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THE UNUSUAL ELECTROMAGNETIC PROPRIETIES OF FABRIC REINFORCED EPOXY COMPOSITES

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ABSTRACT

In this research, the electromagnetic behavior of four composite materials was investigated as an important issue of composite researchers is to control the electrical properties of polymer matrix composites. The four materials are epoxy matrix fabric reinforced composites. Each of the reinforcements is accomplished from 17 layers of fibers fabric of each type, excepting the medial layer which is made of a hybrid fabric meant to solve two issues – the first issue refers to gathering information about the materials loading state while the latter is to increase the electromagnetic shielding properties of the formed materials. The four used fabrics are simple plain fabrics made of yarns of carbon fibers, aramid fibers and, respectively, two types of glass fibers. All the reinforcement layers, excepting the medial one, have the yarns of warp and fill, respectively parallel, while the medial layer has warp yarns perpendicular on the warp yarns of the other layers. The matrix of the wet lay-up technique formed materials is made of epoxy system Epiphen RE 4020 – DE 4020.

KEYWORDS: dielectric permittivity, electrical conductivity, magnetic permeability, epoxy matrix

1. Introduction

The composite materials with unusual electromagnetic properties, which exhibit negative value of electrical and magnetic properties, are of particular interest. The materials with negative values of dielectric permittivity and magnetic permeability are known as meta-materials. Meta-materials which exhibit simultaneously negative dielectric permittivity and negative magnetic permeability are called left-handed materials. They have the negative index of refraction, so that these materials have the similar function of a lens [1-5]. It means that phase and group velocity of an electromagnetic wave can propagate in opposite direction [6, 7], leading to the disappearance of the object in the radar field. When these parameters have different signs, these materials are called right-handed materials [8]. In this case, the electromagnetic wave cannot spread [9].

For a negative ε, the force between two electrons will be attractive, leading to electron-pairing if other electron instabilities can be arrested. Electron-pairing has been demonstrated to be responsible for superconductivity in the conventional low temperature superconductors as well as in the newly discovered high temperature superconductors [10].

In spacecraft construction, meta-materials are important due to their electromagnetic shielding, which can protect the spacecraft against radiation and overheating.

The constitutive elements of a meta-material are meta-atoms or meta-molecules. Among the meta-atoms, we can identify wire meshes, splitter ring resonators, conical Swiss rolls, Swiss rolls, further development of this fascinating domain allowing for other types of constitutive elements [11].

Other structures were also suggested to instigate meta-material behavior, including multi-layers composed of alternately overlapped negative permittivity and negative permeability layers. In the exploration of meta-materials, polymers have been applied only as an insulating host, but the specific contributions of the polymer layer were rarely mentioned, which may be due to the weak electromagnetic responses to outer electric or / and magnetic field with respect to ferromagnetic materials [4].

Moreover, the composite materials with special electromagnetic properties are studied for the manufacturing of smart composites, whose important characteristic is the auto-repairing of damage area. By measuring the electrical conductivity of the object, it can be determined the mechanical damage area and then a strong electric pulse can be applied for partially melting the polymer matrix in the area of damage, which would eliminate the defect [12, 13]. Carbon fiber reinforced polymer composites are multifunctional materials in which the damage is coupled with the material electrical resistance, providing the possibility of real-time information about the damage state through the monitoring of the resistance [14]. The heterogeneous smart materials might exhibit new properties not existing in any of the constituents due to the coupling of different fields [15].

2. Materials

Four fabric reinforced epoxy matrix composites were formed for this study. They were named HCH – carbon fiber fabric reinforced epoxy composite, HKH aramid fiber fabric reinforced epoxy composite, H1SH and H2SH glass fiber fabric reinforced epoxy composites. The fabrics were simple plain fabrics: 4×4 plain weave carbon fabric with 160 g/m^2 density designated as C, 6.7×6.7 plain weave aramid fabric with 173 g/m^2 density designated as K, 12×12 plain weave glass fabric with 163 g/m^2 density designated as 1S and 6×6 plain weave glass fabric with 390 g/m^2 density designated as 2S. All the materials had 17 of layers reinforcements symmetrically distributed relatively to the medial layer. The medial layer only was made of a special hybrid fabric that had been obtained by replacing each second yarn of aramid fibers in the fill by a mixed carbon-aramid fabric.

The mixed fabric had the structure of 2:1 carbon: aramid yarns on warp and 1:2 carbon: aramid yarns on the fill. Each second yarn of aramid fibers in the fill was manually replaced with a glass fibers yarn of 200 tex in which a tinned cooper wire 0.2 mm diameter was inserted. (Fig. 1).

