STAINLESS STEEL AND COPPER MAGNETRON PLASMA COATING OF FABRICS WITH METALLIC YARNS FOR ELECTROMAGNETIC SHIELDING APPLICATIONS

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Electromagnetic shielding is needed to protect human beings from undesired non-ionizing radiation and to protect electronic equipment from EM interferences. Shielding solution of Electromagnetic Compatibility domain is tackled nowadays by modern manufacturing methods of flexible textile fabrics with electrically conductive properties. Our research focuses on the additional electromagnetic shielding effectiveness (EMSE) rendered by plasma coating of flexible woven fabrics with inserted conductive yarns. EMSE was computed for an experimental plan formed of plasma coating with Copper and Stainless steel with thicknesses of 400 nm and 1200 nm on both sides of woven fabrics with inserted conductive yarns of stainless steel and silver. An additional EMSE of 5-20 dB on the frequency range of 0.1-1000 MHz was achieved by plasma coating. This proves the enhancement of the shielding properties by magnetron plasma coating, without altering the bulk properties of textile fabrics, such as flexibility and mechanical resistance. The paper presents EMSE results in relation to fabric structure, raw metallic materials and frequency of the incident electromagnetic field.

Keywords: magnetron plasma, fabrics, electromagnetic shielding effectiveness

INTRODUCTION

Electromagnetic shielding is useful nowadays in various applications, such as avoiding interference of electronic equipment and ensuring wellbeing of humans, against hazards caused by non-ionizing radiation. Electromagnetic shielding' theoretical background is related to the larger field of Electromagnetic Compatibility (EMC) (Schwab and Kuerner, 2012). Two mathematical models describe the electromagnetic shielding effectiveness in relation to the geometric and electric parameters of the shielding material: the impedance method and the circuit method (Kaden, 1959). The progress of textile technology in manufacturing metallic yarns, leaded to the development of textile based electrically conductive structures with flexible properties. The main required property of textile shields is their electric conductivity. Two main technologies of imparting electrical conductivity may be distinguished within the scientific literature: inserting metallic yarns into the fabric structure and coating with metallic layers (Ziaja and Jaroszewski, 2011). The present paper is a contribution to new manufacturing methods of textile shields and combines these two main technologies: woven fabrics with metallic yarns (of steel and silver) within their structure are coated with thin metallic layers (of copper and steel) by magnetron sputtering. Recent developments encompass additional properties rendered to textile shields: hydrophobic character (Dai *et al*., 2020), good air permeability (Liu *et al*., 2021), wash-ability (Xu *et al*., 2020), good mechanical resistance (Pakdel *et al*., 2020) and self-cleaning (Kardarian *et al*., 2014). Aspects such as the cover factor (Surdu *et al*., 2020) and yarn's density (Radulescu *et al*., 2020) on the shielding effectiveness of the

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mentioned structures were studied too, as well as a model related to the main electric and geometric parameters (Radulescu *et al*., 2021).

EXPERIMENTAL

Two manufacturing stages were accomplished in order to produce textile shields with inserted metallic yarns and plasma metallic coating:

1. Manufacturing of woven fabrics with inserted metallic yarns of steel and silver;
2. Coating of these woven fabrics by magnetron sputtering with thin layers of copper and steel.

The design and the physical-mechanical parameters of the woven fabrics produced at stage one is presented in Table 1.

Table 1. Design and physical-mechanical properties woven fabrics with inserted conductive yarns

Fabric design and physical-mechanical properties	F1 – woven fabric with inserted stainless-steel yarns	F2 – woven fabric with inserted silver yarns
Linear density of yarns [dtex]	400	220
Float repeat warp	6:2	no yarns
Float repeat weft	6:2	6:1
[Cotton yarns: Metallic yarns]		
Yarn density warp [yarns/10 cm]	180	650
Yarns density weft [yarns/10 cm]	170	340
Distance conductive yarns [mm]	4	4
Specific mass [g/m^2]	143	114
Thickness [mm]	0.55	0.33

The experimental plan of plasma coating of the raw fabrics F1 and F2 at stage two is presented in Figure 1. The two fabrics were coated with copper and steel on both sides with thicknesses of 400 nm and 1200 nm.

