ELECTROMAGNETIC SHIELDING ACHIEVED BY PLASMA COATED FABRICS

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ABSTRACT

Electromagnetic shielding (EM) achieved by flexible materials has gained an increased significance in today's radiation polluted environment. In order to obtain electromagnetic shielding fabrics, two main technologies are available: insertion of conductive fibers/yarns and coating with conductive films. This paper focuses on manufacturing and investigation of EM shielding fabrics achieved by combining both technologies: fabrics with inserted conductive yarns of stainless steel and silver were coated with a thin copper film obtained by magnetron sputtering. Scanning Electron Microscopy (SEM) and atomic absorption spectroscopy measurements evidenced the copper content while electromagnetic shielding tests by means of Transversal Electromagnetic (TEM) cell evidenced good shielding effectiveness of 20-35 dB within 0.1-1000 MHz frequency range.

Key Words: Fabrics, copper thin films, conductive yarns, shielding effectiveness

1. INTRODUCTION

Human's health and wellbeing is affected by non-ionizing radiation of electromagnetic waves, such as the radiation of mobile GSM communication or internet WiFi networks [1]. Electromagnetic waves cause a heating of cellular tissues with negative long-term effects [2]. Moreover, the functioning of electronic devices may interfere with electromagnetic waves from various sources (such as power transmission lines, telecommunication, broadcasting), causing Electromagnetic interference (EMI) [3].
This problem requires adequate solutions. Shielding of electromagnetic waves belongs to Electromagnetic Compatibility (EMC) discipline. EMC's main aim is to ensure proper functioning of electronic devices and integration with other electronic components [4]. Thus, in order to avoid interference with other electronic devices functioning at various frequencies, a rigorous set of measures has to be followed within design of electronic devices. Shielding materials are based on good electrical conductivity, being conventionally made out of metallic plates and also out of fabrics with metallic insertion or coatings [5]. When compared to metallic plates, the electrically conductive fabrics present some advantages, such as flexibility, lightweight, mechanical resistance and shape-ability, well described in scientific literature [6]. Magnetron plasma is a modern technology for coating fabrics with metallic layers on nanometer scale [7-8], while inserting conductive yarns into a fabric structure is already a conventional approach.

The main aim of this paper is to comparatively study on manufacturing methods for electromagnetic shields out of fabrics, based on magnetron plasma coating and inserted conductive yarns. The paper focuses mainly on both manufacturing methods and on the results evaluation based on shielding effectiveness of the fabrics.

2. MATERIALS AND METHODS

2.1 Materials

2.1 Raw materials

Two types of raw materials were selected for fabric's structure, namely cotton and polyester. Raw fabrics with different yarn count, density and specific mass were manufactured. Two variants of fabrics had inserted conductive yarns out of stainless steel (in warp and weft direction) and out of silver (in weft direction). All variants of fabrics were subsequently coated on both sides by magnetron sputtering with Cu film having the thickness of 1200 nm.
The structural and physical-mechanical properties of raw fabrics are presented in table 1:

Table 1 – Physical-mechanical properties of fabrics

Property / Sample code	P1	P2	P3	P4
Fiber composition yarns	100% PES yarns	100% Cotton yarns	100% Cotton yarns + 80/20% Cotton/ Stainless steel yarns	100% Cotton + Silver coated PA6.6 yarns
Yarn count Warp Weft	 167/48x2 dtex 167/48x2 dtex	 Nm 20/1 Nm 20/1	 Nm 50/2 Nm 50/2	 Nm 85/2 Nm 85/1 + 117 dtex
Weave	Twill 2/1	Twill 3/1	Plain weave	Plain weave
Repeat conductive yarns	-	-	Warp: 6:2 Weft: 6:2	Warp: - Weft: 6:1
Specific mass [g/m^2]	207	231	143	113
Density Warp [No. yarns/cm]	36.4	30	18	65
Density Weft [No. yarns/cm]	21.4	16	17	34
Tensile strenght Warp [N]	2345	910	513	520
Tensile strength Weft [N]	1331	363	511	455
Rel. Elong. Warp [%]	40,0	10,61	10,85	12,52
Rel. Elong. Weft [%]	38,2	8,63	10,28	11,87

