ELECTRICAL CONDUCTIVITY OF FABRIC REINFORCED FILLED EPOXY PLATES

BUNEA MARINA,
Associate professor, PhD,
Cahul State University "Bogdan Petriceicu Hasdeu",
Republic of Moldova
"Dunarea de Jos" University of Galati, Romania
e-mail: bunea.marina@usch.md
e-mail: marina.bunea@ugal.ro

CÎRCIUMARU ADRIAN,
Professor, PhD in Physics
"Dunarea de Jos" University of Galati, Romania
e-mail: adrian.circiumaru@ugal.ro

BÎRSAN IULIAN GABRIEL,
Professor, PhD of Engineering
"Dunarea de Jos" University of Galati, Romania
e-mail: iulian.birsan@ugal.ro

Abstract. *In this paper, the electrical conductivity of the fabric reinforced filled stratified epoxy composites measured by two methods was investigated. This electrical parameter was measured by two-point and four-point (Van der Pauw) techniques. It was studied the electrical behavior of the epoxy composite materials reinforced with carbon, glass and aramid fabrics with the medial layer made of three different types of fibers (carbon, aramid and glass) and copper wire. In this investigation, also, it was analyzed the influence of the ply orientation and the fillers addition in the epoxy matrix composition. The test results showed that the fiber orientation led to an increase of the electrical conductivity of the carbon fabric reinforced plate and the fillers improved significantly this property of the hybrid fabric reinforced plate.*

Keywords: *epoxy composite, filled matrix, hybrid fabric, Van der Pauw method, electrical conductivity*

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Introduction

In recent years, in all domains are used fiber reinforced polymeric composite materials, due to their thermal, electrical, mechanical properties and low cost. Generally, most often are used as reinforcement carbon fibers/fabrics for polymeric composites, to improve the electrical conductivity. To form multifunctional epoxy composites, which will show good mechanical, thermal and electrical properties, it can be used mixed carbon, glass and aramid fiber/fabrics as reinforcement, because the hybrid laminates combine the advantages of each constituent fiber [1]. In this case the layer configuration will depend on hybrid laminate destination.

Also, the polymer industry solved many problems regarding the processing problems, the limits of properties performance and environmental protection by using of fillers [2]. To improve the mechanical strength, wear resistance, low coefficient of thermal linear expansion, good electrical conductivity, etc., it is using many types of fillers or filler mixtures in epoxy matrix composition. But it must take in account that some fillers can improve the mechanical properties and affect the thermal and electrical properties, or reversely. So, if it will be taken in consideration the properties of each constituent filler and fiber, it will be possible to manipulate the laminate structure and to form the composite material with desired properties. The added fillers in the matrix composition can be synergistic with reinforcing fibers, leading to improvement of the system [3], but the filler content should not exceed 30-40% of the matrix volume [4], because it can be affected the mechanical performance of the hybrid laminate. Regarding the improvement of mechanical, electrical and thermal properties of composite materials, many researches showed that it is more effective the use of the fillers together with the reinforcing fibers. For example, the electrical conductivity of composites can be significantly improved by adding carbon black in matrix composition of carbon fiber reinforced laminate [5–7]. The electrical conductivity of the glass fiber reinforced composites can be improved by using of the carbon black or recycled chopped carbon fibers [8–10]. Another used fillers are carbon nanotubes [11–13], graphite powder [14], fullerenes [15], graphene nanoplatelets [16, 17], ferrites [18–20], etc. This electrical parameter of the laminates depends on the fiber-matrix and filler-matrix interface quality and mixture rule.

Generally, the aim of the research was to form multifunctional epoxy composites with high mechanical performance, impact resistance, good electrical conductivity and thermomechanical behavior. These materials can be formed by layer-by-layer technique and using various fillers and fibers as reinforcements. In this paper will be investigated the electrical conductivity of carbon, glass, aramid and hybrid fabric reinforced laminates with filled stratified epoxy matrix measured by two methods and to analyze the influence of the fiber orientation and fillers.

Materials

In this study it will be analyzed the electrical conductivity of 11 fabric reinforced epoxy composites, which were formed by the wet lay-up method, because this method provides the samples with minimum defects. By this method each ply of fabric was impregnated with epoxy system mixture and placed into a glass mold (fig. 1). After polymerization the plates were cured 8h at 60°C, 4h at 80°C and 2h at 90°C according to polymer producer recommendation.