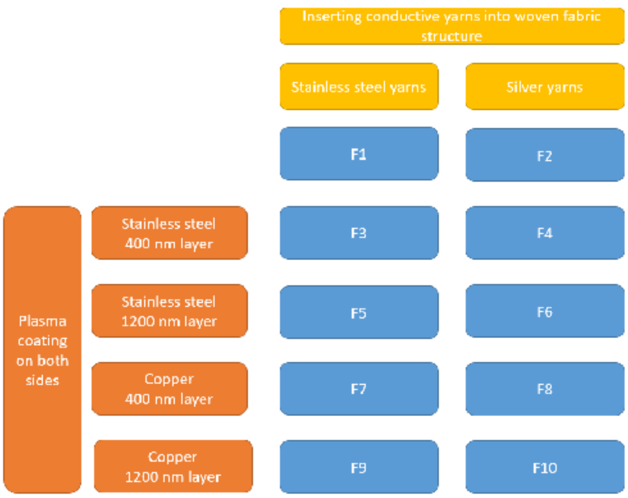

Figure 1. Experimental plan of plasma coating on fabrics

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The coating technology of fabrics with thin layers was based on magnetron sputtering from copper and stainless-steel targets, respectively. The coatings were achieved at INFLPR into a dedicated stainless steel spherical vacuum chamber (K.J. Lesker, UK), pumped out by an assembly of a fore pump and turbomolecular pump (Pfeiffer, DE), which allowed the obtaining of a base pressure down to 3 × 10−5 mbar. 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 allowed establishing the processing pressure around 5 × 10−3 mbar. The chamber is provisioned with a 2” magnetron sputtering gun from K.J. Lesker, accommodating the target. The magnetron discharge was running at 100 W by means of a radio frequency generator (13.56 MHz) provisioned with an automatic matching box for adapting the impedance, and the deposition time was set to ensure coating thicknesses of 400 nm and 1200 nm on each side of the textile fabrics. Enhanced deposition uniformity was achieved by rotating the samples during the deposition process (200 rotations/ min).

Electromagnetic shielding effectiveness (EMSE) was measured at ICPE-CA according to the standard ASTM ES-07, via a TEM cell and the related signal generator, power amplifier and spectrum analyzer.

RESULTS AND DISCUSSION

The physical-mechanical properties of the achieved samples F3-F10 are presented in Table 2.

Table 2. Physical-mechanical properties of plasma coated samples

	Mass [g/m^2]	Thickness [mm]	Yarns density [yarns / 10 cm]	
			Warp	Weft
F3	149	0.55	180	170
F4	125	0.39	660	330
F5	158	0.523	180	170
F6	131	0.38	660	330
F7	155	0.58	180	170
F8	119	0.48	650	340
F9	164	0.52	180	180
F10	133	0.38	660	330

An increase of the shields’ mass by an increased thickness of metallic layer may be deducted from the physical-mechanical properties. The thickness of the shield, although measured with a precision of 1 µm, shows relevant increase too. The plasma coating has less influence on the fabric’s yarn density.

The EMSE was measured in the frequency domain of 0.1-1000 MHz at various key frequencies and represented on a logarithmic scale (Figures 2-5).

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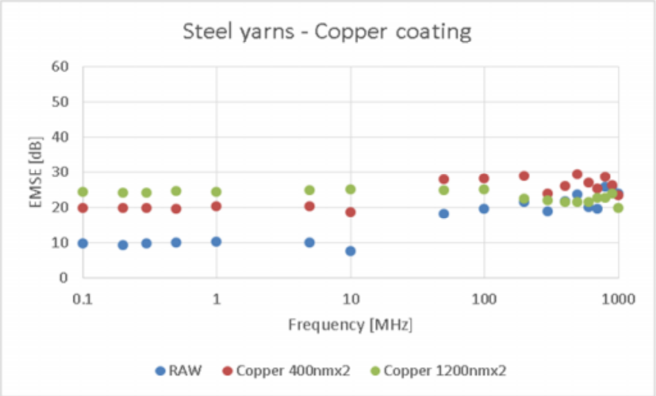

