ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

INFLUENCE OF PLASMA COATED WOVEN FABRICS YARN’S DENSITY ON ELECTROMAGNETIC SHIELDING EFFECTIVENESS

RĂDULESCU Ion Răzvan[1], SURDU Lilioara[1], VISILEANU Emilia[1], SCARLAT Răzvan[1], CONSTANTIN Cătălin[2], MORARI Cristian[3], MITU Bogdana[2]

[1] INCDTP - Bucharest, Str. L. Patrascanu 16, 030508, Bucharest, Romania, office@incdtp.ro

[2] INFLPR – Magurele, Bucharest, Str. Atomistilor 409, 077125, Bucharest, Romania, mitub@infim.ro

[3] ICPE-CA – Bucharest, Splaiul Unirii 313, 030138, Bucharest, Romania, cristian.morari@icpe-ca.ro

Corresponding author: Rădulescu, Ion Răzvan, E-mail: razvan.radulescu@incdtp.ro

Abstract: *Electromagnetic radiation in our environment means hazard~~s~~ for human’s health and interference for electronic equipment. One method of protection according to electromagnetic compatibility is shielding. Conductive textiles represent a modern solution for electromagnetic shielding, due to their specific properties like lightweight, flexibility, mechanical resistance and 3D – shape ability. There are mainly two methods for imparting electric conductive properties on textile materials: insertion of conductive yarns within the fabric structure and coating of the fabric surface with conductive raw materials. This paper presents textile EM shields achieved by combining these methods: woven fabric structures with inserted silver yarns in warp and weft direction with various fabric densities were designed and manufactured and afterwards coated by magnetron plasma with a copper thin film. Electromagnetic Shielding Effectiveness (EMSE) measurements were conducted on these fabrics in the frequency range of 0.1-1000 MHz. Values of EMSE reached 40-55 dB. The main aim of the paper is to show that fabrics with a low yarn density have a better gain of EMSE values after plasma coating with copper. This fact may be explained by an interpenetration of the copper films from one side to the other side within the woven fabric structure for low yarn densities and formation of electrically conductive paths.*

Key words: *textiles, silver, cotton, magnetron, copper*

1. INTRODUCTION

Flexible electromagnetic shields out of textile fabrics represents a solution well documented within the literature. The research studies are focused towards various directions in the inter-disciplinary field of textiles and electromagnetic compatibility [1,2]. As such, research papers tackle first of all new manufacturing methods for achieving EM shields out of textile materials [3-7]. Main aim is to achieve a performant shielding effectiveness (EMSE), by considering cost-effectiveness and resource efficiency. A second priority is to describe new methods for measuring electric properties in case of conductive textiles, such as electric resistivity / conductivity and EMSE [8]. Such scientific contributions have as purpose achieving most precise measurement methods in case of the composite textile materials. Another valuable direction is the modelling of electric properties for textile materials (conductivity, EMSE), followed by subsequent validation of proposed mathematical relations by experimental measurements [9,10]. Main aim is to consider a mathematical model, simple enough to precisely estimate the experimental evolution of the physical property [11]. Other research contributions tackle resource efficiency and environmental friendliness of the manufacturing technologies, even by LCA studies [12, 13]. The present paper contributes to new manufacturing methods of flexible EM shields, namely magnetron plasma coating and has as main aim a correlation between woven fabric structure (yarn's density) and achieved EMSE properties.

