Effectiveness of electromagnetic shielding in the case of electromagnetic shields based on ferromagnetic materials

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ABSTRACT – REZUMAT

Effectiveness of electromagnetic shielding in the case of electromagnetic shields based on ferromagnetic materials

This paper presents a study concerning the effectiveness of electromagnetic shielding of textile structures coated with ferromagnetic materials. For this scientific approach, 6 experimental models of composites-based fabrics with electromagnetic properties were made by applying paste/dispersion based on polymeric matrices (polyvinyl alcohol (PVA), polyvinylpyrrolidone (PVP)), copper microparticles (Cu), nickel (Ni), aluminium (Al), silver (Ag), and graphene oxide (GO) using classical deposition (immersion, scraping) and ultrasonic technologies. The effectiveness of electromagnetic shielding has been evaluated using a coaxial cell model TEM 2000, oscilloscope model MDO 3102, power amplifier Model SMX5, signal generator type E8257D. The measurements were performed in the frequency range 0.1 MHz – 1 GHz and power 30 W. from all samples, the samples based PVA-Ni and PVA-Ni-Al exhibit pronounced surface conductivity and increased effectiveness of electromagnetic shielding for low and high frequencies.

Keywords: *composites, textile, electromagnetic shielding, resistance, conductive, nickel, aluminium*

Eficacitatea ecranării electromagnetice în cazul ecranelor electromagnetice pe bază de materiale feromagnetice

Această lucrare prezintă un studiu privind eficacitatea ecranării electromagnetice a ecranelor realizate din materiale textile cu acoperiri feromagnetice. Pentru acest demers științific, au fost realizate 6 modele experimentale de compozite pe bază de ţesături cu proprietăţi electromagnetice obţinute prin aplicarea pastei/dispersiei pe bază de matrici polimerice (alcool polivinilic (PVA), polivinilpirolidonă (PVP)), microparticule de cupru (Cu), nichel (Ni), aluminiu (Al), argint (Ag) și oxid de grafen (GO)), prin intermediul tehnologiilor clasice de depunere (imersie, raclare) și tehnologiilor bazate pe ultrasunete. Eficacitatea ecranării electromagnetice a fost evaluată utilizând o celulă coaxială model TEM 2000, un osciloscop model MDO 3102, un amplificator de putere Model SMX5, un generator de semnal tip E8257D. Măsurătorile au fost efectuate în intervalul de frecvență 0,1 MHz – 1 GHz și putere 30 W. Dintre toate probele analizate, probele pe bază de PVA-Ni și PVA-Ni-Al prezintă o conductivitate ridicată și eficiență crescută a ecranării electromagnetice pentru frecvențe joase și înalte.

Cuvinte-cheie: *compozite, textil, ecranare electromagnetică, rezistență, conductiv, nichel, aluminiu*

INTRODUCTION

Numerous researches present different techniques starting from numerical simulation [1] and experimental development of the electromagnetic shields. Materials such as iron, cobalt and nickel are ferromagnetic materials having a positive susceptibility to the magnetic field and are commonly used for non-volatile information storage in tapes, hard drives. Different studies show intensive research in the synthesis of the nanostructures-based iron-nickel [2–4] using different techniques such as electrodeposition [3], integration of the metal particles in silicone [5, 6] or polymethacrylate matrix [7], plastic or metal matrix [8], low-density polyethene composite [9] or carbides [10]. Another versatile technique consists of using arc thermal spray deposition [11]. However, the coating of the textile materials with metals integrated into dispersions, paste [11–13] can lead to obtaining a material with good electromagnetic interference shielding effectiveness [14, 15]. Another challenge is to use carbon materials [14, 15] or conductive polymers [16] for electromagnetic shielding. However, an intense concern is to use nano or micro-structured composites based on copper and nickel [14] or aluminium.

