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EXPERIMENTAL RESEARCH ON TEXTILE AND NON-TEXTILE MATERIALS WITH APPLICATIONS TO ENSURE ELECTROMAGNETIC AND BIO-ELECTROMAGNETIC COMPATIBILITY

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Abstract: *The paper presents a synthesis of the research performed on the electromagnetic properties and characterization of textile and non-textile materials with applications in shielding and protection from the electromagnetic field. The composite structures of functional textiles intended for protective clothing or general applications for electromagnetic immunity are presented and characterized. There are analyzed composite textiles with amorphous, ferrous or non-ferromagnetic metallic threads manufactured by means of woven and knitting classical technologies as well as materials using non-metallic, electrically conductive powders. The properties of the plain jersey, rib jersey, full and half cardigan fabric, Milano rib, are presented, too. Besides textiles, there are also characterized some composite and non-composite structures using metallic yarns and carbon powder. Another direction of interest relates to the use of textile materials with amorphous metal structure with the scope of achieving a more efficient protection to the electromagnetic fields used in cellular systems and Wi-Fi networks. In addition, a comparative analysis of the methods of characterization of composite structures is made.*

Keywords: biocompatibility, EMC, EMI, hybrid yarn, knitted fabric, textile composite

1. Introduction

The discovery of the electromagnetic field (EMF) has led to the radical change of the environment, starting with the use of electricity, mainly due to anthropogenic sources. The world, in its structure, is of electromagnetic nature, which can explain the direct interaction with the electromagnetic field and its influence on the living. The field interaction with the living is generally accomplished through its components defined according to Electromagnetic Compatibility (EMC) norms: static electric and static magnetic fields, and time varying non-ionizing electric, magnetic, and electromagnetic fields with frequencies up to the upper microwave range. Regarding the high energy ionizing fields, corresponding to frequencies higher than of the ultraviolet radiation, the EMF interaction exhibits some particularities specific to the quantum

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phenomena. According to the classification of EMFs, two groups of field sources are differentiated:

- Low and very low frequency sources (0-3 kHz);
- EMF radiation sources from the area of radio frequencies and microwaves up to the lower limit of IR radiation (3 kHz - 300 GHz).

The first group includes industrial systems for electricity generation, transport and consumption. The second group includes all anthropogenic sources of EMF with medical and industrial applications, communications, military, research, information technology, etc. The interest in EMF interaction with the living emerged as a result of epidemiological and biological studies on the occurrence of some affections correlated with the presence of the EMF or with specific activities in electromagnetic environments. These have led to the natural need to prevent the biological risks of interfering with the EMF. The field effects may be direct, as a result of direct exposure to the field source, or indirect - due to the presence of objects in the environment, that may pose a threat to biological or instrumental security. In general, the direct effects of EMF are divided into two main groups:

- Non-thermal effects (e.g. stimulation of muscles, nerves, and sensory organs),
- Rapidly emerging thermal effects (heating of tissues).

The direct effects are relatively well known and studied, but the EMC Directive only takes into account effects that are well understood and based on known mechanisms. Since the Directive 2013/35/EU [1] distinguishes between sensory effects (vertigo, dizziness, phosphenes, thermal sensations on the skin, or acoustic effects – microwave hearing) [2,3], and health effects with well-defined causes, the exposure limit values (ELV) for sensory effects are defined separately from those for health effects. Ensuring the functioning of structures and living organisms in the presence of EMF can be provided by means specific to the field of bio-electromagnetic compatibility.

The interaction of EMF with electronic equipment and devices is achieved through specific mechanisms, and the provision of immunity and protection is established by EMC standards and rules. The simplest interaction effect is the temporary degradation of the performance of a susceptible device, culminating in the equipment destruction by a field produced by another device called a generator. This field is studied by electromagnetic interference (EMI).

