make us more comfortable while using them. For instance, the touch screen display in electronics products is a smart phone's or a tablet computer's primary input device. Still, traditional leather will not function properly in a cold climate or other specific conditions. To make it conductive in such conditions, the double in-situ polymerization of the pyrrole coating method was used. The aim of this study was to observe the electrical properties of conductive leather. At the same time, it stands up to a wide range of different air temperatures, and relative and absolute humidity. These properties are essential because designers and textile engineers should be familiar with them when they decide to use materials in different smart products. Electricity conductivity tests were carried out in year-round temperatures from 7.5 °C to 28.1 °C, with a relative humidity from 18% to 77% and a vapor air concentration from 2.77 g/kg to 12.46 g/kg. The so-called "multiple-step method" was used to test leather's electrical resistivity for the first time. The method considers a material's compressional properties and provides an indicator inherent for a material's electrical properties, regardless of the mass and shape of samples. The results showed a strong dependence between water vapor air concentration and electrical resistivity, described using the formula $\rho = 1.310^{3}\ H^{-1.04}\ \Omega\text{m}$, with a correlation coefficient of 0.87. There was no relation between relative humidity and electrical resistivity, and resistivity and air temperature. Also, the results confirmed again that changes in the shape of the sample used during tests did not influence the measurement's results, but supported the appropriateness of the measuring method.
Keywords: air humidity, conductive leather, electrical resistivity, multiple-step method.

Izvleček

Usnje se kot material že stoletja uporablja v različnih aplikacijah. Danes, ko živimo v dobi visoke tehnologije, smo obkroženi s pametnimi izdelki. V ta namen je treba tradicionalne izdelke spremeniti ali izboljšati, da bi jih nadgradili in naredili primernejše za rabo. Na primer, v elektronskih izdelkih je zaslon na dotik primarna vhodna naprava pametnega telefona ali tabličnega računalnika. Ker tradicionalno usnje v hladnem okolju ali drugih posebnih razmerah ne deluje, *je bilo površinsko obdelano z metodo dvojne in situ polimerizacije pirola. Cilj te študije je opazovati električne lastnosti prevodnega usnja v širokem razponu različnih temperatur, relativne in absolutne vlažnosti zraka. Te lastnosti so bistvene, ker oblikovalci in tekstilni inženirji morajo poznati te lastnosti, ko se odločijo za uporabo materiala v različnih pametnih izdelkih. Testi elektroprevodnosti so potekali eno leto pri temperaturah od 28,1 °C do 7,5 °C, pri relativni zračni vlažnosti od 77 % do 18 % in koncentraciji vodne pare v zraku od 12,46 g/kg do 2,77 g/kg. Prvič je bila za testiranje električne upornosti usnja uporabljena t. i. „metoda z več koraki". Ta upošteva tlačne lastnosti materiala in zagotavlja indikator, ki je vezan na električne lastnosti materiala, ne glede na maso in obliko vzorcev. Rezultati so pokazali močno odvisnost med koncentracijo vodne pare v zraku in električno upornostjo, opisano z zvezo* $\rho = 1.310^{3} H^{-1.04}$ *Ωm, s korelacijskim koeficientom 0,87. Med relativno zračno vlago in električno upornostjo ter upornostjo in temperaturo zraka ni bilo povezave. Prav tako so rezultati ponovno potrdili, da spremembe oblike vzorca, uporabljenega med preizkusi, niso vplivale na rezultate meritev, kar potrjuje vrednost merilne metode.*

Ključne besede: zračna vlaga, prevodno usnje, električna upornost, večstopenjska metoda

1 Introduction

Leather is a natural product made by converting animal hides and skins using tannage [1]. This material has been used in different applications for centuries after numerous mechanical and chemical operations. Moreover, this material has excellent insulating properties [2, 3], making it essential for various applications such as clothing, upholstery, footwear, automotive products and accessories.