Four simple plain weave fabrics were used as reinforcement: C – carbon fiber fabric with 160 g/m^2 specific density, G – glass fiber fabric with 163 g/m^2 specific density, A – aramid fiber fabric 173 g/m^2 specific density and H – hybrid fiber fabric with 270 g/m^2 specific density. The hybrid fabric is a modified mixed simple plain carbon-aramid fabric with 2:1 in the warp direction and 1: 2 in the weft direction [21, 22]. This fabric was modified by replacing in the weft yarns direction of each second aramid fiber with 200 tex glass fiber together with 0.2 mm tinned copper wire (fig. 2).

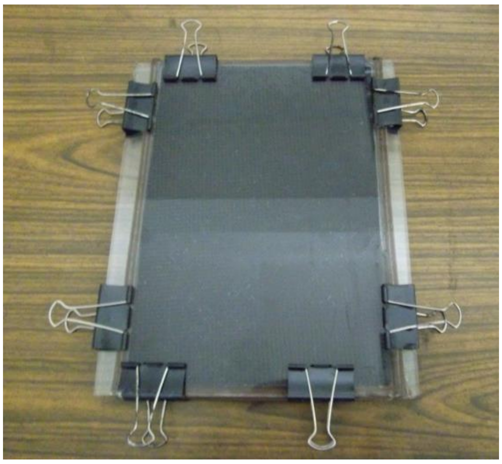

Figure 1. The formed fabric reinforced epoxy composite by wet lay-up method.

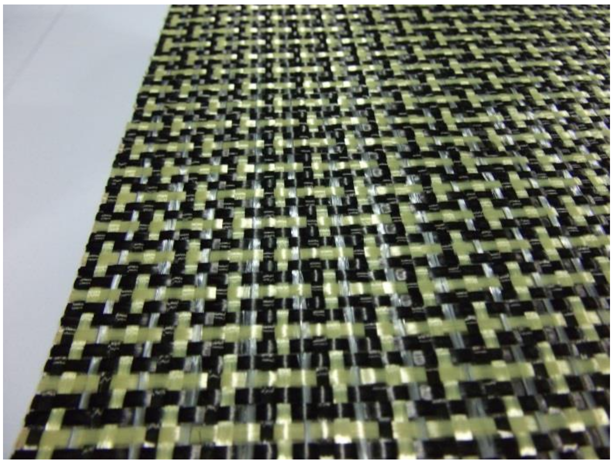

Figure 2. The special hybrid fabric made of three alternating fibers (carbon, aramid and glass) and tinned copper wire.

The laminates were made of each fabric type and contain 17 layers, where for the 9th layer was used the special hybrid fabric. To study the influence of fiber orientation and fillers on electrical conductivity, it was formed from carbon, glass and aramid fabrics: non-filled epoxy laminates with ply orientation at 0° (CE0, GE0 and AE0); non-filled epoxy laminates with ply orientation at various angles (CE, GE and AE) and filled epoxy laminates with ply orientation at various angles (CF, GF and

AF) (table 1). Also, two composite materials were made of hybrid fabric with fiber orientation at 90° (HE and HF), to analyze the effect of this fabric on the electrical behavior of the composites and the effect of the fillers on electrical conductivity of the reinforced composite only with this fabric. The laminates with fiber orientation at various angles have anti-symmetrical balanced distributed layers relative to the medial layer.

Table 1. The layer configuration of the fabric reinforced epoxy composites with ply orientation at various angles.

Filled matrix	MF1					MF2							MF1				
Layer / Material	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17
CE/CF	0	45	0	30	15	-30	0	30	H90	-30	0	30	-15	-30	0	45	0
GE/GF	45	30	15	-30	45	30	-15	45	H90	45	15	-30	45	30	-15	-30	45
AE/AF	0	45	30	15	-30	-15	30	45	H90	45	-30	15	30	-15	-30	45	0

The epoxy system EPIPHEN (DE 4020 resin and RE 4020 hardener) was used as matrix. Two types of filled epoxy matrices were used for composite materials: MF1 – 10% VR (volume ratio) of potatoes starch, 10% VR of aramid powder and 10% VR of carbon black; MF2 – 10% VR of potatoes starch, 10% VR of carbon black and 10% VR of barium ferrite. To avoid the sedimentation and to provide the uniform distribution of the components, initially, the epoxy system was mixed with the potatoes starch due to its swelling in the liquid. Then, it have been added the other mixed components. MF1 filled epoxy matrix type was used between 1-5 and 13-17 layers and MF2 filled epoxy matrix type between 6-11 layers.