EXPERIMENTAL PART

In the experimental part, we developed 23 experimental samples using cotton fabric (BBC) 100% with different structures (e.g., plain weave, twill, panama) with electroconductive properties based on classical technologies for thin-film deposition by scraping and immersion/ultrasonic technologies using the polymeric matrix (PVA, PVP), copper (Cu) or nickel (Ni), aluminium (Al) or silver (Ag) microparticles and graphene oxide (GO). To evaluate the effectiveness of electromagnetic shielding (SEdB) 6 functionalized fabrics (M1-M6) were selected and cut in the form of discs (figure 1) to the required dimensions and drilled

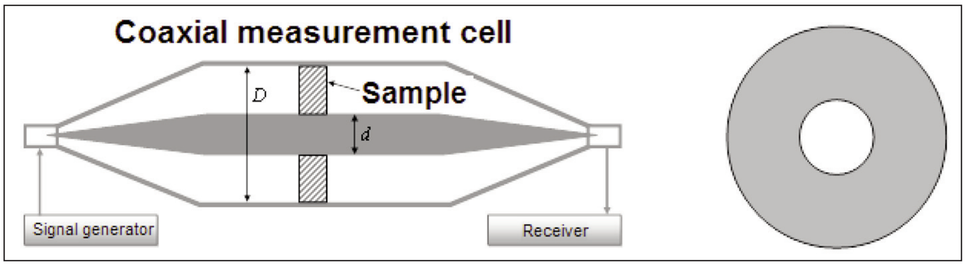

Fig. 1. Measurement assembly and shape of the measurement samples

The Schelkunoff equation 1 was used to evaluate the effectiveness of electromagnetic shielding:

$$SE_{dB} = 10 \log_{10} \frac{P_1}{P_2} \quad (1)$$

where: P_1 in dB is the signal strength detected in the absence of the electromagnetic screen; P_2 in dB is the signal strength detected in the presence of the electromagnetic screen.

The SE_{dB} is given by the difference between the signal level measured without a sample and the signal level measured with a sample mounted inside the measuring cell, both measured in dB (according to the IEEE Standard 299-2006). The tests were based on the ASTM ES7-83 standard.

Figure 3 shows the efficiency of electromagnetic attenuation depending on the values set for the frequency in the range 0.1 MHz – 1 GHz. From the series of experiments subjected to testing, the U4 and U5 samples proved to be effective. The results of

Fig. 2. Ag-contoured samples to measure the effectiveness of electromagnetic attenuation

in the centre to be mounted in the TEM cell measuring (outer diameter of 100 mm and inner diameter of 30 mm). After the discs were cut, a layer of silver-based conductive paint was applied to the edges of the samples to ensure proper electrical contact with the measuring cell (figure 2). The tests were performed at a temperature of 22°C and a humidity of 40%. For the investigation of the attenuation of the electromagnetic screens, the following specific equipment was used (from the endowment of INCDIE ICPE-CA): coaxial cell model TEM 2000; Tektronix oscilloscope model MDO 3102; power amplifier Model SMX5; signal generator type E8257D. The measurements were performed in the frequency range 0.1 MHz – 1 GHz (table 1).

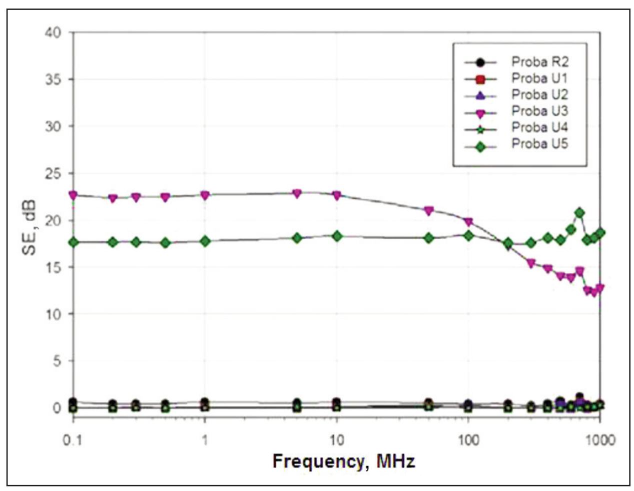

Fig. 3. Graphical representation of electromagnetic attenuation efficiency vs. frequency