Today, however, we live in a high-tech world surrounded by smart products. For this reason, traditional products must be changed or improved to support and make us more comfortable while using them.

For instance, the touch screen display in electronics products is the primary input device of a smart phone or a tablet computer. Still, traditional leather will not function properly in a cold climate or other specific conditions.

A great deal of research has been done on the transformation of textiles into conductive materials, including leather in the last decade. In this way, electrically conductive materials can be applied to the leather's surface to be used as a touching operator for a capacitive touch screen panel.

Consequently, the treated leather samples show electrical conductivity and are expected to have a reasonable working performance on a capacitive touch screen [2–10].

Various methods are used to evaluate the electroconductive properties of textile and leather materials. Those methods provide indicators that are difficult to compare with each other. For this reason, we decided to use the so-called "multiple-step method" for measuring the electrical resistivity of our manufactured leather's electrical resistivity [5, 11, 12]. The method takes into consideration the compressional properties of a material. It provides an indicator inherent for a material's electrical properties, regardless of the mass and shape of samples.

When investigating the electrical resistivity of conductive leather, certain parameters such as environmental conditions must be considered. We typically take into account standard air temperature and humidity conditions for textile materials' physical and mechanical properties.

Nevertheless, it is important for applications of conductive leather to know what happens to the electrical properties in a wide range of air temperatures and relative and absolute humidity. In this paper, we attempt to give more information about this smart leather to designers and textile engineers, who should be familiar with these properties when they decide to use this smart material in different applications such as clothing, bags, footwear, automobile seats or furniture.

2 Experimental

2.1 Materials and methods

White sheep crust leather of Albanian origin was used in this research. The leather was initially cut into 8 cm x 8 cm pieces with a thickness of 0.97 mm ± 0.2 mm. The leather was only chrome tanned and dried. A double in-situ polymerization of pyrrole coating was used to make the material conductive. The chemicals used here were pyrrole, ferric chloride, anthraquinone-2-sulfonic acid sodium salt monohydrate of laboratory-grade and high purity [2]. The multiple-step method was used to measure the electroconductive properties of this conductive leather [11–12].

This method consists of measuring the electrical resistance of the sample compressed to different volume fractions within a measuring cell, as shown in Figure 1. A reciprocal power function then approximated the dependence of the textile material's electrical resistance on its volume fraction (V_f) within the measuring cell.

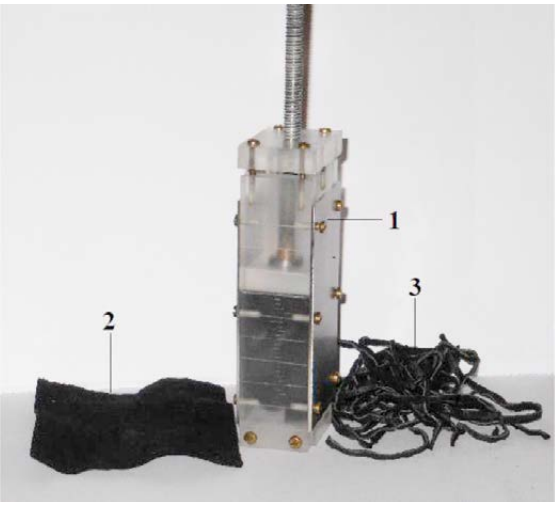


Figure 1: View of the measuring cell (1) and two sample shapes: sheet shape (2) and strip shape (3)

The specific resistance was calculated using the formula:

$$\rho = R * \left[\frac{m}{d \cdot a^2}\right] * Vf^b \rho = R_f \left(\frac{m}{da^2}\right) V_f^{-b} \qquad (1)$$

where ρ represents electrical resistivity in Ωm, m represents the mass of the sample, R_f represents the electrical resistance of the sample in volume fraction V_f calculated from the approximation function $Rf = f(V_f)$, Vf represents the ratio between the intrinsic volume of the sample $V_0 = m/d$ and volume occupied in the measuring cell, d represents the density of leather's material, a represents the distance between the measuring electrodes of the measuring cell, and b represents a power index calculated using the approximation of the set of resistances of the sample compressed in different volume fractions.