Experimental methods

The electrical conductivity of the fabric reinforced epoxy plates was measured by two methods. The first method consisted in determination of the electrical resistance of the composite materials by two-point measurements. The tests were performed by using of TeraOhm 5 kV insulation tester. It was used the function Step Voltage Insulation Resistance testing. The electrical resistance was measured on the 100 mm distance between test leads, on 600 – 3000 V direct current (DC) voltage range. The test specimens with 140×15 dimensions were used to perform the electrical measurements (fig. 3). All the electrical tests were performed at environmental conditions.

Figure 3. The measurement of the electrical resistance by two-point method.

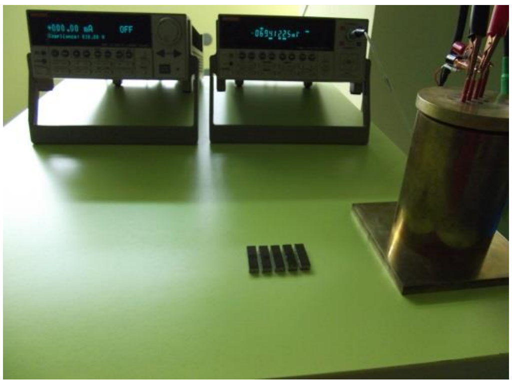

Figure 4. The measurement of the electrical resistance by four-point method.

The second measurement consisted in determination of the composites electrical resistance by four-point method (fig. 4). It was used KEITHLEY instruments: 6221 DC and AC current source and 2182A Nanovoltmeter models. For these electrical tests were used the test specimens with 30×8 mm dimensions. The four-point measures were performed with ± 100 nA alternating current (AC) current range and applied voltage of 10 V. The electric conductivity was calculated by Van der Pauw technique [23]. According to this method, the electrical resistivity ρ_a was calculated by using of the measured $R_{12,34}$ and $R_{31,24}$ resistances. Also, the electrical resistivity ρ_b was calculated by using of the $R_{12,43}$ and $R_{21,34}$ resistances. Then, the electrical conductivity of the composites was calculated by using of the average of the resistivities. All electrical measurements were performed at environmental conditions.

Results and discussions

The electrical conductivity of the composite materials depends on the properties of the fibers, epoxy matrix, fillers, fiber-matrix and filler-matrix interfaces and the uniform distribution of the fillers particles in matrix. Generally, the carbon fibers are used as conductors and glass and aramid fibers are used as insulators. In fig. 5 are plotted the values of the electrical conductivity of the studied materials measured by two-point method.

