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THE ELECTROMAGNETIC PROPRIETIES OF HYBRID COMPOSITES

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ABSTRACT

This research investigates the electromagnetic behaviour of hybrid composites with heterogeneous epoxy matrix. The hybrid composites were formed by the wet lay-up method and were made of three types of simple plain fabrics as sheets. In order to improve the electrical and magnetic properties of hybrid materials and to modify the basic properties of epoxy resin, fillers such as carbon black and ferrite were used. Analysing the electromagnetic properties of the formed hybrid composites, it was observed that the composites with outer layers made of carbon fabric sheets exhibited higher dielectric permittivity and electrical conductivity in comparison with other materials. The magnetic permeability of the studied composites showed negative values within the whole range of frequencies, but the materials with aramid fabric in outer layers exhibited more negative values of magnetic constants.

KEYWORDS: electrical conductivity, magnetic permeability, hybrid composites, filled matrix

1. Introduction

The advancement in fibres reinforced composites leads to the achievement of materials with unusual electromagnetic behaviour. Many studies have shown that the polymeric composites are electrical non-conductive, but their electrical properties can be improved by using fillers such as carbon nanotubes (CNT), carbon black, graphite, graphene, short carbon fibres and their magnetic properties can be enhanced by using barium ferrite (BaFe). It is necessary to know that the use of fillers in the structure of composites may improve the electrical and magnetic properties. Also, they can affect the mechanical properties, and this is why it must be considered the weight fraction of the used fillers, because it should not exceed 30-40% of the matrix, due to its different arrangement directions and its multiple geometric patterns which are formed [1].

Short fibres are used not only to improve the mechanical properties, but also to improve the electrical properties [2]. Carbon nano-fibres (CNFs) can effectively improve the electrical conductivity of CNFs/epoxy nano-composites, which can form the conductive path at a low content, and the threshold of CNFs/epoxy nano-composites ranges between 0.1% and 0.2% weight ratios [3].

Markov *et al.* [4] studied the influence of carbon black and short carbon fibres on electrical and mechanical properties of unidirectional glass fibre reinforced polyethylene. An anisotropic electrical conductivity was determined within the range of percolation threshold. Also, Wong *et al.* [5] investigated the influence of recycled carbon fibres on the development of electromagnetic shielding.

Witchman *et al.* [6] studied the influence of carbon nanotubes, fumed silica and carbon black on the mechanical and electrical properties of glass fibre reinforced epoxy composites. They showed that the electrical conductivity could be included into the FRPs by using only very small amounts (0.3%) of carbon nanotubes without any decreasing of the mechanical properties. The nanoparticles (fumed silica and carbon black) had improved the mechanical properties and had exhibited an adjustable electrical conductivity.

In this paper the electrical and magnetic properties of six fabric reinforced composites with heterogeneous epoxy matrix were analysed. The type of fabric sheets in the outer layers of hybrid

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composites affected the electromagnetic parameters. The negative magnetic permeability values of the studied hybrid composites were obtained. The negative magnetic permeability is identified by many scientists in the case of meta-materials, which are artificial materials with simultaneously negative dielectric permittivity and negative magnetic permeability at the same frequency, leading to negative refraction index, or one of these parameters can have a negative value and the other a positive value. When these parameters have different signs, the electromagnetic wave cannot spread [7-10].

2. Materials

For this research, six different hybrid reinforced composite materials with heterogeneous epoxy matrix were formed. The reinforcement was made of three types of fibre fabrics, namely: carbon fibre fabric designated C, aramid fibre fabric designated K and glass fibre fabric designated G. The orientation of layers was different as it may be noticed in Table 1. Each composite was reinforced with 17 layers of the above mentioned fabrics excepting the medial layer that was made of a hybrid fabric.

The hybrid fabric was obtained by replacing each second yarn of aramid fibres on the fill of a mixed simple type fabric with 2:1 (carbon:aramid) yarns on warp and 1:2 (carbon:aramid) yarns on the fill with a glass fibres yarn of 200 tex in which a tinned cooper wire of 0.2 mm diameter had been inserted.

The three types of fabrics were symmetrically distributed relatively to the medial layer but based on their orientation they displayed an anti-symmetrical balanced structure.