2. MATERIALS

Woven fabrics with inserted conductive yarns and coated in magnetron plasma were used for this study. The woven fabrics consist out of 100% cotton yarns Nm50/2 and conductive yarns out of silver coated polyamide 117/17 dtex (STATEX), inserted in warp and weft direction. Sample F5 had silver yarns inserted only in weft direction. The woven fabrics had plain weave, with various densities (number of yarns per 10 cm). The structural and physical-mechanical properties of the achieved fabric samples are presented in table 1:

Table 1: *Structural and physical-mechanical properties of samples*

Fabric samples / Properties		*F1*	*F2*	*F3*	*F4*	*F5*
Float repeat: [Basic:conductive yarn]	Warp	6:2	6:2	6:2	6:2	1:0
	Weft	3:2	3:2	4:2	5:2	6:1
Density [No. of yarns / 10 cm]	Warp	160	163	168	168	624
	Weft	110	124	140	150	326
Fabric thickness [mm]		0.516	0.495	0.506	0.495	0.490
Specific mass [g/m^2]		98	106	113	118	208

The electrical conductivity of the silver yarns was of σ = 111kS/m. This value was computed by measuring the linear resistance of the yarn and applying the resistivity relation. The relative magnetic permeability and the relative electric permittivity of silver equal to 1. The weaving of combined cotton/silver textiles was conducted to insure 1 silver yarn every 4 mm on both warp and weft direction.

3. EXPERIMENTAL

The woven fabrics samples (F1-F5) were coated by magnetron plasma with copper layers on both sides for improvement of EMSE. EMSE was measured by TEM cell according to standard ASTM ES-07 for initial and coated fabric samples.

3.1. Plasma coating of fabrics

The copper coating of the textile fabrics was performed at INFLPR into a dedicated spherical stainless steel vacuum chamber (K.J. Lesker), pumped out by an assembly of a fore pump and turbomolecular pump (Pfeiffer), which allowed the obtaining of a base pressure down to 3x10^{-5} mbar [14]. A constant argon flow (purity 6.0) of 50 sccm was continuously introduced into the chamber by means of a Bronkhorst mass flow controller, which insured to establish the processing pressure around 5 x10^{-3} mbar. The chamber is provisioned with magnetron sputtering gun from K.J. Lesker, accommodating a high purity copper target (99.999%). The discharge was ignited by means of an radio frequency generator (13.56 MHz) provisioned with an automatic matching box for adapting the impedance, and the deposition time was set to insure a coating thickness of 400 nm and

1200 nm on each sides of the textile fabrics. Enhanced deposition uniformity was achieved by rotating the samples during the deposition process (200 rotation/min).

The five woven fabric samples previously described in table 1 were coated on both sides with copper thin films by magnetron sputtering. A number of new five samples with destination electromagnetic shielding resulted (table 2) resulted upon plasma processing.

***Table 2:** Plasma coated fabric samples*

Sample code	F6	F7	F8	F9	F10
Coating thickness on both sides [nm]	1200	1200	1200	1200	400

3.2 EM Shielding effectiveness measurement

EMSE measurement was accomplished according to the standard ASTM ES-07, via a Transversal Electric-Magnetic cell (TEM Cell). EMSE is defined as:

$$EMSE = 10\log_{10}\left(\frac{power\ of\ incident\ signal}{power\ of\ transmitted\ signal}\right) \quad \textbf{(1)}$$

A scheme of the coaxial TEM cell is presented in figure 1 and a picture of the TEM cell in figure 2.

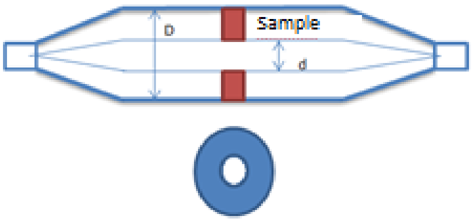

***Fig.** 1: Scheme of the TEM cell and of the testing woven fabric sample*

***Fig.** 2: Picture of the TEM cell ICPE-CA*

Tested fabric samples were tailored in annular shape having an outer diameter of 100 mm and an inner diameter of 30 mm and fixed onto the cell by means of colloidal Ag paste. The measurement system included a signal generator E8257D, a Power amplifier model SMX5, the Coaxial TEM cell model 2000 and an Oscilloscope Tektronix model MDO3102. The EMSE measurements were accomplished within the frequency range of 100 kHz to 1 GHz. EMSE was measured for each of the resulted samples (F1 – F10).