Table 1

PHYSICO-MECHANICAL AND ELECTRICAL PROPERTIES OF THE SAMPLES											
Sample no.	**PVA**	**PVP**	**GO**	**Ni**	**Ag**	**Cu**	**Al**	**Water**	**Rs* (Ω)**	**M** (g/m²)**	**δ*** (mm)**
M0	-	-	-	-	-	-	-	x	10^{12}	518	1.36
M1	x	-	-	x	-	x	-	x	10^{7}	623.2	1.424
M2	-	x	x	-	-	-	-	x	10^{10}	671	1.51
M3	-	x	-	-	x	-	-	x	10^{10}	656	1.59
M4	x	-	-	x	-	-	-	x	10^{3}	834	1.71
M5	x	-	-	-	x	-	-	x	10^{3}	608	2.096
M6	x	-	-	x	-	-	x	x	10^{3}	769.6	3.878

Note: *Rs – Surface resistance, **M – Mass, ***δ – Thickness.

Table 2

ELECTROMAGNETIC SHIELDING EFFICIENCY (SEDB)						
Frequency (MHz)	**Electromagnetic shielding efficiency (SEdB)**					
	Sample M1	**Sample M2**	**Sample M3**	**Sample M4**	**Sample M5**	**Sample M6**
0.1	0.6	0	0	22.7	0	17.7
0.2	0.4	0	0	22.4	0	17.7
0.3	0.4	0.1	0	22.5	0	17.7
0.5	0.4	0	0	22.5	0	17.6
1	0.6	0.1	0	22.7	0	17.8
5	0.5	0	0	**22.9**	0.1	18.1
10	0.6	0.1	0	22.7	0	18.3
50	0.5	0.2	0	21.1	0.1	18.1
100	0.4	0	0.2	19.9	0	18.4
200	0.4	0	0	17.3	0	17.6
300	0.2	0	0	15.5	0	17.6
400	0.4	0	0.1	14.9	0	18.1
500	0.7	0	0.4	14.1	0	17.9
600	0.3	0	0	13.9	0.1	19
700	1.2	0.7	0.6	14.6	0	**20.8**
800	0.3	0	0	12.6	0.1	17.9
900	0	-	0.1	12.4	0.1	18.1
1000	0.4	-	0.2	12.8	0.3	18.7

the electromagnetic attenuation efficiency are presented in table 2.

Figure 4 presents the topographic analysis of the surface of the textiles on the basis of the optical microscopy with the digital camera, magnification (60×), the surface of the initial fabric M_0 (without metallic microparticles) (figure 4, *a*) and the surface of the fabrics metallic microparticle and GO (figures 4, *b–g*).

The surface resistance investigation was performed using a resistance meter with built-in parallel electrodes and we obtained a surface resistance of 10^3 Ω for samples M_4–M_6, which indicates the composite based on microparticles of Ni, Al and Cu present pronounced surface conductivity and can be used to develop electromagnetic shields.

RESULTS AND DISCUSSIONS

From the experimental samples of 3D composite based on polymer matrices with electromagnetic properties for electromagnetic screens, experimental models U_3 and U_5 obtained by immersion and ultrasound were selected because they show a uniform electrical conductivity over the entire surface after