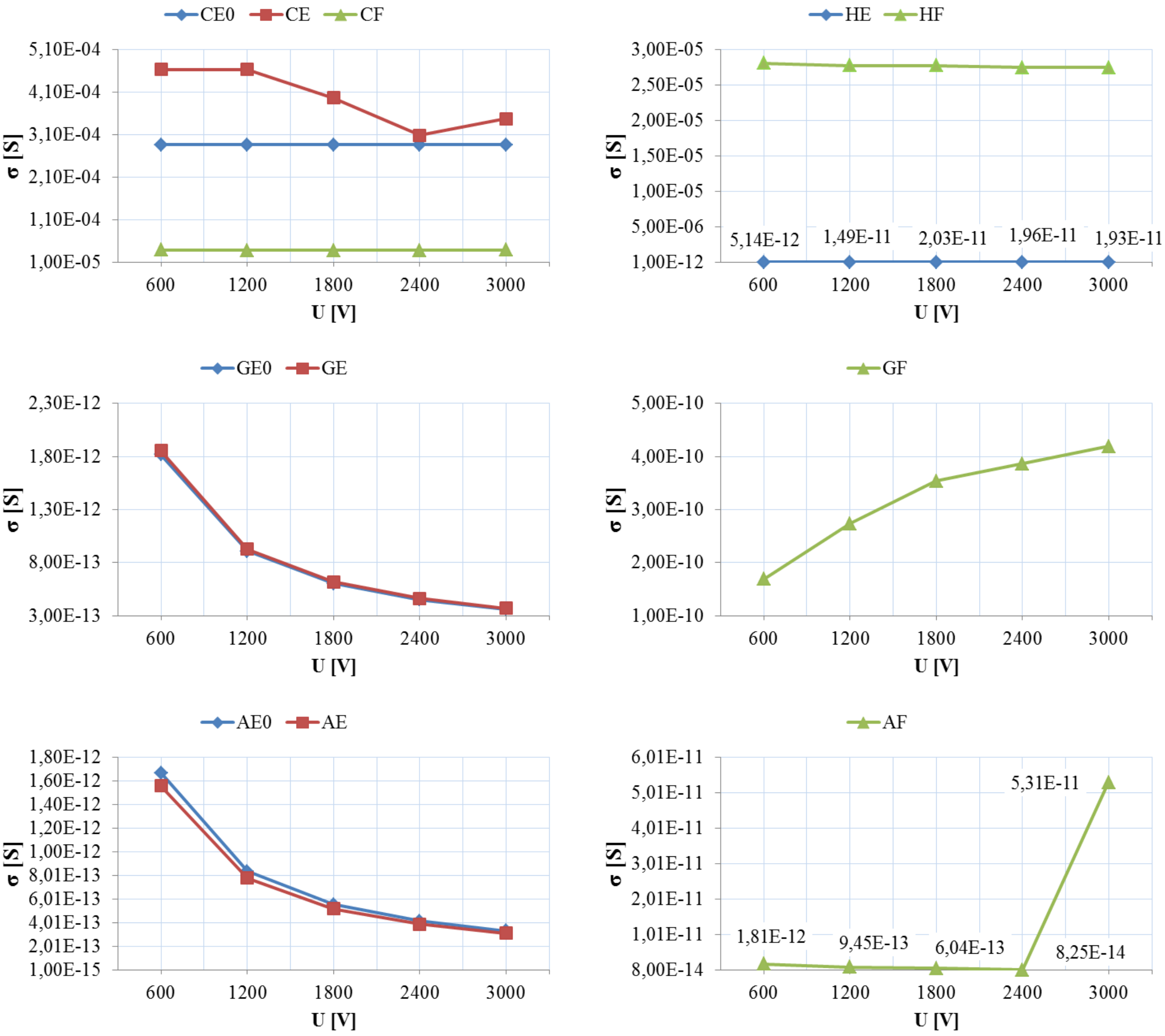

Figure 5. The electrical conductivity of the composite materials measured by two-point method.

How it can be seen, the carbon fabric reinforced epoxy laminates exhibited the highest electrical conductivity. With the increasing of the electrical voltage on the 600 – 3000 V range, it can be observed that the laminates behaved differently. So, regarding the laminates with fiber orientation at 0°, the carbon reinforced composites has not suffered any change with increasing of the voltage unlike the glass and aramid reinforced composites, whose electrical conductivity decreased. The glass and aramid reinforced laminates showed almost the same electrical behavior, so as their electrical conductivity exhibited a decreasing of values more faster up to voltage of 1200 V than on 1200 – 3000 V range. The hybrid fabric reinforced non-filled epoxy composite showed an increasing of electrical conductivity up to 1800 V with the increasing of voltage and then an insignificant decrease on 1800 – 3000 V range.

The ply orientation not influenced the electrical behavior of the glass and aramid reinforced non-filled epoxy composites, but the electrical conductivity of the carbon laminate was improved. How it can be remarked, regarding the behavior of the carbon laminate, its electrical conductivity decreased on 1200 – 2400 V voltage range and, then, increased up to 3000 V.

Generally, the usage of the fillers in the epoxy matrix composition of the laminates improved their electrical conductivity, but affected the conductivity of the carbon fabric reinforced composite. In case of the hybrid fabric reinforced laminate, the modification of the epoxy matrix improved significantly its electrical conductivity and led to a stable invariable behavior with the increasing of the applied voltage. The conductivity of the glass composite increased with the increasing voltage, but in case of aramid laminate, it was recorded a decrease of the conductivity up to 2400 V and a sudden growth at 3000 V. The usage of fillers mixtures in epoxy matrix composition led to a significantly decrease of the conductivity of the carbon laminate due to aramid power and it showed a stable invariable behavior over the entire voltage range. The aramid power was used to improve the impact resistance and mechanical properties of the studied materials, which will be discussed in next papers.

In fig. 6 are plotted the results of the electrical conductivity of the fabric reinforced epoxy composite materials measured by four-point method and calculated by Van der Pauw technique.