4. RESULTS AND DISCUSSION

The five fabric samples with inserted conductive yarns and the same substrates coated by magnetron plasma were investigated regarding EMSE. Figure 3 and figure 4 present EMSE values measured for specific points within the frequency range 100 kHz – 1 GHz.

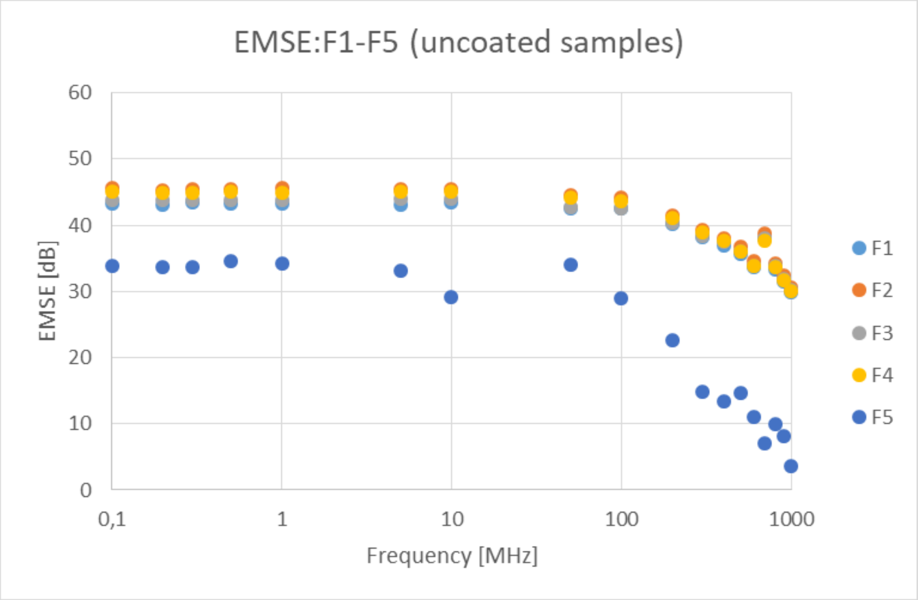

***Fig.** 3: EMSE values for fabric samples F1-F5 (uncoated samples)*

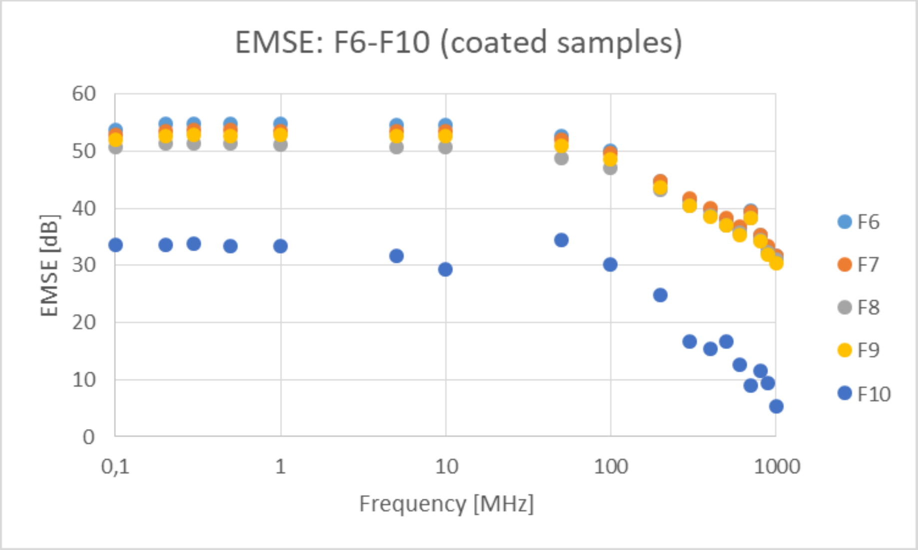

***Fig.** 4: EMSE values for fabric samples F6-F10 (coated samples)*

The measured values of EMSE show that plasma coating renders an increase of 6-12 dB in the frequency range of 100 kHz-100 MHz. Coated textiles are part of the small-aperture metal electromagnetic shields family which can be seen as arrays of waveguides below cutoff. For this type of shielding materials, EMSE is mainly due to reflection loss, absorption and correction factor of multiple reflections having a less significant contribution. When the apertures become a very small fraction of wavelength, the electromagnetic wave “sees” the material as a homogenous media. As the aperture size increase, becoming a larger fraction of wavelength, the electromagnetic wave starts to propagate inside the structure and EMSE drops. This phenomenon explains the decrease in EMSE at frequencies above 100 MHz which can be observed in figures 3 and 4. Moreover, the electrical contact between sample and the test cell becomes very important at high frequencies where leakages may occur if the contact resistance is low. The sample with high yarn density (F5) shows the smallest EMSE values for the frequency range, for it presents silver yarns only in weft direction. The other four samples have similar EMSE values on the entire frequency range due to similar fabric structures, with single variation of the yarn density. Figure 5 shows explicitly the gain