In both areas – the living and the electromagnetic devices, securing the normal operation of electronic devices can be achieved by various means: design, execution, shielding, earthing, filtering, insulation, etc. Regarding the general population, shielding requirements are different. Thus, it is recommended to use special materials for shielding walls, windows, and clothing - all these elements being made in the form of complex, composite structures of classical materials used in the textile industry, to which there are added components with properties corresponding to the reflection and absorption of the EMF. The technologies of manufacturing these composite textile structures are very different, ranging from deposits of metal layers of Ag, Cu, Ni, on the textile structure using chemical deposition, to vacuum evaporation, sometimes combined with plasma treatment [4,5].

2. Experimental results

Several textile composite structures with shielding role and different parameters and structures have been investigated and characterized. In a first stage, there were used metallic threads inserted into textile composite structures, in various forms: amorphous magnetic wires, copper wires, stainless yarns. Another research turned to the graphite powder. The amorphous thread fabric (Figure 1) is made of cotton yarns in which the amorphous wires of 17 microns fineness have been inserted [6].

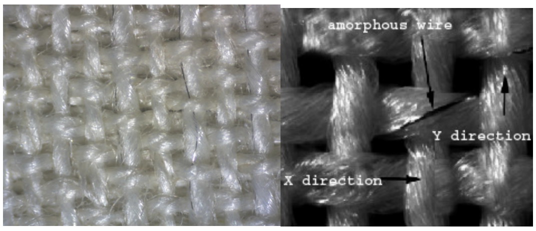

Figure 1. The amorphous thread fabric (x200)

The amorphous magnetic wire is achieved by rapid cooling in glass sheath, and has the chemical composition Co68Mn7B15Si10. The ratio of fabric and amorphous thread insertion is 1:2. Because the magnetic wire is particularly friable, it was fixed by twisting a cotton yarn on the cotton yarn carrying the magnetic wire, as shown in Figure 2.

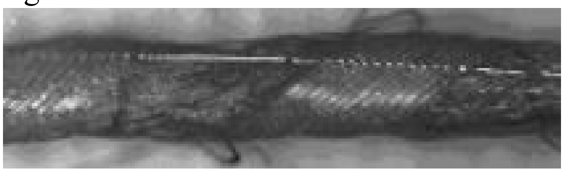

Figure 2. Amorphous thread and cotton - detail

The determination of the shielding factor was made in an anechoic chamber using two axially centered transmitting (Tx) – receiving (Rx) antennas with the electrical component vertical and parallel to the amorphous wire. By rotating the textile structure so that the amorphous yarns make an angle with the electric component, one can determine the shielding or the transmission factor, according to Malus' law. If the two antennas are arranged in an orthogonal configuration and the material is inserted into the space between them, then Malus' law becomes:

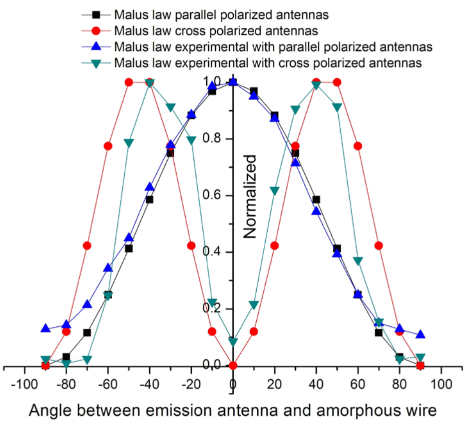

Figure 3. Representation of the Malus' law

$$\frac{E}{E_0} = (\sin\theta\cos\theta)^2 \qquad (1)$$

The graphical representation in Figure 3 of the EMF transmission factor for the cross polarized antennas indicates the occurrence of two maxima, corresponding to an angle of 45^0. The data dispersion for the cross polarized antennas is higher than for parallel polarized antennas, and it is amplified by the antennas' position.

Next, the copper textile composite structure is made up of two textile layers consisting of a base material (cotton yarn fabric) between which copper wires are inserted by a heating and bonding process. The diameter of the copper wire is 0.2 mm. The metal wire is inserted in parallel directions, at 0.5 cm distance from each other, with a linear density of 200 yarns/m. The schematic diagram is shown in Figure 5, in which the following notations were made: 1- basic material; 2 inserted copper threads; 3- adhesive layer.