Figure 2. EMSE results of fabrics with steel yarns and copper coating

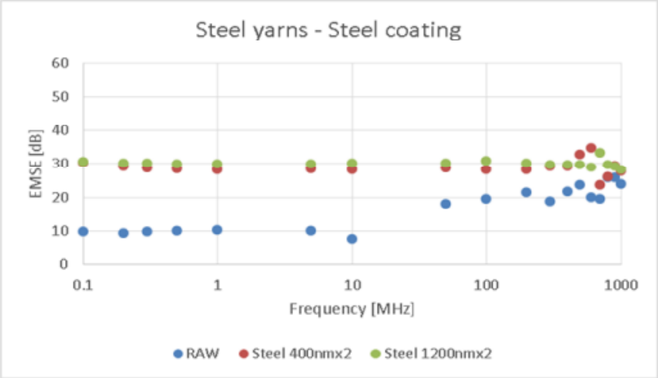

Figure 3. EMSE results of fabrics with steel yarns and steel coating

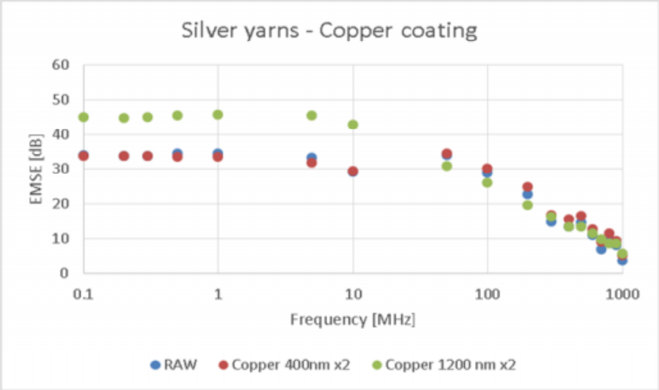

Figure 4. EMSE results of fabrics with silver yarns and copper coating

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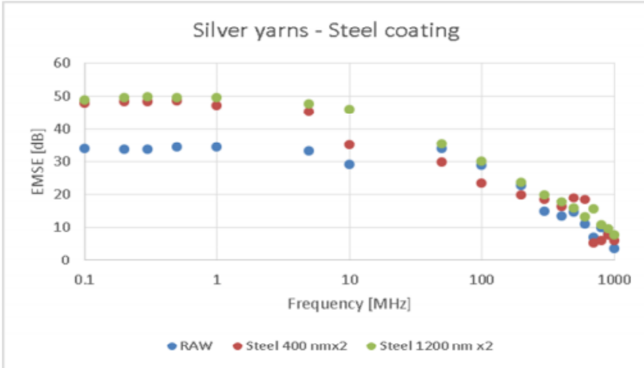

Figure 5. EMSE results of fabrics with silver yarns and steel coating

Plasma coating of the woven fabrics improves EMSE with 5-20 dB on the frequency domain 0.1-100 MHz, which represents a significant result. The steel coating has better results on steel yarns (an increase of 20 dB), a fact to be explained by the homogeneity of the metallic material (Figure 3). A significant difference between the 400 nm layer and the 1200 nm layer is shown in case of the copper coating of the woven fabric with silver yarns (an increase of 10 dB – Figure 4) and steel yarns (an increase of 5 dB – Figure 2). This fact may be explained by the superior conductivity properties of copper and the relevance of the coating thickness. The woven fabrics with silver yarns and steel coating (Figure 5) have best EMSE properties in the frequency range of 0.1-10 MHz with values reaching 50 dB.

For the frequency range of 100-1000 MHz a decrease of EMSE is shown in Figures 2-5. According to the accepted shielding theory (White, 1980), for homogenous conductive materials EMSE shows an almost exponential increase at high frequencies, where the material becomes electrically thick. In practice, it is difficult to have the same conditions assumed in the theoretical model and the measurements often offer results that don't follow the theoretical prediction due to the leakages that can appear. Thus, two factors could explain the decrease shown in Figures 2-5. The first, relates to the fact that perforations could exists in the metallic coated layer through which EM field is likely to leak thus altering the shielding capability of the samples at high frequencies. The second factor, refers to the leakages that appear at the contact between the material sample and the sample holder (in this case the TEM cell) and that increase with frequency.

CONCLUSION

A new manufacturing method of flexible EM shields is proposed by plasma metallic coating of woven fabrics with inserted metallic yarns. A comprehensive experimental plan of coating two woven fabrics with steel and silver yarns by magnetron plasma of copper and steel on both sides of the fabric with thicknesses of 400 nm and 1200 nm was accomplished. EMSE results show variations related to the applied metallic raw materials. The magnetron plasma coating preserves the flexibility of the textile shield and improves EMSE with 5-20 dB on the frequency range of 0.1-100 MHz. Best EMSE

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results is achieved by steel coating of woven fabric with silver yarns with 50 dB on the frequency range of 0.1-10 MHz. These types of flexible EM shields may find different application fields, such as curtains and panels for EM shielding in Buildtech domain, medical clothes for radiation shielding in Medtech domain, or special RF suits for working in antenna proximity environment in Clotech domain.

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