achieved by the copper plasma coating on the five fabric samples. Once again, the fabric with the highest density (F10/F5) shows the smallest gain of up to 2 dB upon Cu coating. Yet, it has to be noted that sample F10 had only 400 nm coating thickness, showing also that the thickness of the coating layer is important to improve EMSE. However, the woven fabric with the low yarn density (F6) shows the highest gain of EMSE of up to 12 dB, followed by F7, which is closely tracked by F8 and F9 with similar EMSE values. These experimental considerations prove the initial premise of the study: fabrics with low yarn density subjected to magnetron plasma coating show better EMSE properties.

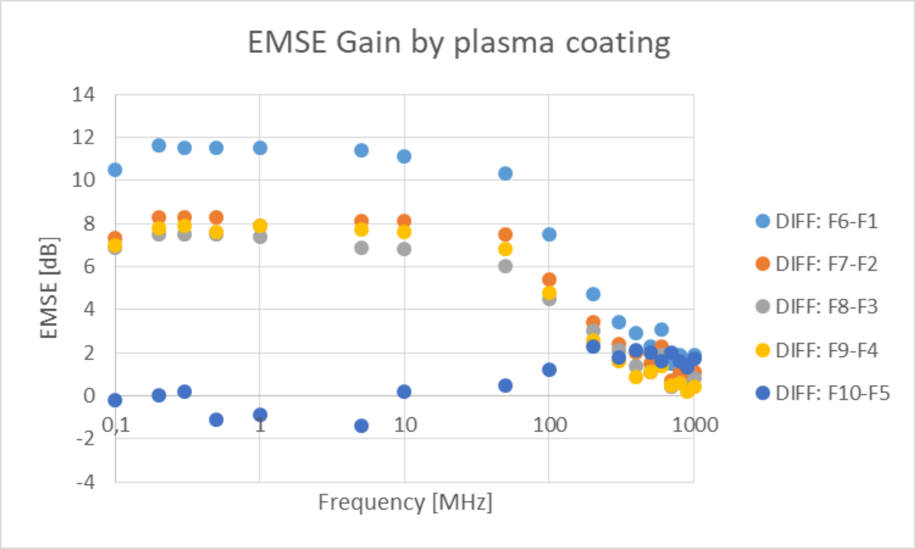

***Fig.** 5: Gain of EMSE on the five woven samples by plasma coating*

This fact may be explained by an interpenetration of the layers on one side to the other one in the existing spaces between the yarns in the weft and warp directions, which is more pronounced in the woven fabrics with low yarn density. This allows the formation of electrically conductive paths inside the fabric that contribute to the overall electromagnetic shielding of the material.

5. CONCLUSIONS

Woven fabric samples with inserted conductive silver yarns and different densities on warp and weft direction were designed and manufactured with destination EM shielding. All fabric samples were subsequently coated by copper magnetron plasma for improvement of EMSE properties. Premise of the study was better electrically conductive and EMSE properties for the coated samples with a low yarn density. Experimental results of EMSE measurement proved this premise. The better electric properties in case of plasma coated fabrics with lower yarn densities may be explained by a better penetration of copper particles inside the fabric structure.