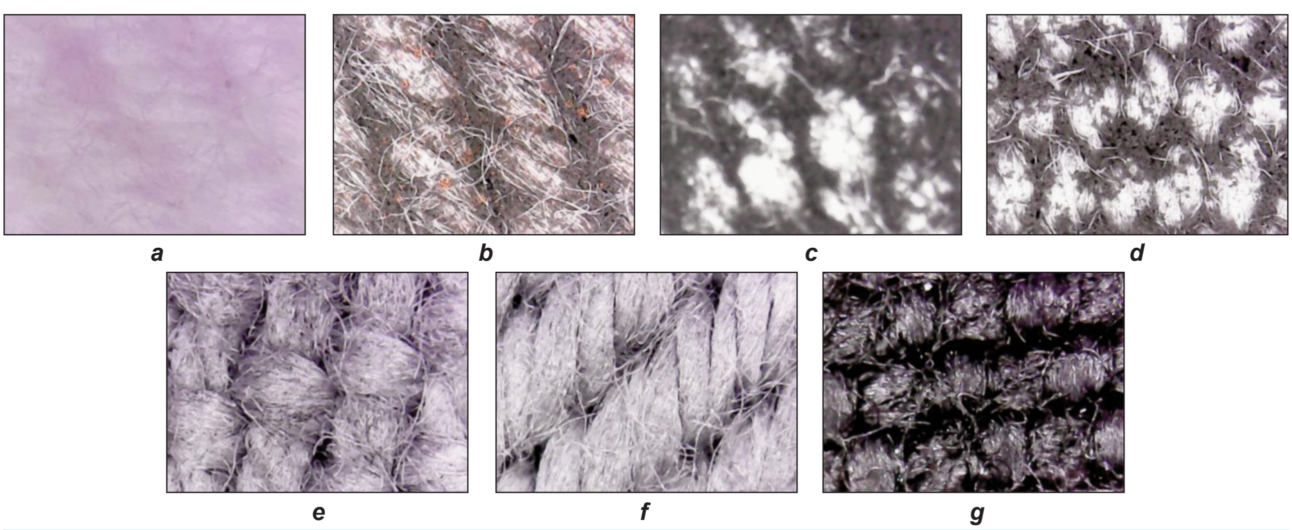

Fig. 4. Topographic analysis of the surface of the textiles based on the optical microscopy: *a* – fabric without microparticles submitted; *b* – Sample M1; *c* – Sample M2; *d* – Sample M3; *e* – Sample M4; *f* – Sample M5; *g* – Sample M6

drying and crosslinking, low surface resistance (Rs = 10^3 Ω) and have the highest electromagnetic efficiency.

Following the electromagnetic effectiveness and surface resistance tests, we observed that:

- Between the efficiency of the electromagnetic shielding and surface resistance of the obtained samples, it is an indirect relationship of dependence.
- Experimental tests performed by scraping off the conductive paste-based Ni and/or Al show surface resistance values similar to those obtained for samples made by immersion/ultrasound in dispersions based on PVA and Ni and Al microparticles (M4, M6).
- The efficiency of electromagnetic shielding in the case of screens based on Ni microparticles (M4 test) is higher than the efficiency of shielding in the case of electromagnetic screens based on Al and Ni (M6 test) at low frequencies (0.1–325 MHz).
- The efficiency of electromagnetic shielding in the case of screens based on Al and Ni microparticles (sample M6) is higher than the efficiency of shielding in the case of Ni-based screens (sample M4) at high frequencies (326 MHz – 1 GHz).

For parameters such as electrical surface resistance, the thickness (δ), mass (M), and electromagnetic shielding efficiency ($S1$ for 5 MHz frequency and $S2$ for 700 MHz frequency) have been developed a multivariate analysis.

In figures 5–10 are presented the 3D representations of the electrical resistance (Rs) in the function of the thickness (δ), mass (M), electromagnetic shielding efficiency at 5 MHz ($S1$) and electromagnetic shielding efficiency at 700 MHz ($S2$) using MATLAB software. For experimental parameters (Rs, M, δ, $S1$, $S2$) was performed an analysis of the correlation coefficient Pearson between Rs and M, δ, $S1$, $S2$:

$$r_{xy} = \frac{\frac{1}{n}\sum(x-\bar{x})(y-\bar{y})}{s_x s_y} \quad (2)$$

where x, y represent the individual values of the variables x and y; $\bar{x}$, $\bar{y}$ represent the arithmetic mean of all the values of x, y; s_x, s_y represents the standard deviation of all values x and y.