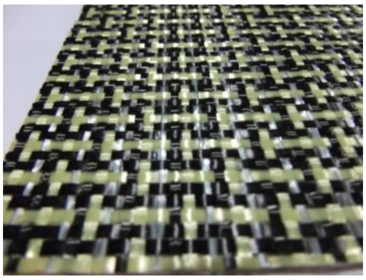

Fig. 1. *The special modified fabric M*

Each material had 16 layers of reinforcement of the same fabric while the medial layer consisted of the above described fabric. For all the 16 identical layers the directions of warp yarns and fill yarns were respectively parallel, while the fill yarns of medial layer were perpendicular on the other layers fill yarns.

The materials were formed using the wet lay-up method placing each pre-polymer imbued sheet of fabric into a glass mold. After polymerization, all the materials were thermally cured according to the epoxy system producer in order to reach the best properties of the polymer.

3. Experimental method

The measurement of electromagnetic parameters of composite materials was performed with a LCR-meter Protek 9216A at five frequencies (100 Hz, 120 Hz, 1 kHz, 10 kHz and 100 kHz) in the four modes that the LCR meter is build: R+Q (resistance and quality factor), L+Q (inductance and quality factor), C+D (capacitance and dielectric loss and C+R (capacitance and resistance). 1V driver voltage was used for measurements. The dimensions of the tested specimens were 281×194 mm. For each sample, five complete sets of measurements were made – with the measuring cell in different points on the surface of the sample – according to the standard electric characterization of plates used in electric and electronic applications.

4. Results and discussion

The evaluations of dielectric permittivity, electrical conductivity and magnetic permeability were made based on the 200 measured values of each C, R and L parameters and were calculated by the formulas given in [16]. In Fig. 2-5 are plotted the values of surface and bulk dielectric permittivity of the composite materials. The higher values of dielectric constants were determined at 100 Hz frequency and then these values were decreased with the increasing of frequency, with the exception of aramid fabric reinforced epoxy composite. As it can be seen in Fig. 3 and 5, the carbon fabric reinforced epoxy composite exhibits negative values of surface and bulk dielectric permittivity in 0.1-10 kHz. The dielectric values were calculated based on the recorded values of the electrical capacitance.

The negative capacitance was observed in solid state device structures and explained by reference to impact ionization, injection of minority carriers, or an imaginary component in the carrier mobility [17]. The dielectric constant of conducting polymer composites becomes negative after the forming of a continuous conducting pathway because of the charge delocalized at a macroscopic scale [6].

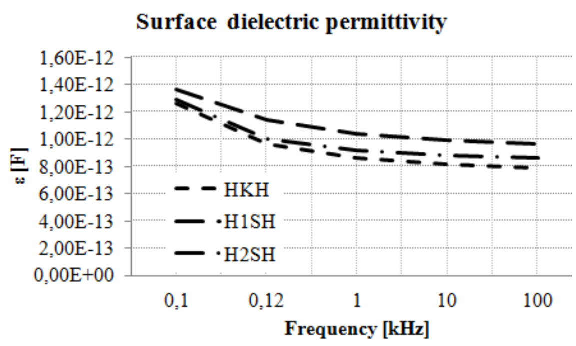

Fig. 2. *The surface dielectric permittivity of the fabric reinforced epoxy composite materials*

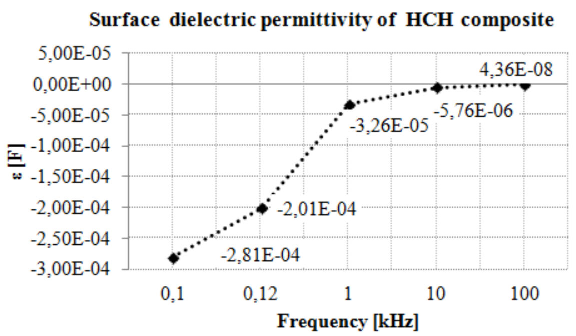

Fig. 3. *The surface dielectric permittivity of carbon fabric reinforced epoxy composite material*

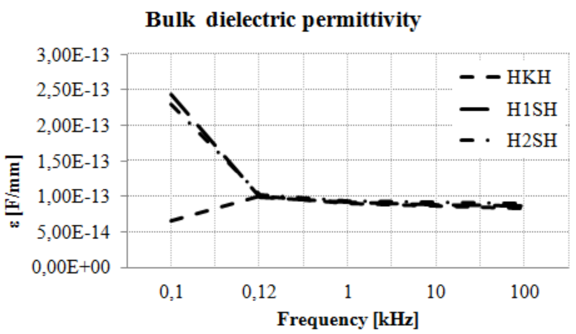

Fig. 4. *The bulk dielectric permittivity of the fabric reinforced epoxy composite materials*

As expected, the carbon fabric reinforced epoxy composite exhibited higher surface electrical conductivity in comparison with other studied composites (Fig. 6). The lower electrical conductivity of aramid and glass fabric reinforced epoxy materials was determined at 0.1 kHz and then the electrical conductivity of these composites decreased with the increasing of frequency, while the electrical conductivity of HCH composite remained unchanged.