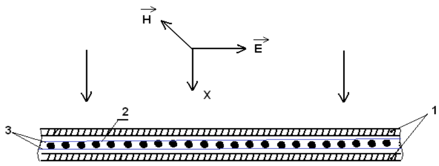

Figure 5. Section in the composite structure

There were also manufactured various types of knitted structures from Bekinox yarns [7]. Figure 7 illustrates two types of Bekinox yarns: on the left side - the BK 50/1-KS FDA (80/20) 1x1 Rib jersey knitted structure, and on the right side – the Bekinox BK 50/2-KS FDA (80/20) yarn – Milano rib knitted structure.

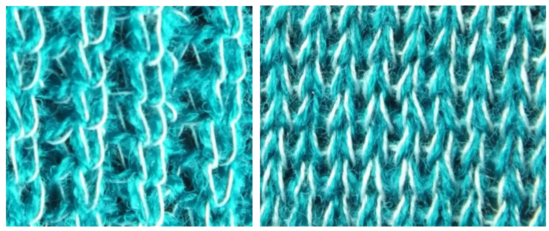

Figure 7. Bekinox yarns: BK 50/1-KS FDA Rib (left); and BK 50/2-KS FDA Milano rib (right)

Another composite textile structure is made of two layers of non-woven material comprising an intermediate layer of carbon powder with a mass density of 1150 g / m^2, obtained by a bonding and heat setting process. This composite textile structure was made by hand but in order to fix the carbon powder in a uniform layer a coating technology was used. The shielding efficiency testing results of the composite textile structures are shown in Table 1. Table 2 presents a synthesis of the results for Bekinox knitted structures. Regarding the CEM standards, manufacturers have used both national and international standards [9-12].

Table 1. Shielding efficiency of the investigated textile composite structures

Textile structure	Composition	Shielding efficiency (dB)	Frequency
Amorphous magnetic woven fabric	Amorphous magnetic wire coated with glass filament and twisted with cotton or synthetic thread	17	800-2000 MHz
	Dry textile material	21	8.7 GHz
	Wet textile material	40	8.7 GHz
Textile composite structure with copper wire	Copper threads inserted 0.5 cm away from each other	23	30 MHz-1.5 GHz
	Dry textile material	31	8.7 GHz
	Wet textile material	41	8.7 GHz
Textile composite structure with carbon powder	Carbon powder content	0.2 ÷ 1.2	30 MHz-1.5 GHz
	Dry textile material	18	8.7 GHz
	Wet textile material	29	8.7 GHz
Textile composite structure with stainless steel	Stainless steel wires inserted randomly	10.2	30 MHz-1.5 GHz
	Dry textile material	28	8.7 GHz
	Wet textile material	35	8.7 GHz

Table 2. Types of yarns and knitted structures

Yarn type	***Knitted structure***	***Shielding effectiveness (dB)***	***Yarn type***	***Knitted structure***	***Shielding effectiveness (dB)***
Bekinox BK 50/1-cotton (80/20)	1. Plain jersey	1.29	*Bekinox BK 50/2-KS FDA (80/20)*	1. 1x1 Rib jersey	16.2
	2. 1x1 Rib jersey	10.1		2. Half cardigan	7.35
	3. Full cardigan	17.3		3. Full cardigan	7.23
	4. Half cardigan	20.8		4. Milano rib	11.9
Bekinox BK 50/1-KS FDA (80/20)	1. Plain jersey	15.8		5. Plain jersey	18.2
	2. Full cardigan	9.16	*Bekinox BK 50/2-cotton (80/20)*	1. Plain jersey	28
	3. Half cardigan	13.4			
	4. 1x1 Rib jersey	18.4			

3. Methods for evaluation the shielding properties

The shielding effectiveness (SE) is the most widely used electromagnetic property of composite materials. A complete electromagnetic characterization involves the determination of characteristics both with respect to the applications and the frequency domain. For the scope of comparing different methods for assessing the SE, a particular screen was studied: copper wires of 2 mm diameter, forming an orthogonal grid, with a density of one thread per cm. The optical transparency of the screen is 62%.