ACKNOWLEDGEMENTS

Research work for this study has been performed within ERA-NET Manunet project Ctr. 28/2018 TexEMFiRe – “Manufacturing textiles with electromagnetic shielding and fire retardant properties by plasma based methods" and Nucleus project PN19150101 – "Emerging research on lasers, plasma and radiations and their applications in the fields of smart specialization and public interest", while publishing has been funded by Ministry of Research and Innovation, by Program 1 – Development of the national system for research-development, Subprogram 1.2 – Institutional performance – projects for funding excellence in RDI, contract no. 6PFE from 16.10.2018.

REFERENCES

[1] A. Schwab, W. Kuerner, "*Compatibilitate electromagnetica*", AGIR publishing, 2013

[2] C.R. Paul, "*Introduction to Electromagnetic compatibility*", Wiley series in microwave and optical engineering, 2006

[3] B. Moazzenchi, M. Montazer, "*Click electroless plating of nickel nanoparticles on polyester fabric: Electrical conductivity, magnetic and EMI shielding properties*", Colloids and Surfaces A 571 (2019) pp. 110–124

[4] V. P. Anjua, M. Manojb, Pezholil Mohananb, Sunil K. Narayanankuttya, "*A comparative study on electromagnetic interference shielding effectiveness of carbon nanofiber and nanofibrillated cellulose composites*", Synthetic Metals 247 (2019) pp. 285–297

[5] D. Meher, Suman, N. Karna, B.P. Sahoo, „*Development of Poly (vinylidene fluoride) and Polyaniline blend with high dielectric permittivity, excellent electromagnetic shielding effectiveness and Ultra low optical energy band gap: Effect of ionic liquid and temperature*", Polymer 181 (2019) 121759

[6] Hyo-Jun Oha, Reddicherla Umapathi et al., „*Effect of various seed metals on uniformity of Ag layer formed by atmospheric plasma reduction on polyethylene terephthalate substrate: An application to electromagnetic interference shielding effectiveness*", Thin Solid Films 676 (2019) pp. 75–86

[7] J. Ziaja, M. Jaroszewski, "*EMI shielding using composite materials with plasma layers*", InTechOpen, 2011

[8] Morari, C., Patroi, E., Balan, I., "*Composite materials for electromagnetic shielding*", U.P.B. Sci. Bull., Series B, Vol. 78, Iss. 2, 2016

[9] T. Rybicki și S. Brzenski, "*Modelling protective properties of textile shielding grids against electromagnetic radiation*", Fibers and Textiles in Eastern Europe, vol. 21, nr. 1 (97), pp. 78-92, 2013.

[10] M. Neruda, L. Vojtech, "*Electromagnetic Shielding Effectiveness of Woven Fabrics with High Electrical Conductivity: Complete Derivation and Verification of Analytical Model, Materials*" 2018, 11, 1657;

[11] K. Velten, "*Mathematical modelling and simulation*", WILEY-VCF Verlag, 2009.

[12] L. Surdu, I.R. Radulescu, I. Barbu, "*Life cycle assessment for medical textiles treated with plasma*", Industria Textila 5/2015, 360-364

[13] I. R. Radulescu, L. Surdu, M. Badic, C. Morari, "*Mathematical modelling of the shielding effectiveness for PES/stainless steel fabrics*", Annals of the University of Oradea, Fascicle of Textiles, Leatherwork – 18th Internatonal Textile Conference Oradea, Romania, 2017

[14] L. Surdu, I.R. Rădulescu, E. Visileanu, C. Stancu, A. Ardeleanu, I. Sandulache, C. Mitran, B. Mitu, *Research regarding the cover factor of magnetron sputtering plasma coated fabrics*, Industria Textila 2/2019, ISSN 1222–5347 2/2019