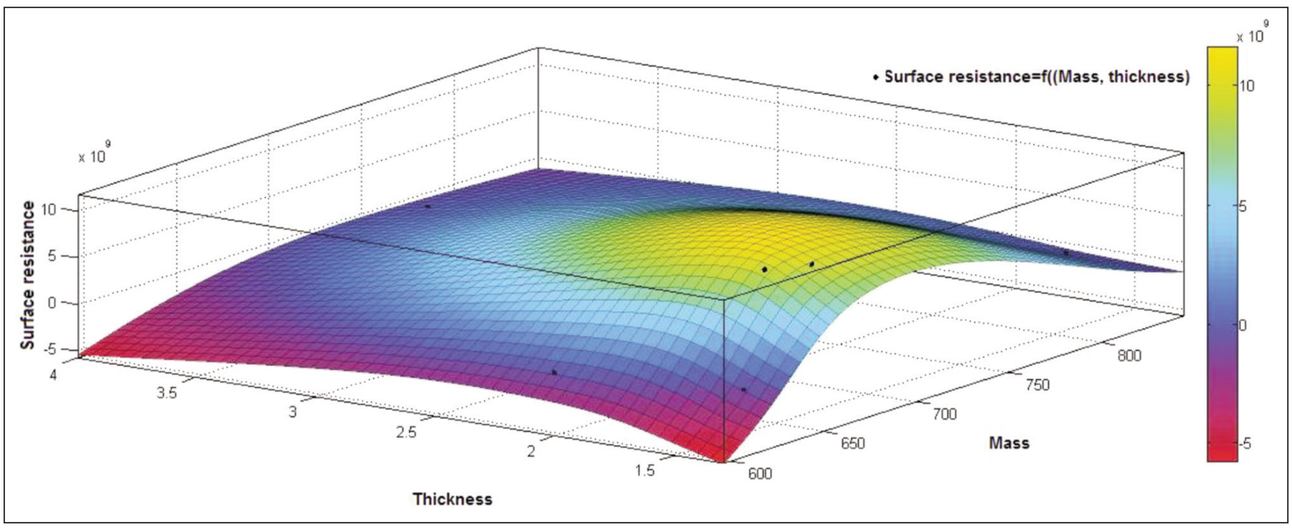

Fig. 5. 3D representation of the surface resistance according to the mass (M) and thickness (δ), $Rs = f(M, δ)$)

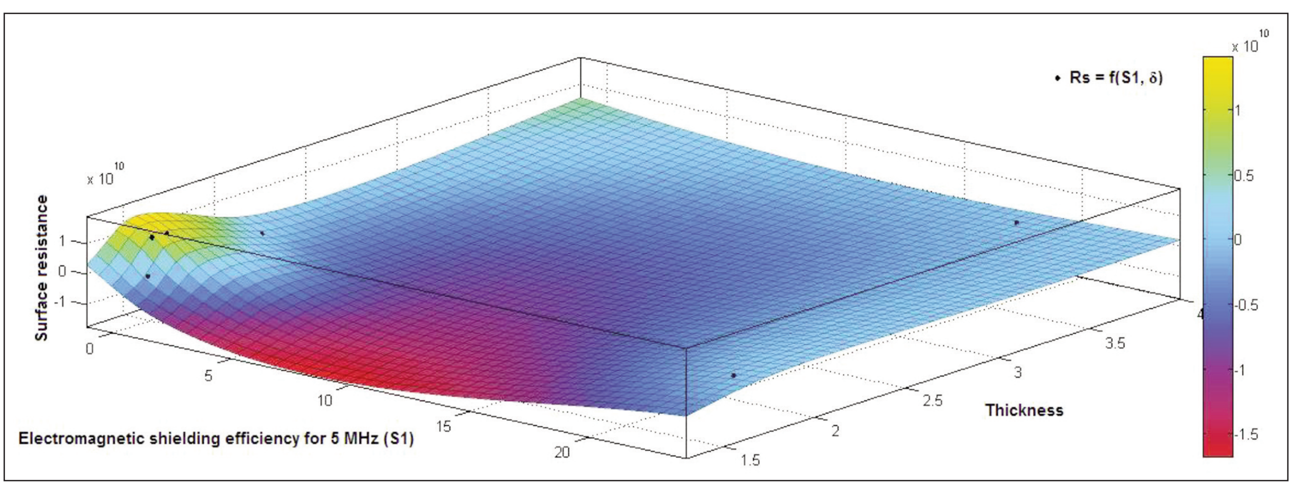

Fig. 5. 3D representation of the surface resistance (Rs) according to the electromagnetic shielding efficiency at 5 MHz ($S1$) and thickness (δ), $Rs = f(S1, δ)$