Similar values of electrical conductivity of the composites were determined for bulk measurements (Fig. 7), with the exception of H1SH composite which exhibited the negative electrical conductivity at 0.1 kHz frequency, but from 0.12 kHz frequency upwards the electrical conductivity of this composite was similar to that of HKH and H2SH composites (Fig. 8).

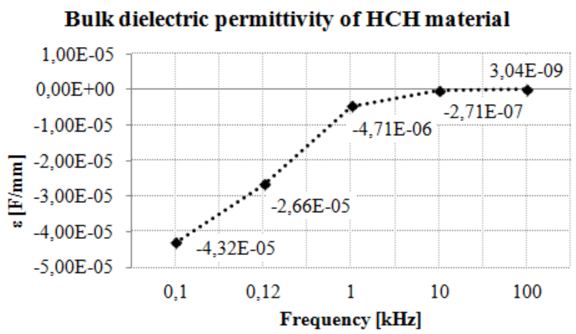

Fig. 5. *The bulk dielectric permittivity of carbon fabric reinforced epoxy composite material*

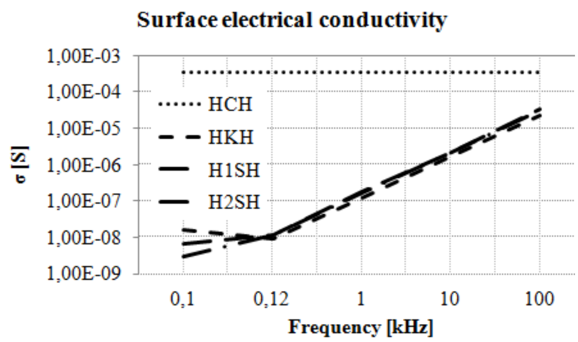

Fig. 6. *The surface electrical conductivity of fabric reinforced epoxy composite materials*

It is possible that negative conductivity appearance occurs in a non-equilibrium electron system, i.e., a situation in which the current flows opposite to the electric field [18]. The values of electrical conductivity of composites were calculated on the recorded electrical resistance by LCR-meter. Negative resistance means that the more positive the voltage is, the more negative the current is, i. e. the current–voltage characteristic is a straight line of negative slope through the origin. Although the negative resistance is apparent, its mechanism resembles that of true negative resistance, i.e. the electrons traveling in the unexpected direction relative to the applied voltage gradient [19].

In Fig. 9-12 are plotted the unusual values of the magnetic permeability of the composites.

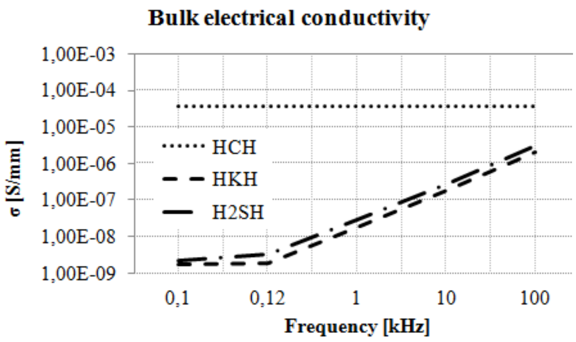

Fig. 7. *The bulk electrical conductivity of fabric reinforced epoxy composite materials*

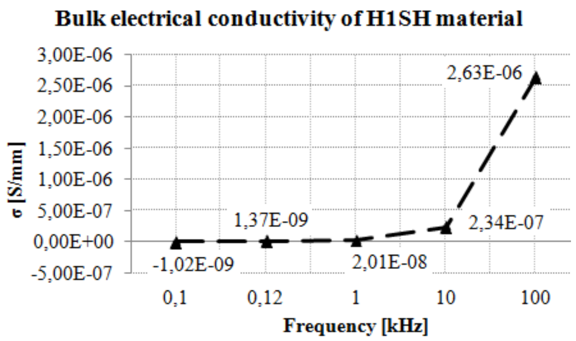

Fig. 8. *The bulk electrical conductivity of 1S glass fabric reinforced epoxy composite material*

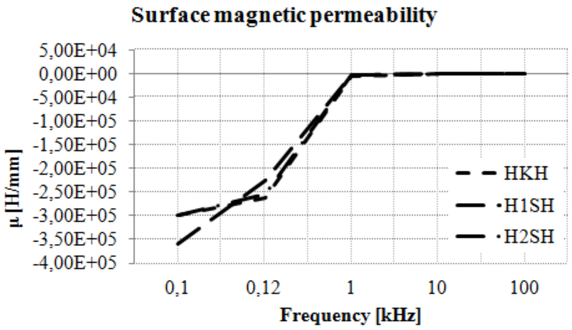

Fig. 9. *The surface magnetic permeability of fabric reinforced epoxy composite materials*

