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# ELECTRICAL PROPERTIES STUDY OF FIBRE REINFORCED POLYMERIC MATERIALS USED IN AIRCRAFT STRUCTURES

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***Abstract***

*Aircraft are exposed to lightning strikes. Lightning strike protection (LSP) devices involve additional weight of the aircraft. Therefore, multifunctional materials that allows the conductivity of electrical current and, simultaneously, holds the mechanical properties required to withstand the typical conditions for an aerospace material are widely researched. A typical resin used in aviation is an insulator, so main research is done to reduce its resistance. On the other hand, the type of reinforcement can have a large influence on the electrical conductivity in the plane of reinforcement. The aim of the article is to evaluate the effect of the type and the basis weight of reinforcement on the electrical conductivity. For this purpose, with the use of a hydraulic press, different four-layer composites based on epoxy resin were produced. Each differing is in combination of carbon, glass layers and their basis weight (from 48 kg/m$^2$ to 245 kg/m$^2$). The measuring proceedings were carried by an RMS multi meter and, more accurate, by an LCR meter with 4 selectable test frequencies. The measurements were made both along the strand fibres and at a 45-degree angle. The results made it possible to determine which reinforcement of aircraft composites should be selected at the aircraft design level to provide increased electrical conductivity along the reinforcement fibres and thus influence one of the factors affecting the protection of the aircraft against the effects of lightning.*

***Keywords:*** *composite materials, electrical conductivity, carbon fibre reinforced polymer (CFRP), glass fibre reinforced polymer (GFRP), aerospace materials, lightning strike protection (LSP)*

## 1. Introduction

In the last decades, important improvements have been carried out as regards as aircraft design; among others, the use of fibre-reinforced composites for the fuselage and the interior. Polymeric composites possess good mechanical properties being lighter than metals, allowing an increase on the strength-to-mass ratio, thus resulting in a reduction of fuel consumption. They have better resistance against corrosion and they are, in addition, fatigue-resistant.

Despite of the mentioned advantages, there is a significant drawback: the polymers that form the composites matrix are dielectric. Therefore, a high electrical discharge as can be a lightning strike during operation causes the insulating air to become plasma (very conductive) resulting in a sudden rise of the channel temperature (even thousands of ºK), carrying two main phenomena: overpressure and resistive heating [4].

The first one is a result of an acoustic wave that, together with the stalked structure, origins the breakage of the external layers and their delamination, intensified by the heat flow due to the electrically insulating effect of the composite [17]. The latter initiates local decomposition and vaporization of the polymeric matrix, the reinforcement ablation and, in the worst case, the structure ignition. Damaged elements need reparation and certification, this way increasing the maintenance costs. Considering all these hazards, it becomes mandatory to come up with lightning strike protection (LSP) solutions. Several LSP solutions have been developed to date.

Conductive metal coatings such as metallized paints and sprays have a low manufacturing cost [16] but also poor effectiveness against high current discharges. The advanced, but also less cost-effective, LSP may consist of two layers: a buckypaper and an adhesive one [3]. Another solution is a composite that is reinforced by metallized fibre, mesh or foil. This method has a good effectivity [2] as regards discharges protection but increases significantly the mass of the structure and implies a complicated manufacturing, thus raising its costs. Moreover, in case of structural damage, the interaction with the environment can origin corrosion processes. Other interesting solutions, such as accumulation of reduced graphene oxide (RGO) on the composite surface, have not yet been developed [15].

In the light of these disadvantages, electrically conductive polymer composites (CPCs) appear as a more promising solution. There are several ways to obtain a CPC. One is to add a conductive filler to a resin, in particular a nanofiller. The second is to add an Intrinsically Conductive Polymer (ICP). The third method is to increase the conductivity with a conductive fibre reinforcement.

As far as fillers are, concerned carbon materials (including graphite, carbon nanotubes and graphene) are widely discussed [1]. Epoxy nanocomposites with improved conductivity have been investigated in detail [9]. As for the resin, there are also alternatives, such as bismaleimide (BMI) and polyetheretherketone (PEEK) [6]. Carbon nanofiber epoxy nanocomposites [13] and graphene/ polyhedral oligomeric silsesquioxane (POSS) epoxy hybrid are reported to be suitable for aircraft lightning strike protection [12]. Carbon nanotube reinforced composites (CNTs), are purely investigated since the manufacturing costs are too high to apply them in the industry so far. Another interesting approach is the use of polymer blends composed of two polymers and carbonaceous filler [10].