The double in-situ polymerization of the pyrrole coating method was used to make the leather conductive. The leather samples were first cut into in 8 cm x 8 cm squares and treated with a mixed pyrrole/AQSA solution for one hour at room temperature, rotating manually at 10 rpm. A ferric chloride solution, which plays an oxidant role, was then added to the mixture to initiate the polymerization, which was carried out for two hours at 5 °C, rotating manually at 10 rpm. The polypyrrole coated leather samples were washed with distilled water and dried at 35 °C. The concentration of monomer (pyrrole), AQSA as a dopant and $FeCl_3$ as an oxidant were varied and optimized to ensure the leather's maximum conductivity. The sample was then treated following the same procedure to obtain double in situ polypyrrole coated leather. In the end, the coated leather was washed four times with distilled water and dried at 35 °C.

The colour of the sheep leather samples treated using this method changed from white to black at the end of the experiments.

3 Results and discussion

The samples's electrical resistance compressed in different volume fractions (V_f) was measured using a Tektronix DMM4050 Multimeter. The voltage used was 10 V DC. For each sample, a set of electrical resistance results compressed by at least fifteen different volume fractions was used to calculate power index b of approximation power function of the form $R_f = f(V_f^{-b})$ needed to calculate the resistivity ρ. Correlation coefficients R^2 in each case were more than 0.95. Figure 2 illustrates a typical case of approximation.

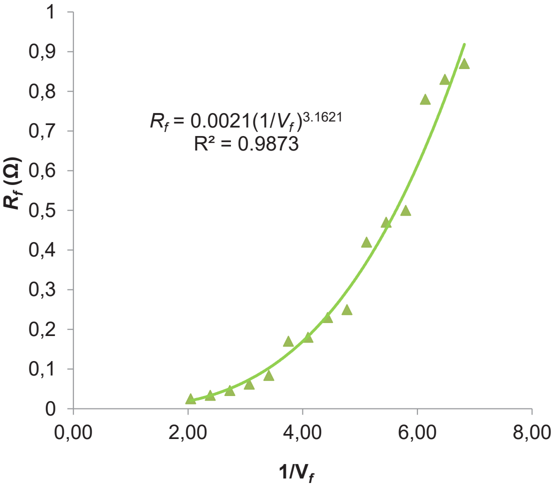


Figure 2: Typical curve of dependence between electrical resistance of the tested sample in Ω and inverse of volume fraction 1/V_f

The mass of the sample used for these measurements was 4.54 g. The density of leather was 0.86 g/cm^3, while intrinsic volume was $V_0 = 5.28$ cm^3. Each sample was first tested in its initial square sheet shape (8 cm × 8 cm). It was then cut into thin strips and again tested for electrical resistance (Figure 1). We did this because our initial objective was to verify whether this method of measurement of resistivity, originally applied to textile fibres, could be successfully applied to leather, as well. The samples were randomly placed in the measuring cell.

In our previous research, [5] it was observed that the electrical resistivity of conductive leather, unlike the methods and standards used today for measuring surface resistance, was shown to be an inherent indicator of bulk conductivity of a leather assembly and was not influenced by sample shape or the way it is placed in the measuring cell.

After proving the objectivity of the method, we decided to continue the measurements for nearly one year to observe how the conductive leather will behave in natural environmental conditions. In this way, the tests were carried in natural weather conditions that included a wide range of humidity and air temperatures, using products made from this material. The objective of this research was to understand how the conductive leather applied in a smart product will react due to environmental conditions. Measurements of the sample's resistivity in two different shapes and different environmental conditions are shown in Table 1.