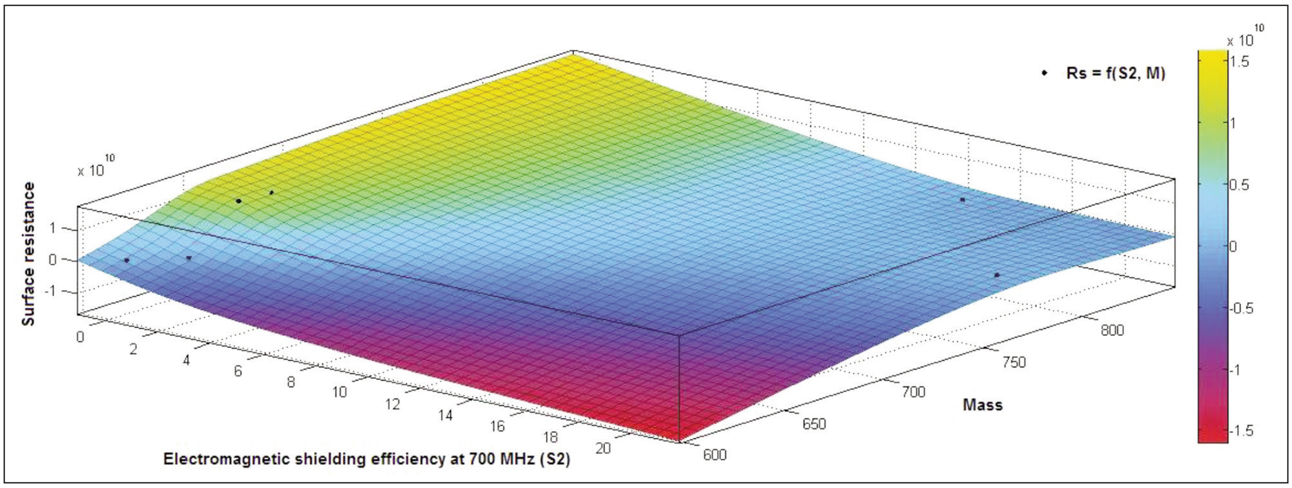

Fig. 7. 3D representation of the surface resistance (*Rs*) according to the electromagnetic shielding efficiency at 700 MHz (*S*2) and mass (M), *Rs* = *f*(*S*2, *M*)