The matrix of materials was made of epoxy system EPIPHEN RE 4020 - DE 4020 (Bostik). Epoxy resins exhibit superior mechanical and electrical properties in comparison with other resins [11]. The heterogeneous epoxy matrix was formed by modifying the epoxy system with 10% wr of starch, 10% wr of aramid powder and, 10% wr of carbon black (MF1) and 10% wr starch, 10% wr carbon black and, 10% wr ferrite (MF2). The MF1 filled matrix was used for reinforcement layers 1 to 5 and 13 to 17, while MF2 filled matrix was used for reinforcement layers 6 to 12.

These fillers were used to improve the electromagnetic properties of the studied materials. So, the ferrite was used to enhance the magnetic properties, but the particle size, the filler concentration and the mutual orientation of the ferrite particles in the matrix affect the value of these properties [12]. That is why the potato starch was used, to prevent the sedimentation of the other fillers.

The carbon black was used for improving the electrical properties and aramid powder was used for improving the impact properties that will be discussed in another paper.

All the hybrid composite materials were formed by the wet lay-up method with each sheet of fabric imbued with correspondent pre-polymer mixture and then placed into a mould. The microscopical images of the transversal surfaces of materials are presented in Fig. 1.

Table 1. *The layers configuration of hybrid reinforced composite materials with heterogeneous matrix*

Layers	Materials					
	M1F	**M2F**	**M3F**	**M4F**	**M5F**	**M6F**
01	30_K	15_K	30_K	30_G	45_C	0_C
02	-30_K	30_K	15_K	-30_C	-30_C	-30_C
03	45_C	-15_C	0_C	0_K	15_G	45_C
04	0_C	-30_C	45_G	45_G	30_G	0_K
05	45_C	45_G	-30_G	30_C	-30_C	-30_K
06	0_C	15_C	-15_C	15_K	0_C	45_K
07	15_K	30_K	30_K	-30_K	30_G	30_G
08	30_K	45_K	45_K	30_G	45_G	45_G
09	90_M	90_M	90_M	90_M	90_M	90_M
10	-30_K	45_K	45_K	30_G	45_G	45_G
11	-15_K	-30_K	-30_K	45_K	-30_G	-30_G
12	0_C	-15_C	15_C	-15_K	0_C	45_K
13	45_C	45_G	30_G	-30_C	30_C	30_K
14	0_C	30_C	45_G	45_G	-30_G	0_K
15	45_C	15_C	0_C	0_K	-15_G	45_C
16	30_K	-30_K	-15_K	30_C	30_C	-30_C
17	-30_K	-15_K	-30_K	30_G	45_C	0_C

Carbon fabric: 4×4 plain weave, 160 g/m^2.
Aramid fabric: 6.7×6.7 plain weave, 173 g/m^2.
Glass fabric: 12×12 plain weave, 163 g/m^2.

3. Experimental method

To determine the electromagnetic properties, such as dielectric permittivity, electrical conductivity and magnetic permeability of hybrid composites a digital LCR-meter Protek 9216A was used together with the measurement cell, according to [13]. Both bulk and surface measurements were performed at the five built-in frequencies of LCR-meter in five points on each formed material.

The calculation of dielectric permittivity, electrical conductivity, electrical resistivity and magnetic permeability of hybrid composites was done by means of the formulas given in [14].

