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STATISTICAL ANALYSIS OF THE PARAMETERS FOR TEXTILE MATERIALS USED FOR SENSORS

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Abstract: *This paper presents aspects regarding the analysis of the independent parameters of the surface electrical resistance for a series of textile samples made by successive knife coating procedures with conductive paste-based metal microparticles, respectively ultrasound-assisted coating using dispersions based on metal microparticles (Cu, Ni, Al, Zn and Ag). The statistical analysis aims to determine the correlations between the vectors of the independent variables (mass, air permeability and thickness of the conductive textile material) and the dependent variable (surface electrical resistance). These samples are prepared for sensor electrodes and must have a low electrical surface resistance.*

Keywords: *textile, sensors, multivariate, electrical resistance, conductive materials*

1. INTRODUCTION

Electrical conductivity is crucial for intelligent textiles to ensure certain electrode functionalities for sensors or electromagnetic shielding. There are methods based on studies regarding the development of conductive materials of poly (3,4-ethylene dioxythiophene)-poly (styrene sulfonate) (PEDOT: PSS) using binders that help to change the viscosity of the electroconductive paste so that it can use different coating methods (knife coating, pad coating and screen printing) [1, 2]. Using the technique ‘knife coating’ (Doctor Blade Coating), it was found that new properties can be obtained for different textile substrates effectively by integrating various compounds in coating pastes such as graphene nano pellets (GNP), thus providing electrical and thermal conductivity to the fabrics, which can later be used for the development of sensors or thermoelectric resistors for integration into textile articles [3, 4]. In addition, the conductive textiles can also be obtained using electrically conductive paste coatings based on carbon nanotubes (CNT) in water-based polyacrylate dispersions applied to textile materials (fabrics or knits) without polyester or cotton using direct printing, by transfer and screen printing [5, 6]. At the same time, conductive polymers (polyaniline, polythiophene and polypyrrole) based on acrylic binder can be used and deposited on polyester fabrics to obtain conductive textiles [7-12].

2. EXPERIMENTAL PART

In Table 1 are presented samples obtained through knife coating (samples P1, P3, P5, P7, P9, P11, P13, P15, P17) and ultrasound-assisted coating (samples P2, P4, P6, P8, P10, P12, P14, P16, P18) and values for electrical and physical and mechanical parameters obtained after testing in the laboratory (surface resistance (Rs), mass (M), air permeability (Pa) and thickness (δ)).

Table 1: Conductive textile – electrical and physical-mechanical tests

Samples	**Ag**	**Fe_3O_4**	**Zn**	**Cu**	**Al**	**Rs [Ω]**	**Physical-mechanical properties**		
							M [g/m^2]	**δ[mm]**	**Pa [l/m2/sec]**
P1	-	-	-	-	-	10^3	580,8	1,28	56,36
P2	-	-	-	x	-	10^6	672,4	1,28	36,62
P3	-	-	-	x	-	10^{10}	572	1,14	43,50
P4	x	-	-	-	-	10^9	635,2	1,268	35,94
P5	-	-	-	-	x	10^5	557,2	1,37	110,6
P6	-	x	-	-	-	10^9	619.2	1,284	35,94
P7	-	-	-	x	-	10^7	570,8	1,13	42
P8	-	-	-	-	-	10^3	672,4	1,27	24.86
P9	-	-	-	-	x	10^5	577,2	1,25	88,14
P10	-	-	-	-	-	10^3	616,8	1,458	47,78
P11	-	-	-	-	-	10^3	567,2	1,458	39,76
P12	-	-	-	-	x	10^3	634,8	1,766	17,82
P13	-	-	-	x	-	10^8	572,8	1,814	30,52
P14	-	-	-	-	x	10^6	648,8	1,76	8,456
P15	-	-	x	-	-	10^5	559,2	1,684	16,2
P16	-	-	-	-	-	10^7	641,6	1,556	5,436
P17	-	-	-	-	x	10^8	551,2	1,646	30,24
P18	-	-	-	x	-	10^7	815,6	1,852	24,88

3. DISCUSSIONS

In order to evaluate the relationships between electrical parameters (Rs) and physico-mechanical parameters have been calculated the correlation coefficient between surface resistance (Rs) and mass (M), air permeability (Pa), and respective thickness (δ). Table 2 are presented the correlation coefficient obtained. Figure 1 is represented the scatterplot matrix of the independent variables (M, Pa, δ) and dependent variables (Rs). Figures 2-4 present the 3D representation of the Rs depending on air permeability, thickness and mass.