The second idea is based on application of ICP as a filler in the dielectric matrix. Apart from polyaniline (PANI), polypyrrole (PPy) and polythiophene (PTh) are taken into a consideration as well [8]. This attitude is widely investigated nowadays due to the possibility of obtaining the appropriate mixture that allows the composite to be conductive enough to protect against lightning strikes whilst maintaining acceptable mechanical properties (usually given by epoxy resin).

The third approach is rarely discussed. It is possible that a combination of more than one of the above approaches could bring good results.

## 2. Description of the experimental work

In order to prepare the samples, four different grades of fibre reinforcements, in the shape of dry-fabric laminates, were used:

1) carbon fibre fabric of 245 $g/m^3$ density holding twill architecture,
2) carbon fibre fabric of 160 $g/m^3$ density holding twill architecture,
3) glass fibre fabric of 48 $g/m^3$ density holding plain architecture,
4) glass fibre fabric of 160 $g/m^3$ density holding plain architecture.

From these fabrics there were made six different laminate samples as follows:

– 1st laminate – made out of four plies of fabric number 1,
– 2nd laminate – made out of four plies of fabric number 2,
– 3rd laminate – made out of two inner plies of fabric number 1 and two outer plies of laminate number 3,
– 4th laminate – made out of two inner plies of fabric number 1 and two outer plies of laminate number 4,
– 5th laminate – made out of two inner plies of fabric number 2 and two outer plies of laminate number 3,

– 6th laminate – made out of two inner plies of fabric number 2 and two outer plies of laminate number 4.

Subsequently, the plies proceed to be impregnated one by one in the correct order to build the composite material. The polymer resin used in this procedure was CES R72 epoxy resin hardened by means of CES H72 according to the 100:54 weight proportions.

The samples were subjected to 8 tons of force in a hydraulic press for 12 hours. After this process, the laminates were placed in a room where the temperature was 40ºC for 48 hours and, subsequently, in another room under the ambient conditions of 25ºC for a week.

In order to prepare the samples for the measurements, the laminates were cut by means of a CNC milling machine according to the dimensions represented in Fig. 1.

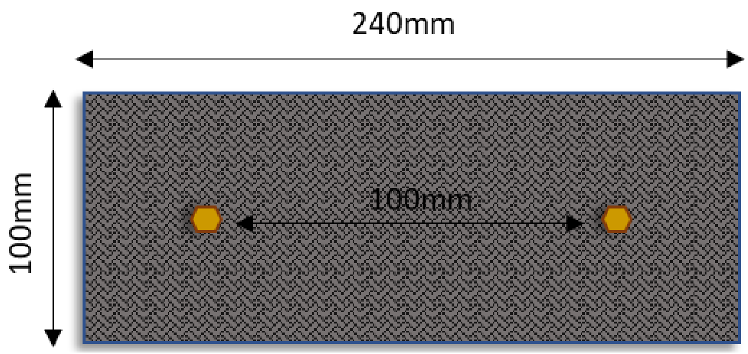


*Fig. 1. Sample dimensions*

Two types of samples were obtained, according to the orientation of its fibres:
– I. – 0º orientation, parallel to the horizontal direction fibres,
– II. – 45º orientation.

With the aim of achieving reliable electrical resistance measurements, two screws to connect the electrodes were installed in the samples, so as to avoid variations related with the boundary imperfections that could appear on the edges. That is because of the fact that machining of CFRP/GFRP material leads to high level of pullout and fibre protrusion [14]. Moreover, it is reported that the dominant failure mechanism during the machining of composites is peel-up and push-out delamination [7].

With the purpose of having a greater number of data, another screw was installed, but only in the 0º orientated samples. The Fig. 2 shows the dimensions representation.