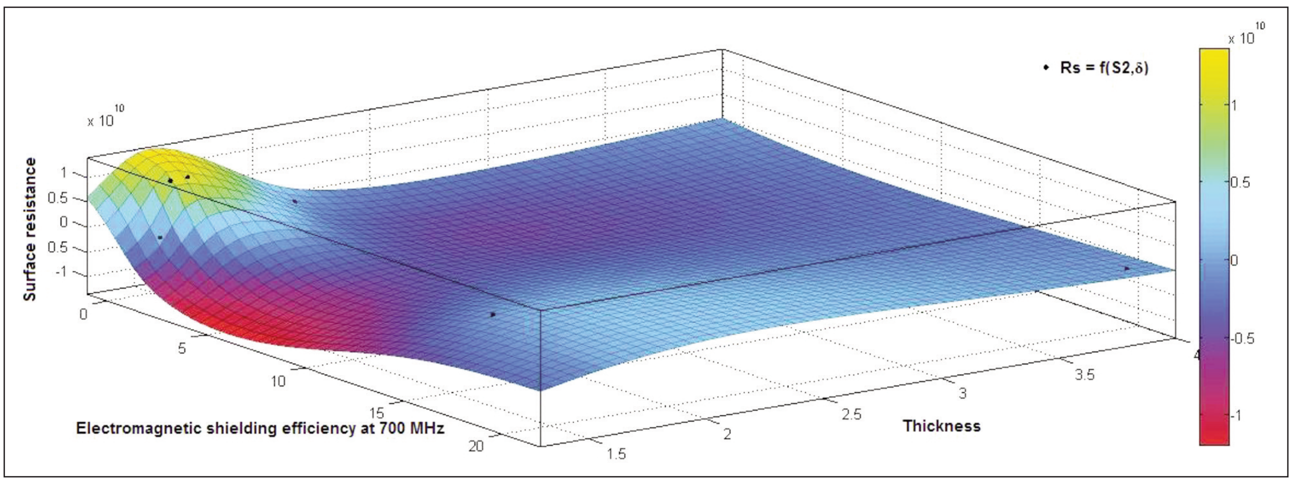

Fig. 8. 3D representation of the surface resistance (*Rs*) according to the electromagnetic shielding efficiency at 700 MHz (*S*2) and thickness (δ), *Rs* = *f*(*S*2, δ)

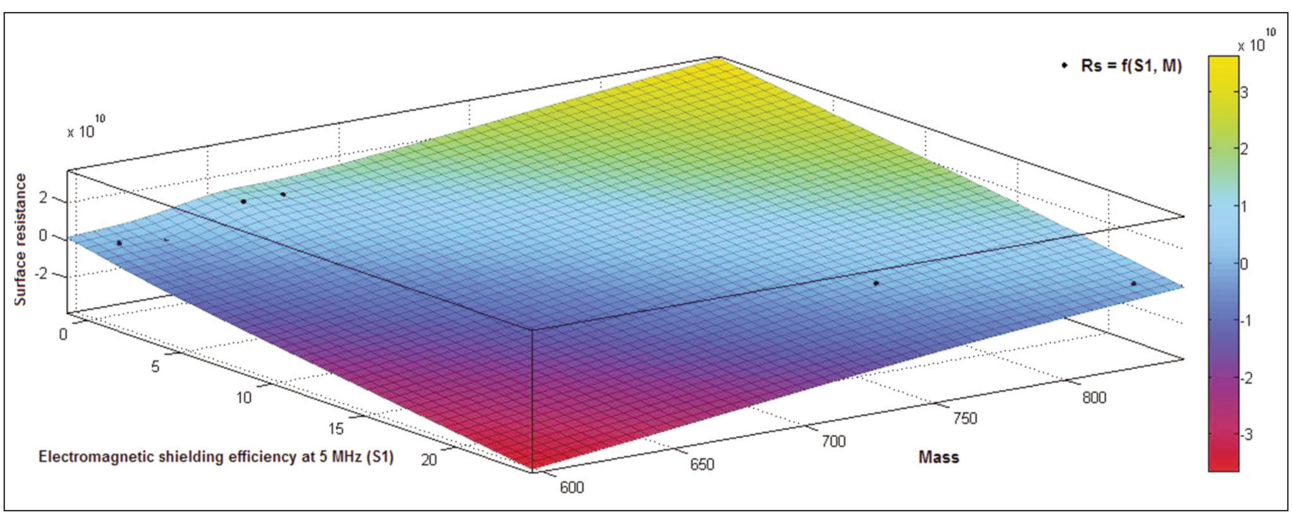

Fig. 9. 3D representation of the surface resistance (*Rs*) according to the electromagnetic shielding efficiency at 5 MHz (*S*1) and mass (*M*), *Rs* = *f*(*S*1, *M*)

$$r_{RsM} = \begin{vmatrix} 1.0000 & -0.2623 \\ -0.2623 & 1.0000 \end{vmatrix} \Leftrightarrow \quad (3)$$
$$\Leftrightarrow r12_{RsM} = r21_{RsM} = -0.2623$$

$$r_{Rs\delta} = \begin{vmatrix} 1.0000 & -0.4027 \\ -0.4027 & 1.0000 \end{vmatrix} \Leftrightarrow \quad (4)$$
$$\Leftrightarrow r12_{Rs\delta} = r21_{Rs\delta} = -0.4027$$