The correlation coefficients values from Table 2 show that the correlation coefficients $r_{Rs,\delta} = -0.3639$, $r_{Rs, M} = -0.1599$, $r_{\delta, Pa} = -0.4889$ has negative values, which means that between surface resistance and thickness, respective mass it is an inverse correlation. The increase of the surface resistance values occurs on the quantity of the conductive paste is low and the thickness of the conductive coating is minimal. At the same time, it can be observed that the coefficients $r_{Rs, Pa} = 0.0398$, $r_{\delta, M} = 0.3029$, have positive values and this means that between surface resistance and air permeability, it is a direct correlation. As a consequence, woven structure with a high value for Pa will also have a maximal value for surface resistance.

Table 2: Correlation matrix

	Rs	M	δ	Pa
Rs	1	-0.1599	-0.3639	0.0398
M	-0.1599	1	0.3029	-0.3838
δ	-0.3639	0.3029	1	-0.4889
Pa	0.0398	-0.3838	-0.4889	1

In Table 3 is presented the correlation matrix for samples obtained through knife coating, and in Table 4 is presented the correlation matrix for samples obtained by ultrasound -assisted deposition.

Table 3: Correlation matrix

	Rs	M	δ	Pa
Rs	1	0.1643	-0.4146	-0.0963
M	0.1643	1	0.3029	0.1167
δ	-0.4146	0.3029	1	-0.4634
Pa	-0.0963	0.1167	-0.4634	1

Table4: Correlation matrix

	Rs	M	δ	Pa
Rs	1	-0.3172	-0.5197	0.3804
M	-0.3172	1	0.4653	-0.1276
δ	-0.5197	0.4653	1	-0.5770
Pa	0.3804	-0.1276	-0.5770	1