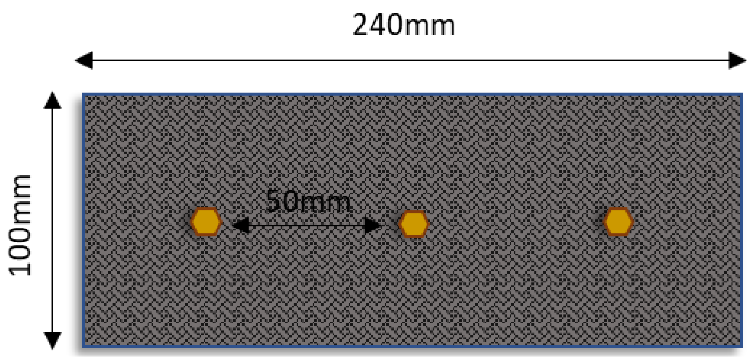


*Fig. 2. Three-screw sample dimensions*

The measuring proceedings were carried by means RMS multi meter and LCR Meter with 4 selectable test frequencies (100 Hz, 120 Hz and 1 kHz and 10 kHz). No change according to electrical resistance was observed when changing the frequencies; hence, 100 Hz frequency was selected.

## 3. Results

Figure 3 presents the data obtained from the measurements. The bar graph shows the results of electrical conductivity measurements for all six laminates in both orientations. This order of magnitude corresponds to the results obtained in other studies [5, 11].

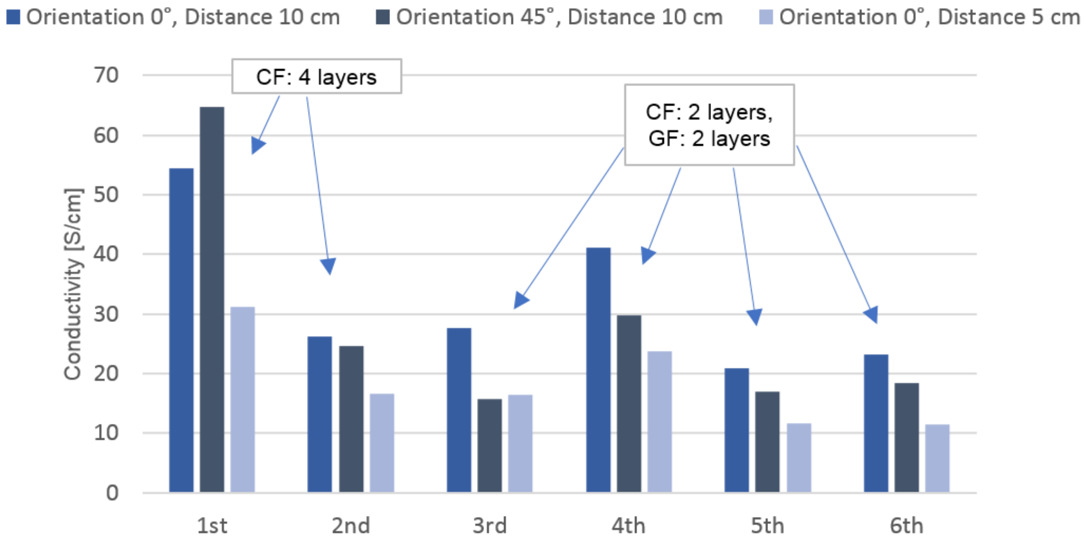


*Fig. 3. Electrical conductivity of all samples, I (0º) and II (45º) orientation*

Every time, regardless of the orientation of the fibres, the electrical conductivity increases with increasing number of layers of CF reinforcement. This is shown in Fig. 4. In the case of II orientation and CF weight of 245 g/m$^3$ (1$^{st}$, 3$^{rd}$ and 4$^{th}$ laminate), this increase is the most significant. In other cases, it ranges from 13 to 97%. This dependence results from the fact that carbon fibres are responsible for transferring the electric charge in the composite.