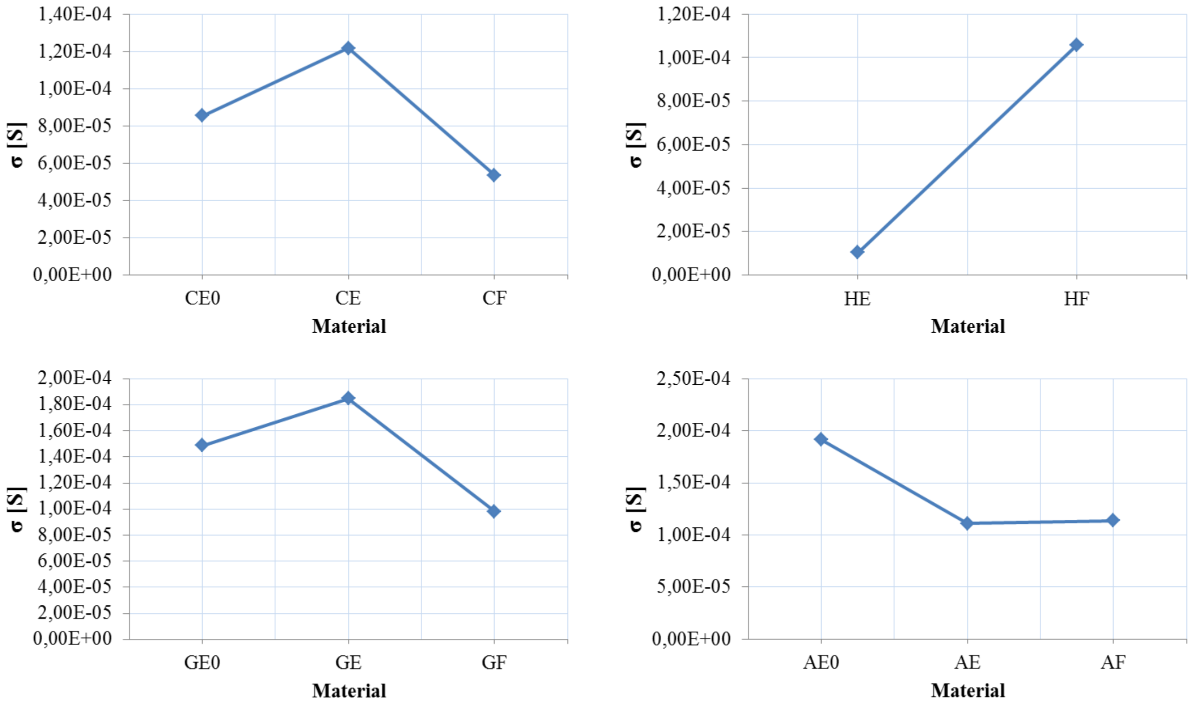

Figure 6. The electrical conductivity of the composite materials measured by four-point method.

The obtained results of the analyzed materials, which were subjected to alternating current, showed a higher electrical conductivity for aramid and glass reinforced laminates than that of carbon and hybrid fabric reinforced composites. The lowest value of the electrical conductivity was exhibited by hybrid reinforced non-filled epoxy composite. The ply orientation led to an increase of the conductivity of the carbon and glass fabric reinforced laminates compared to the aramid laminates, whose fiber orientation led to a decreasing conductivity. The addition of fillers mixtures in epoxy matrix composition reduced significantly the electrical conductivity of the carbon and glass laminates, but the conductivity of the aramid composite remained almost unchanged. In case of hybrid fabric reinforced composite the modification of the epoxy matrix led to a significant improvement.

Conclusions

The electrical conductivity of the fabric reinforced epoxy plates measured by two-point and four-point methods was investigated. By analyzing of calculated data and plotted results in graphs discussed above, it can be made the following conclusions:

- The measurements of the electrical conductivity by two-point tests showed that the highest value of this parameter was exhibited by carbon fabric reinforced plate with non-filled epoxy matrix (CE0) and it showed an invariable behavior over the entire voltage range. The glass and aramid fabric reinforced composites with non-filled epoxy matrix showed almost the same electrical behavior, whose electrical resistivity increase with the increase of the applied voltage. In case of the hybrid fabric reinforced non-filled epoxy composite, it was observed a variable behavior on voltage range, due to its constituent fibers types.
- The electrical conductivity measured and calculated by Van der Pauw technique exhibited higher values for glass and aramid fabric reinforced non-filled epoxy plates with ply orientation at 0° than for carbon and hybrid fabric reinforced laminates. The lowest electrical conductivity was showed by hybrid laminate (HE).
- The fiber orientation at various angles led to increase of the measured electrical conductivity by two-point technique of carbon fabric reinforced plate, but did not influence electrical behavior of the glass and aramid composites. By Van der Pauw measurements it was recorded an increase of this electrical parameter for carbon and glass composites.
- The addition of the filler mixtures in the epoxy matrix composition affected the electrical conductivity of the carbon composite due to aramid powder, but improved significantly this electrical property of the hybrid fabric reinforced plate measured by both methods. Regarding the glass reinforced plate, the fillers addition improved the electrical conductivity measured by two-point method, but in case of four-point measurements it was recorded a reduction of this electrical parameter. In case of the aramid fabric reinforced epoxy laminate, its electrical conductivity was not practically affected by the filler mixtures, but it was observed a sudden increase of this property at 3000 V applied voltage by two-point method.

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