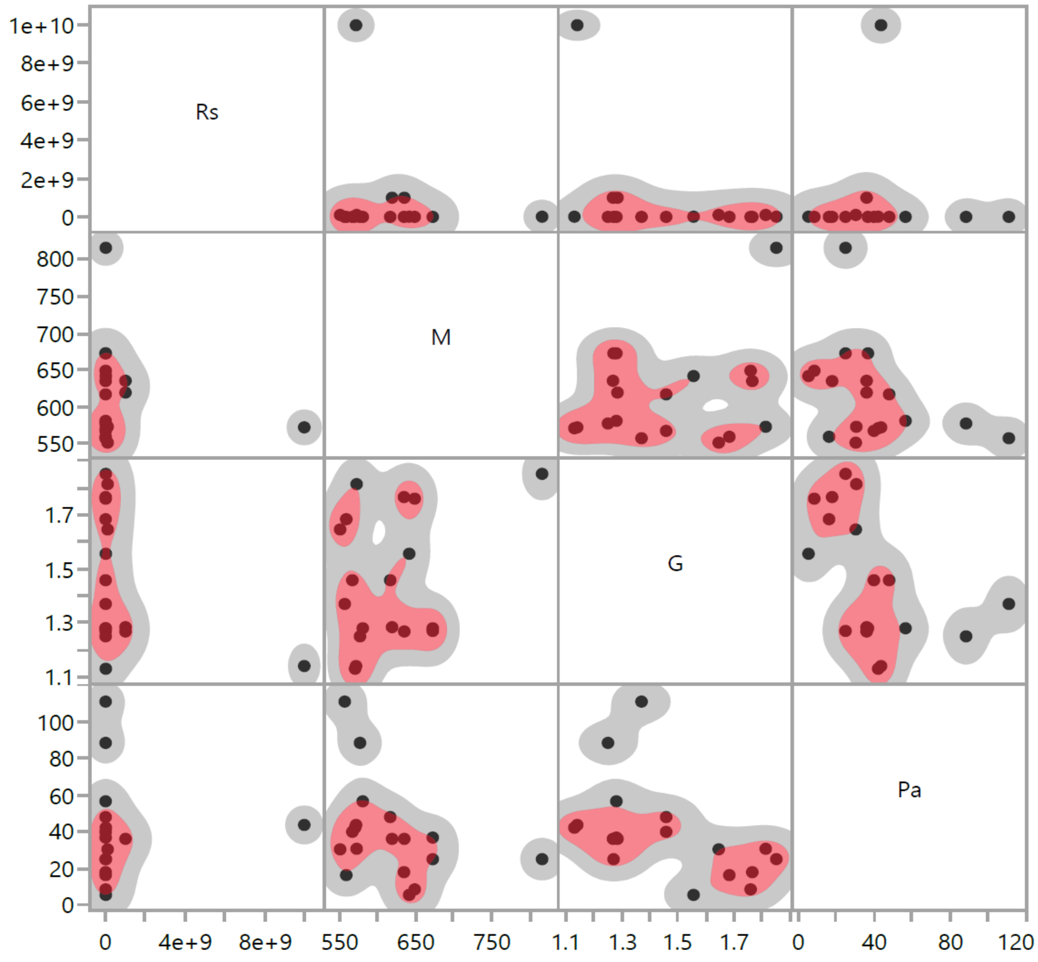

Fig. 1: Scatterplot Matrix-based independent/depend variables

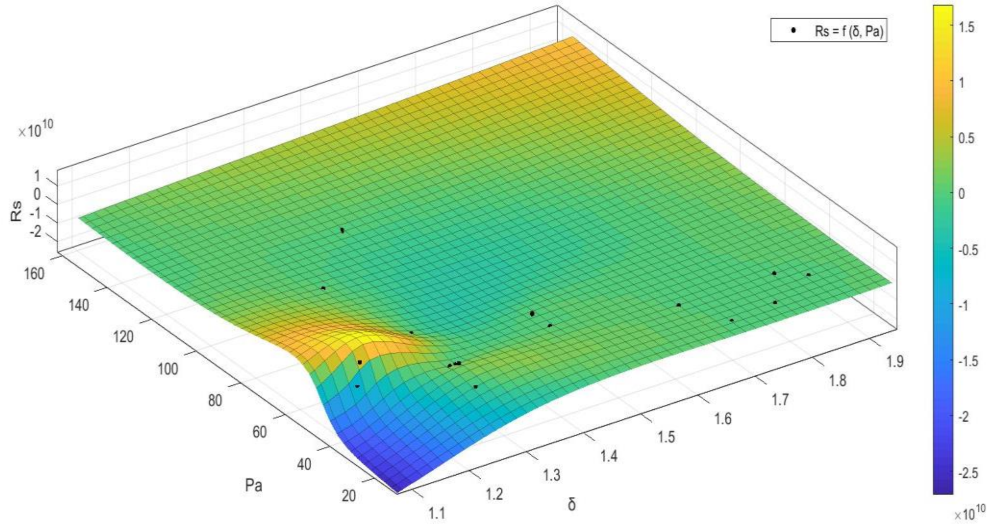

Fig. 2: 3D representation of the surface resistance (Rs) depending on air permeability (Pa) and thickness (δ)