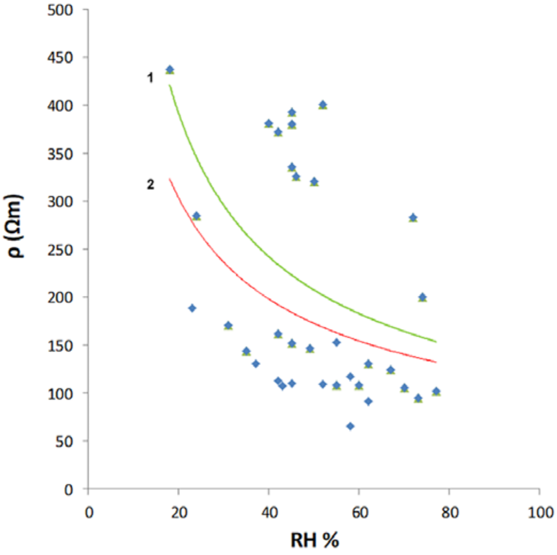
The results of resistivity were plotted versus relative the humidity and water vapor concentration of the air, as shown in Figures 3 and 4, respectively. Also, each figure contains two sets of data: curve 1 corresponds to the dependence of the sample's resistivity in the shape of strips on the relative humidity and vapor concentration in the air. Curve 2 shows the above dependencies, but all results are considered, both for samples in the form of strips and sheets.

As mentioned above, the preliminary objective of the actual study was to test the appropriateness of multiple-step method for measuring the resistivity of leather and its sensitivity to the shape of the sample. This explains why we tested two shapes of the same sample, initially in the form of a sheet and later in the form of strips. A problem arose when comparing the results of the resistivity taken from tests performed on different days when air humidity changed. The discrepancy of resistivity results in different temperatures and humidity raised doubts about the appropriateness of the method. The sample in the shape of a sheet was tested during the summer when temperatures were higher, while tests of the sample in the shape of strips were performed mainly during winter when temperatures were low.

The obvious difference between curve 1 and 2 in Figure 3 create the impression of the ambiguous influence of the sample's shape, air temperature and relative humidity. The correlation coefficient R^2 was 0.21 for curve 1 and 0.14 for curve 2. The values are too low to consider them reliable. In Figure 4, curves 1 and 2 match each other. The correlation coefficient is as high as 0.87, which makes them reliable.

We can conclude that the multiple-step method used to measure resistivity offers satisfactory results for testing leather electrical conductivity. Moreover, the leather's resistivity depends on the water vapor concentration in the air but not on relative humidity. Consequently, there is no visible dependence of the resistivity of conductive leather on temperature. A change in the resistivity of conductive leather with water vapor concentration in the air follows the equation:

$$\rho = 1.3\ 10^3 H^{-1.04}\ \Omega m \qquad (2)$$



Curve 1: $\rho = 3121.3\ RH^{-0.693}$; $R^2 = 0.211$

Curve 2: $\rho = 1910.3\ RH^{-0.614}$; $R^2 = 0.1408$

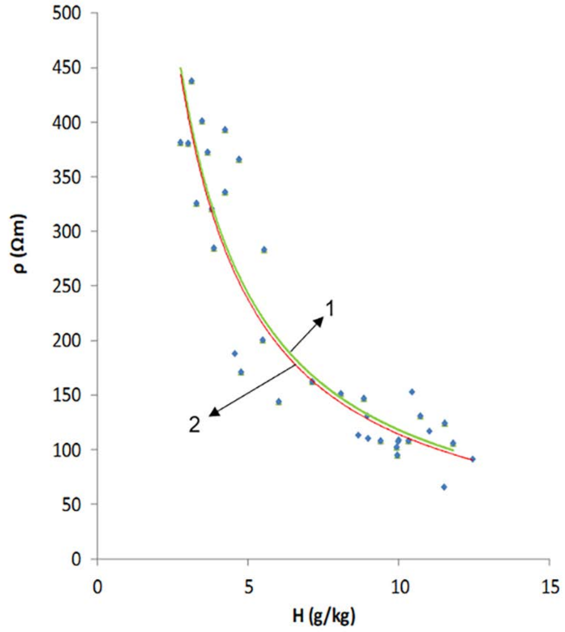
Figure 3: Change in the resistivity of conductive leather with air relative humidity