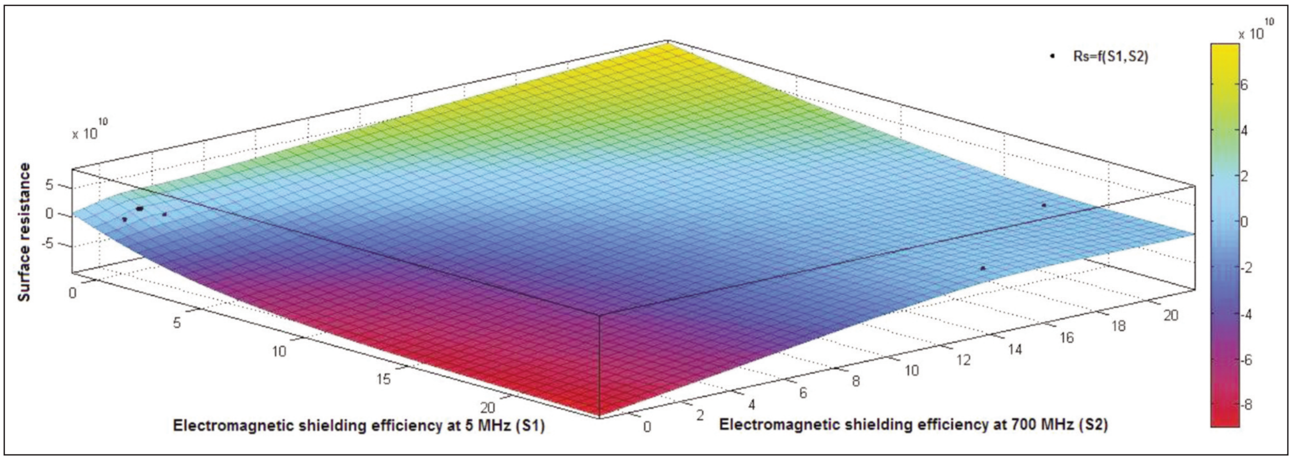

Fig. 10. 3D representation of the surface resistance (*Rs*) according to the electromagnetic shielding efficiency at 5 MHz (*S*1) and electromagnetic shielding efficiency at 700 MHz (S2), *Rs* = *f*(*S*1, *S*2)

$$r_{R_S S1} = \begin{vmatrix} 1.0000 & -0.5061 \\ -0.5061 & 1.0000 \end{vmatrix} \Leftrightarrow \quad (5)$$
$$\Leftrightarrow\ r12_{R_S S1} = r21_{R_S S1} = -0.5061$$

$$r_{R_S S2} = \begin{vmatrix} 1.0000 & -0.4858 \\ -0.4858 & 1.0000 \end{vmatrix} \Leftrightarrow \quad (6)$$
$$\Leftrightarrow\ r12_{R_S G} = r21_{R_S G} = -0.4858$$

Analysing the values of the correlation coefficients $r_{R_S M}$ (equation 3), $r_{R_S \delta}$ (equation 4), $r_{R_S S1}$ (equation 5), and $r_{R_S S2}$ (equation 6) which are all negative, it can be observed that between the surface resistance (*Rs*) and other parameters (mass, thickness, electromagnetic shielding efficiency at 5 MHz (*S*1) and electromagnetic shielding efficiency at 700 MHz (*S*2)), it is a negative inverse proportionality relationship, and this indicates that the increase of the mass or thickness with conductive coatings will generate the decreasing of the surface resistance, and obvious an increasing of the surface conductance and electromagnetic shielding efficiency. On the other side, it is evident the surface resistance and electromagnetic shielding efficiency are in an inverse proportionality relationship.

CONCLUSIONS

In conclusion, polymeric 3D composites obtained based on PVA-Ni, PVA-Ni-Al conductive pastes can be used to make electromagnetic screens for low or high frequencies.

Based on the analysis of the Pearson correlation coefficient, we can appreciate that mass, thickness and electromagnetic shielding efficiency are in inverse dependence relationship with the surface resistance. However, to obtain good electromagnetic shielding efficiency we should reduce the surface resistance. However, in this paper, the paramagnetic property of the nickel was evident and had an important contribution in shielding at different frequencies.

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