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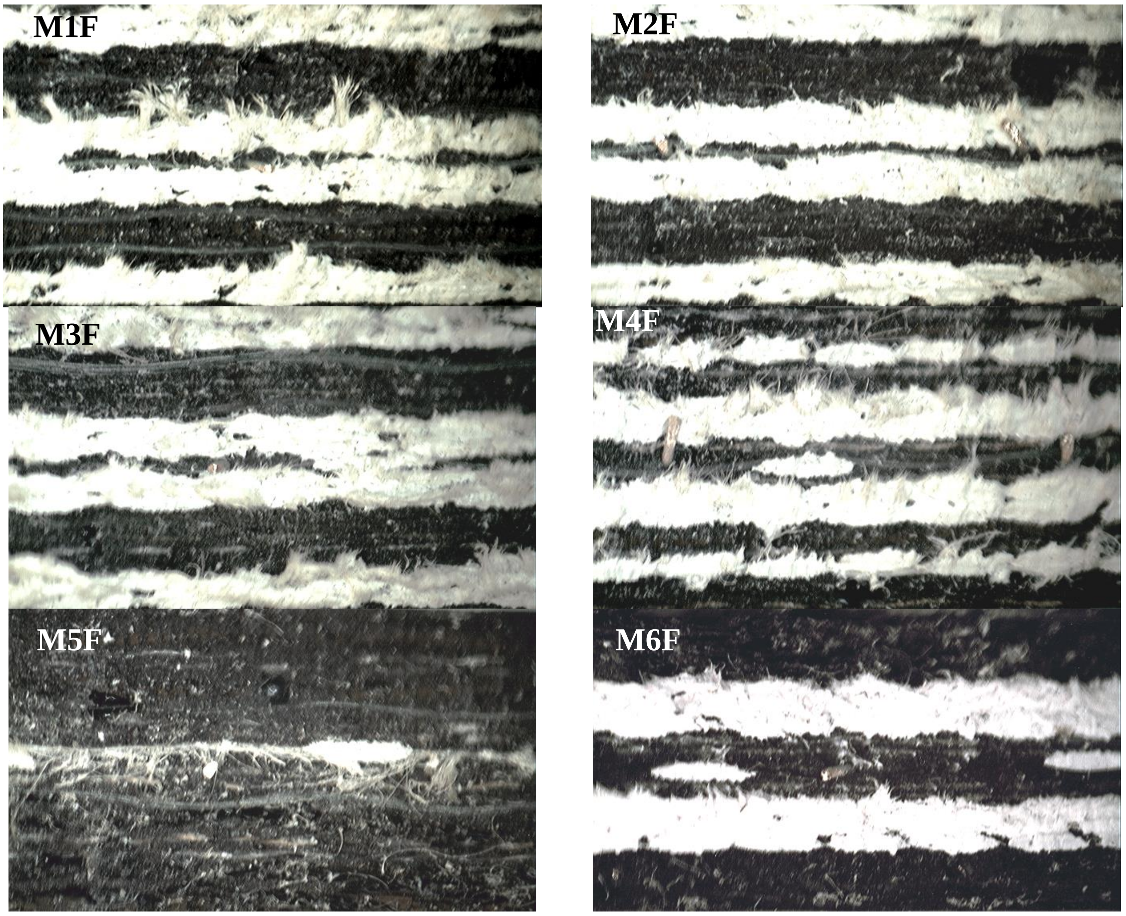

Fig. 1. *The microscopical images of hybrid laminates transversal surfaces*

4. Results and discussion

Generally, the electrical properties of the fibre reinforced composite materials depend on the moisture content, crystalline or amorphous component present, presence of impurities, etc. [15, 16]. In Fig. 2 are plotted the values of surface and bulk dielectric permittivity constants of the materials. The hybrid composite materials with outer layers made of carbon fabric sheets exhibit higher dielectric permittivity values than other hybrid composite materials, whose outer layers are made of aramid and glass fabrics sheets, but these values decrease when increasing frequencies.

The glass fabric reinforced composites and aramid fabric reinforced composites are used as insulators. In this regard, M5F hybrid composite material exhibits the highest value of bulk dielectric permittivity and M6F hybrid composite material exhibits a similar value of bulk dielectric permittivity as those of other hybrid materials, whose values do not vary with frequency.

In Fig. 3 are plotted the values of the electrical conductivity of hybrid composite materials. As it can be seen, the electrical conductivity of materials increased when increasing frequency till the frequency rose to 1 kHz, while the hybrid materials with outer layers made of carbon fabric sheets exhibited higher values of electrical conductivity, but at 10 kHz and 100 kHz these values became almost equal to the values of other studied hybrid materials.

The surface and bulk magnetic permeability constants of all hybrid composites showed negative values on the entire frequency domain (Fig. 4).

All the magnetic values became less negative when increasing frequency. The magnetic permeability of hybrid composites with outer layers made of aramid fabric sheets showed more negative values and the glass fabric outer layers composite exhibited intermediate values of magnetic constants.