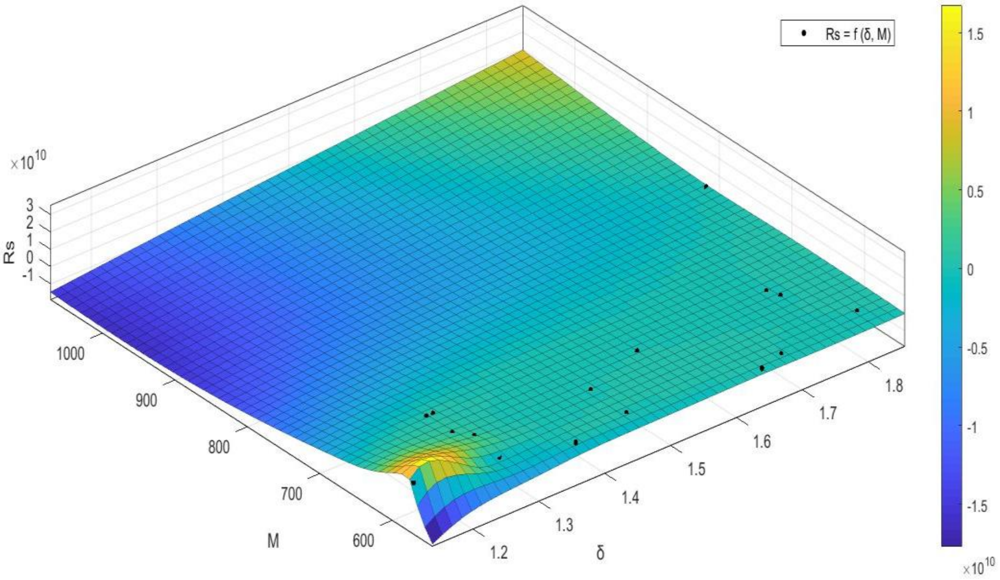

Fig. 3: 3D representation of the surface resistance (Rs) depending on mass (M) and thickness (δ)

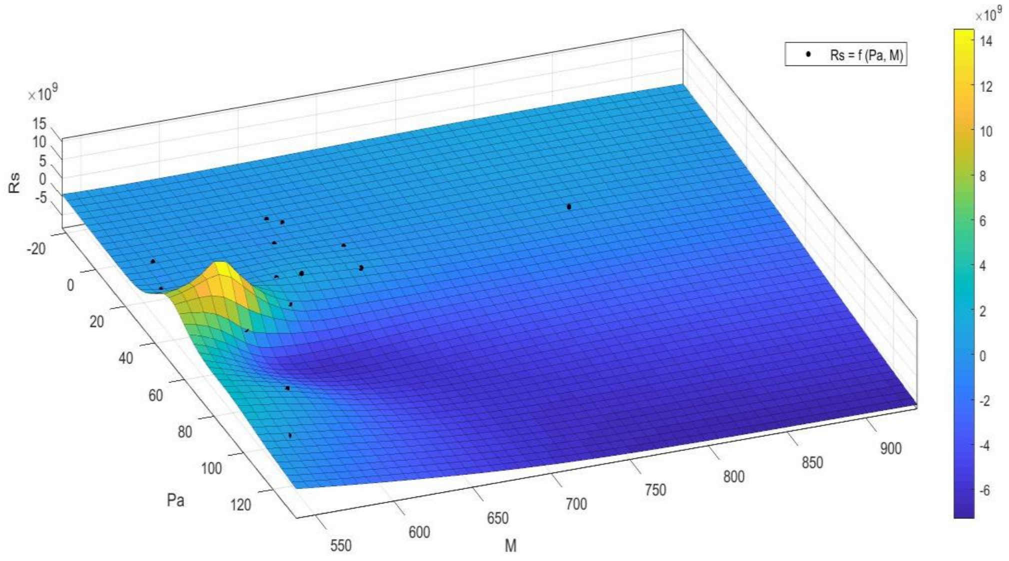

Fig. 4: 3D representation of the surface resistance (Rs) depending on mass (M) and air permeability (Pa)

5. CONCLUSIONS

It can be concluded that the conductivity is in inverse correlation with electrical surface resistance and air permeability and direct correlation with the mass and thickness of the conductive materials. However, the increase of the conductivity at the same time with the mass and thickness of the material is not appropriate sometimes because this means that the materials having an increased thickness will face the reduction of flexibility, being very difficult for wearing or wearable application. In addition, this increase in mass/thickness can reduce the adhesion when the materials are subject to mechanical demands when washing. From this point of view, if the conductive textile is not for single use and is necessary for repetitive washing cycles, it is recommended that the conductive layer's thickness be reduced to keep the material flexible.

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