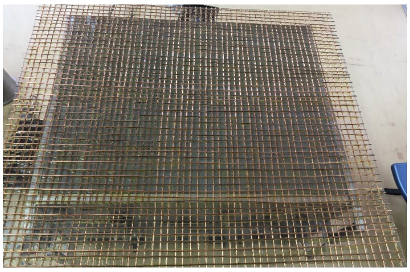

Figure 8. Two-direction copper wires screen

The manufactured screen is shown in Figure 8. The mechanisms of interaction between the respective shield and an electromagnetic wave of 1 V/m, plane wave, of frequency 5 GHz, are illustrated in Figure 9. The shield is placed at the middle, and the plane wave is applied from the right side. Part of the incoming EMF is reflected by the shield, part is absorbed into the shield, and part of the EMF is passing through the shield to the left side.

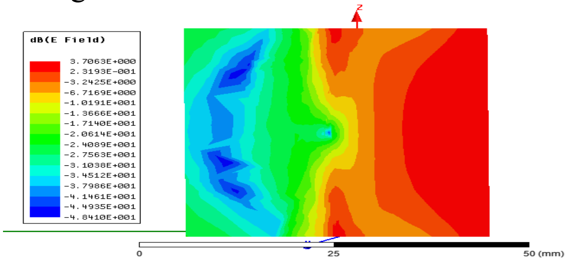

Figure 9. Longitudinal distribution of the electric field for the interaction between the copper shield and a plane wave

In order to experimentally determine the shielding effectiveness of the screen, the measurements were divided into two experimental stages. In the first stage, the measurements were performed indoor, in a non-standard room, and the second stage of measurements were performed in an anechoic chamber. In the first stage, there were studied both the reflective and the absorbing properties of the shield, by means of two measurement configurations. The first setup employed a transmitting (Tx) and a receiving (Rx) antenna, both directive, of horizontal polarization, placed one in front of the other at 3 meters, and the shield between them, at mid-length. Both antennas were connected to a Vector Network Analyzer (VNA), and there was measured the total attenuation the EMF when interacting with the shield, in 5-6 GHz frequency band. The second setup consisted in placing the antennas one near another and measuring the reflective properties of the shield, placed at 1.5 meters from the antennas. An initial measurement with no shield was performed for each setup, and the reported shielding results were computed by subtracting the initial data from field values. The maximum value of the total attenuation is 9.9 dB for 5.3 GHz, and of the reflection attenuation is 5.1 dB for the frequency of 5.4 GHz.

The first location can affect measurements through successive reflections of the EM waves, and the results cannot be used as a standard report. The final stage occurred in an anechoic chamber, with the Rx antenna placed inside a cube of galvanized steel, the shield on one side on the cube, and the Tx antenna outside the cube. A comparison of the results obtained for both experimental stages in measuring the total attenuation, is shown in Figure 10.

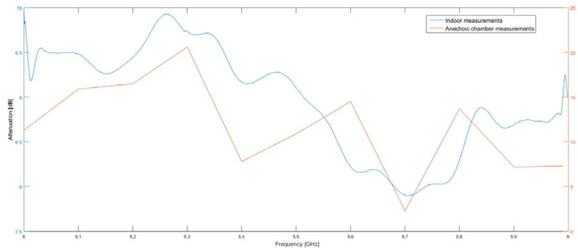

Figure 10. Comparison of the results of measurement performed in the two stages

6. Conclusions

Based on all experimental investigations, several conclusions can be drawn. Classic textile materials can be combined with materials of high electrical conductivity or with ferromagnetic materials. Electrical conductors and ferromagnetic wires inserted into the textile material through certain technologies can shield the electromagnetic field into a wide spectrum of frequencies (MHz, GHz). Textiles exhibiting a regular structure of electrical or magnetic yarns behave like a polarizer of the electromagnetic field. These structures are in accordance with Malus' law in geometric optics. The most advantageous technological solutions proved to be the use of composite materials woven and nonwoven fabric with filaments of stainless conductive materials as well as the insertion of carbon powder. The composite textile structures containing copper wires exhibit rapid oxidation if the conductors do not have protective coatings (varnish) or after mechanical actions (washing) breaking the insulating layer.

Acknowledgements

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