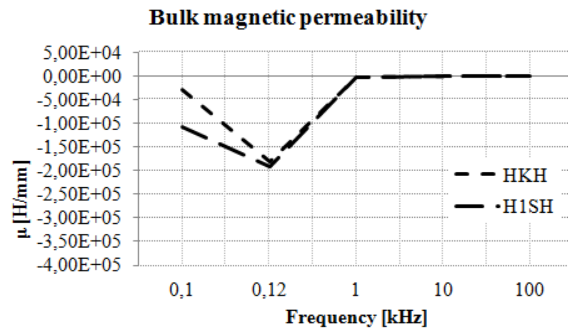

Fig. 10. *The bulk magnetic permeability of fabric reinforced epoxy composite material*

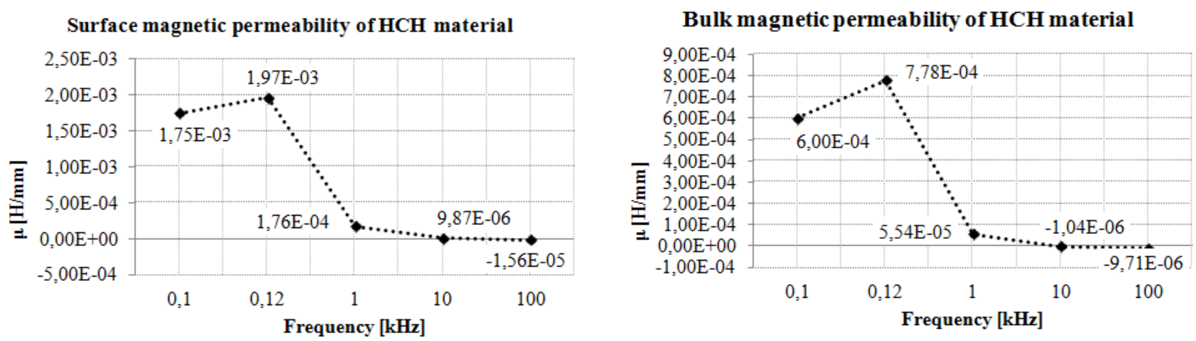

Fig. 11. *The magnetic permeability of carbon fabric reinforced epoxy composite material*

It can be observed that the HKH and H1SH composites exhibit negative values of both surface and bulk magnetic permeability constants at all frequencies in decreasing mode. The composite H2SH exhibits negative magnetic permeability at all frequencies, with the exception of 0.1 kHz where the bulk magnetic constant is positive. Regarding the magnetic behavior of HCH composite, this material exhibits positive values of surface magnetic permeability in 0.1 – 10 kHz frequency range and at 100 kHz the value of the magnetic constant is negative. But the bulk magnetic constants exhibited by HCH composite are positive in 0.1 – 1 kHz frequency range and negative at 10 and 100 kHz frequencies.

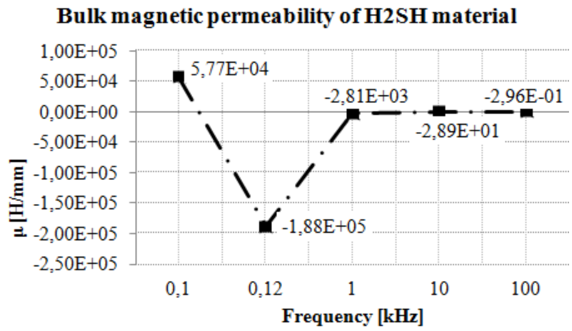

Fig. 12. *The bulk magnetic permeability of 2S glass fabric reinforced epoxy composite materials*

5. Conclusions

The measurements of electrical and magnetic parameters of fabric reinforced epoxy composites were performed. The electric, dielectric and magnetic constants were evaluated and the electromagnetic behaviour of materials was investigated. The conclusions are as follows:

● The carbon fabric reinforced epoxy composite exhibits negative values of dielectric permittivity within 0.1-10 kHz frequency range. The electric conductivity of this material is higher in comparison with other composites and is invariable. It exhibits negative surface magnetic permeability value at 100 kHz and negative bulk magnetic permeability values at 10 and 100 kHz.

● HCH composite exhibits simultaneously negative bulk dielectric permittivity and negative bulk magnetic permeability at the same 10 kHz measurement frequency.

● The magnetic permeability of HKH, H1SH and H2SH composites show negative values on the entire range of frequencies, but only the bulk magnetic constant H2SH of these materials show positive value.

● The bulk electrical conductivity and resistivity of H1SH composite show negative values at 0.1 kHz.

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