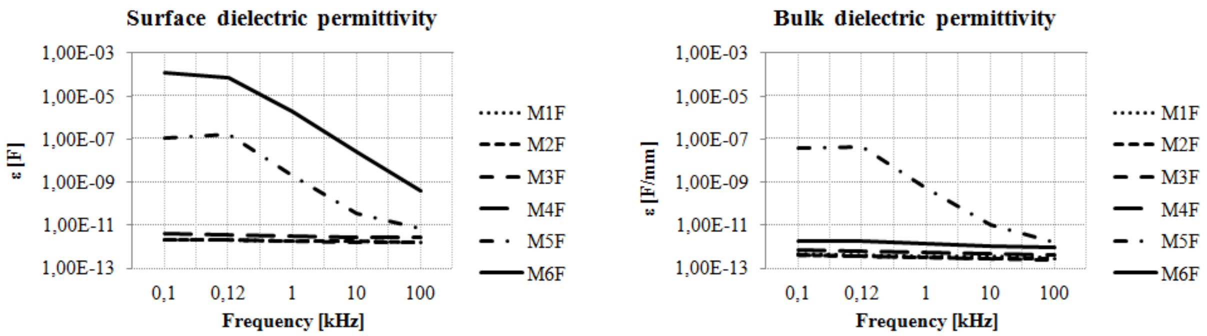

Fig. 2. *The dielectric permittivity of the hybrid composite materials*

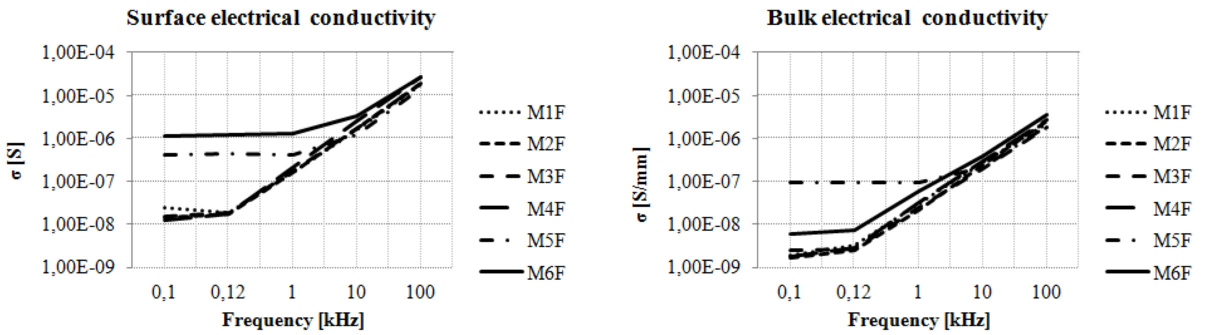

Fig. 3. *The electrical conductivity of the hybrid composite materials*

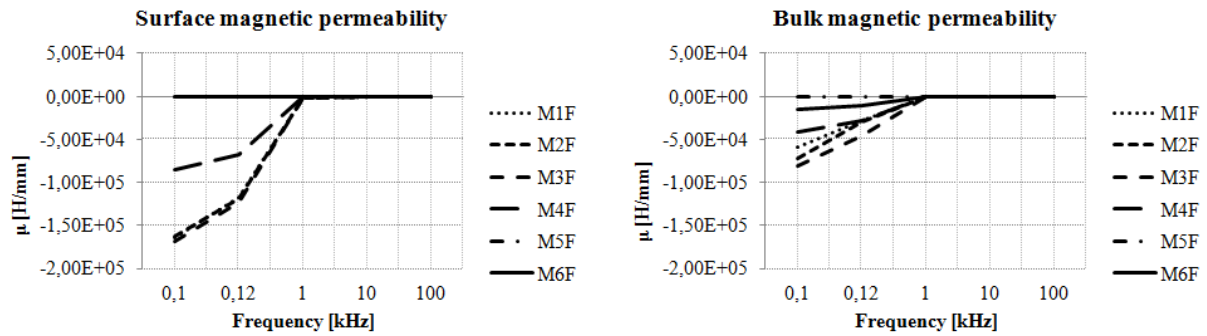

Fig. 4. *The magnetic permeability of the hybrid composite materials*

5. Conclusions

The electrical and magnetic parameters of hybrid composites were measured by standard electrical method applied for plates in electric and electronic engineering and the electrical and magnetic constants were calculated. Analysing the electromagnetic behaviour of the studied hybrid composites, the following conclusions can be drawn:

● The hybrid composites with outer layers made of carbon fabric sheets exhibit the highest dielectric permittivity, which decreases when increasing frequency.

● The highest surface electrical conductivity at 0.1-1 kHz range of frequencies was exhibited by M5F hybrid composite due to its outer layers made of more carbon fabric sheets. The highest bulk electrical conductivity at the same range of frequencies was exhibited by M5F hybrid composite because its structure does not contain aramid fabric sheets. However, at 10 kHz and 100 kHz frequencies, the values of electrical conductivity of these hybrid materials become similar with the values of other hybrid materials studied in this research.

● All the hybrid composites exhibit negative magnetic parameters within the whole range of frequencies.

● The values of magnetic permeability of hybrid composites with outer layers made of aramid fabric sheets were more negative than those of other hybrid composites.

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