2.2 Plasma coating technique

The Cu coating of the textile fabrics was performed 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 3×10^{-5} mbar. The chamber is provisioned with a 2" magnetron sputtering gun from K.J. Lesker, accommodating a high purity Cu target (99.999%). Enhanced deposition uniformity was achieved by rotating the samples during the deposition process (200 rotation/min). A constant Ar (6.0) flow of 50 sccm was continuously introduced into the chamber by means of a Bronkhorst mass flow controller, so that the pressure established during the process was 5.3×10^{-3} mbar. The discharge was ignited at 100 W by using an Advanced Energy RF generator (13.56 MHz) -model CesarR provisioned with an automatic matching box for adapting the impedance. The deposition time was set to insure a coating thickness of 400 and 1200 nm on both sides of the textile fabrics. A sketch of the experimental set-up was provided elsewhere [9]

2.2 Methods

2.2.1 Copper content on plasma coated fabrics

Copper content on plasma coated fabrics was evidenced by SEM images and atomic absorption spectroscopy investigations.
Scanning Electron Microscopy (SEM) technique was used to reveal the morphological properties of Cu coated cotton and polyester fabric samples. SEM measurements were performed on a FEI Quanta 200 high resolution microscope which operating at an accelerating voltage of 10 kV.
Atomic absorption spectroscopy was used to investigate copper content in plasma coated fabrics, according to the following procedure: 5 g of weighted sample was extracted in 100 mL of acid perspiration solution. The resulted solution was stirred in an Erlenmeyer recipient for 30 min at room temperature. Solutions were filtered and analysed on Atomic Absorption Spectrometer AAS 880 Varian, by using a pre-existing calibration curve. Three value readings of metal extracted from each investigated sample was performed and mean values were calculated.

2.2.2 Shielding effectiveness measurement

Electromagnetic shielding effectiveness (EMSE) is defined as:

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

Shielding effectiveness of fabric samples was measured via a coaxial TEM cell, according to standard ASTM ES-07. A scheme of coaxial TEM cell and a load fabric sample is presented in figure 1.