Curve 1 corresponds to sets of data taken from the sample in the shape of strips alone, while curve 2

Table 1: Resistivity of the sample in two different shapes and in different environmental conditions

Nr	Shape	Air temperature (°C)	Relative humidity (%)	Water vapor concentration (g/kg)	Resistivity × 10^2 (Ωm)
1	strips	21.1	60	9.39	1.0846
2	strips	22.6	67	11.52	1.2421
3	strips	22.7	62	10.72	1.3104
4	strips	20.8	31	4.76	1.7104
5	strips	22.6	35	6.02	1.4418
6	strips	24.0	55	10.32	1.0846
7	strips	23.3	45	8.08	1.5174
8	strips	22.4	42	7.13	1.6218
9	strips	23.4	49	8.85	1.4693
10	strips	21.6	24	3.88	2.8489
11	strips	22.8	18	3.13	4.3787
12	strips	22.3	70	11.81	1.0599
13	strips	18.9	73	9.96	0.9529
14	strips	18.0	77	9.94	1.0194
15	strips	13.0	45	4.25	3.3581
16	strips	11.7	42	3.66	3.7270
16	strips	13.0	45	4.25	3.9341
18	strips	8.5	46	3.28	3.2578
19	strips	9.5	50	3.80	3.2091
20	strips	11.7	52	3.48	4.0133
21	strips	7.5	45	3.02	3.8110
22	strips	8.0	40	2.77	3.8150
23	strips	8.7	65	4.70	3.6590
24	strips	9.1	74	5.48	2.0040
25	strip	9.7	72	5.54	2.8300
26	sheet	24.2	55	10.45	1.5298
27	sheet	24.4	52	10.00	1.0922
28	sheet	25.0	45	8.98	1.1007
29	sheet	24.2	58	11.02	1.1714
30	sheet	25.1	62	12.46	0.9109
31	sheet	25.5	42	8.65	1.1321
32	sheet	24.9	58	11.51	0.6584
33	sheet	28.1	37	8.96	1.3086
34	sheet	27.4	43	9.97	1.0711
35	sheet	24.9	23	4.56	1.8825

corresponds to sets of data taken from samples in shape of both strips and sheets.



Curve 1: $\rho = 1300.7\ H^{-1.042}$; $R^2 = 0.8748$

Curve 2: $\rho = 1305.1\ H^{-1.059}$; $R^2 = 0.8701$

Figure 4: Change in the resistivity of conductive leather with vapor concentration in the air H.

Curve 1 corresponds to sets of data taken from the sample in the shape of strips alone, while curve 2 corresponds to sets of all data taken from samples in the shape of both strips and sheets.

4 Conclusion

We can conclude that the multiple-step method for measuring resistivity offers satisfactory results for testing the electrical conductivity of leather. The conductive leather's electroconductive properties were observed at different temperatures from 7.5 °C to 28.1 °C, relative humidity from 18% to 77% and water vapor concentration in the air from 2.77 g/kg to 12.46 g/kg, using the multiple-step method. The analyses of obtained data revealed that conductive leather's electrical resistivity was a property with a strong dependence on environmental conditions, particularly on the air humidity. Resistivity decreased with an increase in relative and absolute humidity. This study observed that the leather's resistivity depends on the water vapor concentration in the air but not on relative humidity. Consequently, there was no visible dependence of the resistivity of conductive leather on temperature. This conclusion regarding the influence of environmental conditions on conductive leather can help researchers understand where and how to apply conductive leather in different smart textile applications.

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