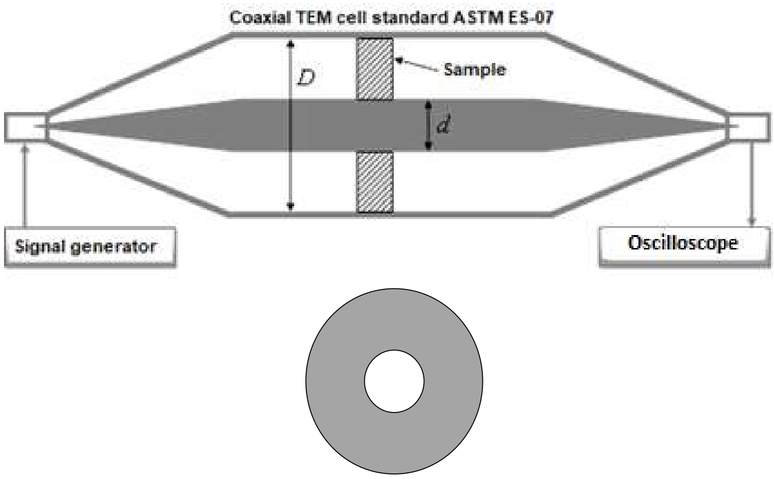


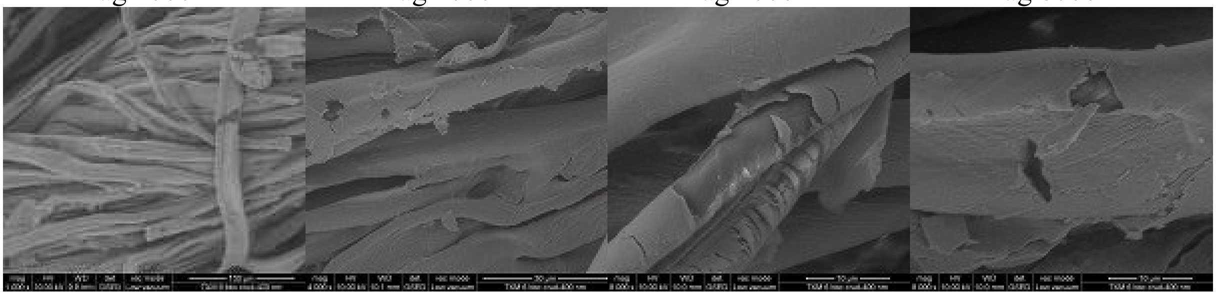
Figure 1. Scheme of TEM cell and load sample according to standard ASTM ES-07

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 chain included a signal generator E8257D, a Power amplifier model SMX5, the Coaxial TEM cell model 2000 and an Oscilloscope Tektronix model MDO3102.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The deposition of copper thin films on the fabrics was evidenced by scanning electronic microscope (SEM) images, as shown in Figure 2 in the case of magnetron plasma coated cotton fabrics with 400 nm film. A uniform coating of the fabric is observed, with regions with tendency of exfoliation evidencing the thin Cu layer as compared to the large diameter of the yarns.

Mag 1000x mag 2000x mag 4000x mag 8000x



a. b. c. d.

Figure 2. SEM images at various magnifications evidencing the covering of the cotton yarns with copper thin film (sample P2)

Atomic absorption spectroscopy determinations are presented in Table 2, which includes as well the calculations of the total Cu amount for the samples P1-P4.

Table 2. Copper content of coated cotton and PES fabrics

Notation samples	P1 Copper coated PES	P2 Copper coated cotton	P3 Copper coated stainless steel inserted	P4 Copper coated silver inserted
Mean (mg/L) in extracted solution	10.749	14.341	12.371	8.008
Mean (mg/L) after applying dilution factor	268.725	717.05	309.275	800.8
Copper quantity (mg Cu/g material)	0.2687	0.717	0.3093	0.8008

The values of table 2 show that 100% cotton fabrics present a higher amount of Cu as compared to 100% PES fabrics. The Copper coated cotton fabrics with inserted stainless steel yarns evidenced lower Cu amount as compared to that obtained in case of Copper coated cotton with inserted silver fabrics. One of the reasons for these scattered values may be related to the differences in the efficiency of the digestion process for each type of fabric, as well as to the sticking coefficient of the Cu atoms originating from the magnetron sputtering process to various types of yarns and weaving of the investigated fabrics.

Figure 5 presents the shielding effectiveness results according to standard ASTM ES-07, in the frequency range 0.1-1000 MHz.

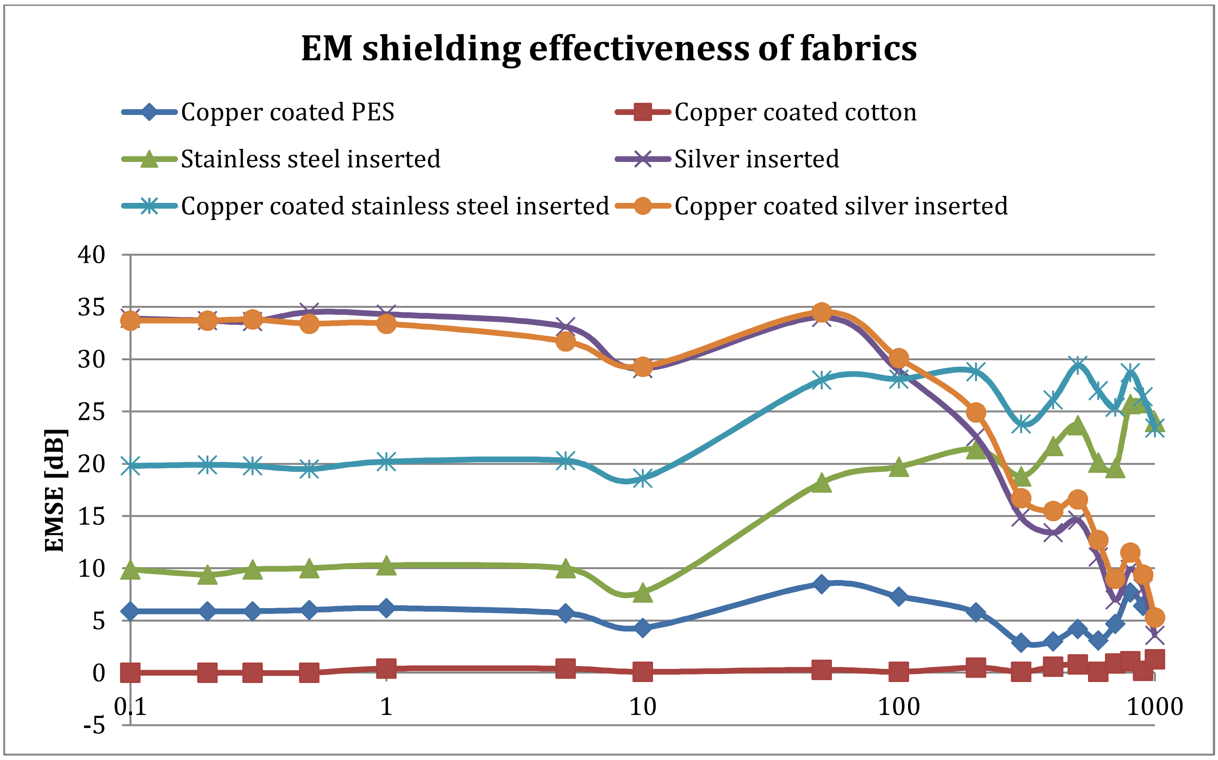


Figure 3. Shielding effectiveness results of the six studied fabrics

Figure 3 shows that copper coating on 100% cotton and 100% PES fabrics had satisfying results only in case of PES with values of 6-8 dB within 0.1-1000 MHz. The fabrics with inserted conductive yarns of stainless steel and silver had values of 10-20 dB, respectively 30-35 dB in the specified frequency range. For both these fabrics the Copper coating improved shielding effectiveness with 6-10 dB for fabrics with stainless steel and only with 2-3 dB for fabrics with silver. Copper coated fabric with silver had however the best overall shielding effectiveness with 35 dB in the frequency range of 0.1-100 MHz.

4. CONCLUSIONS

Both manufacturing technologies of achieving electromagnetic shielding on fabrics were applied within the present research study: insertion of conductive yarns (stainless steel / silver) and coating with Cu films with thicknesses in the micrometres range, by magnetron sputtering plasma. The deposited Cu films were evidenced by SEM images, while the atomic absorption tests showed values in the range of 0.26-0.8 mg Copper per gram of material. Shielding effectiveness tests were conducted according to ASTM ES-07 via TEM cell with values depending on the structure of conductive fabrics. Each of the two technologies renders good surface conductivity and electromagnetic shielding effectiveness (EMSE) to fabrics. Values of EMSE for plasma coated have 5-8 dB for PES fabric, while fabric with inserted yarns have 10-20 dB for stainless steel and 30-35 dB for silver in the frequency range 0.1-1000 MHz. The copper coatings obtained by plasma renders an additional 6-10 dB on stainless steel fabrics and 2-3 dB on silver fabrics. Both technologies improve shielding effectiveness on a single fabric.

5. ACKNOWLEDGEMENT

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