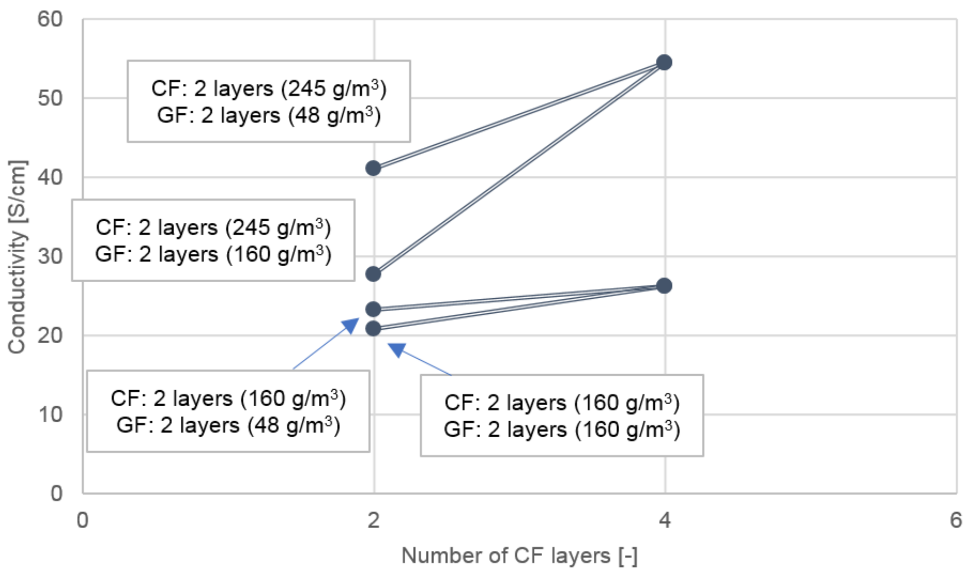


*Fig. 4. Electrical conductivity as a function of number of CF layers, I orientation (0º)*

It can be noticed that the value of electrical conductivity increases with the increase of the density of CF reinforcement, which is presented in Fig. 5. This applies both to the I orientation of the fibres in sample (0º) and II orientation (45º). The only exception is a pair of laminates 3$^{rd}$ and 5$^{th}$ in the II orientation. In this case, there was a slight decrease in conductivity along with the increase in the CF density. The dependence between the density and the electrical conductivity along reinforcement is due to the fact that the higher density allows for a larger amount of CF in one square meter of the composite.

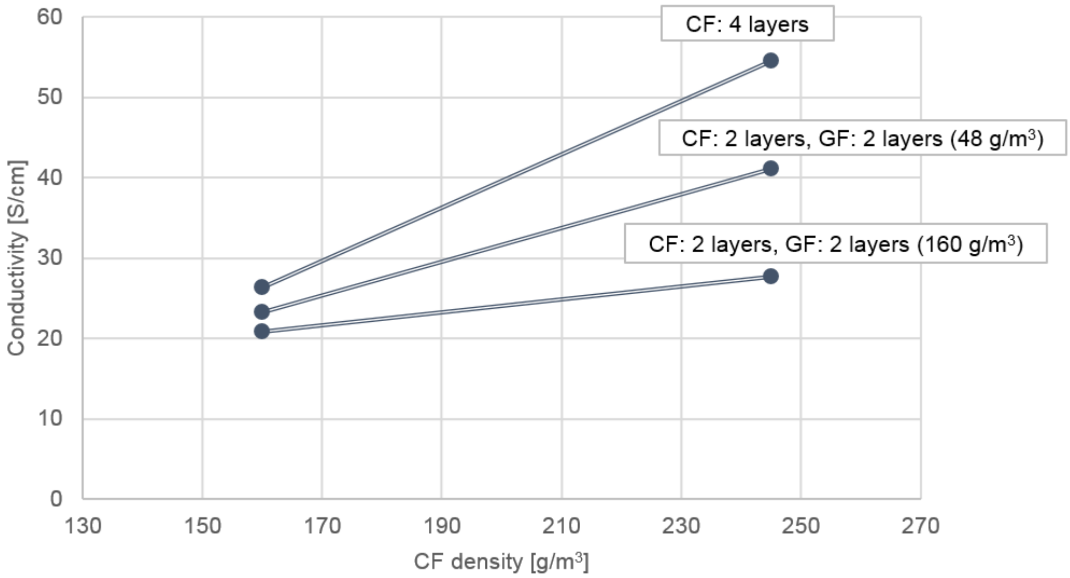


*Fig. 5. Electrical conductivity as a function of CF reinforcement density, I orientation (0º)*

It can be seen on the Fig. 6 that as the orientation of the fibre changes from 0º to 45º, the electrical conductivity decreases. The drop in value is greater for composites with two layers of CF reinforcement (3rd, 4th, 5th and 6th laminate). In the case of the 2nd laminate, the drop is gentle and in the case 1st, laminate there is an increase instead of a decrease. This situation is caused by the fact that in the general case, with II orientation, the electric charges have a longer distance to get through, which increases the resistance. On the other hand, in the case of a larger number of reinforcement layers, alternative charge flow paths appear that can increase the conductivity.

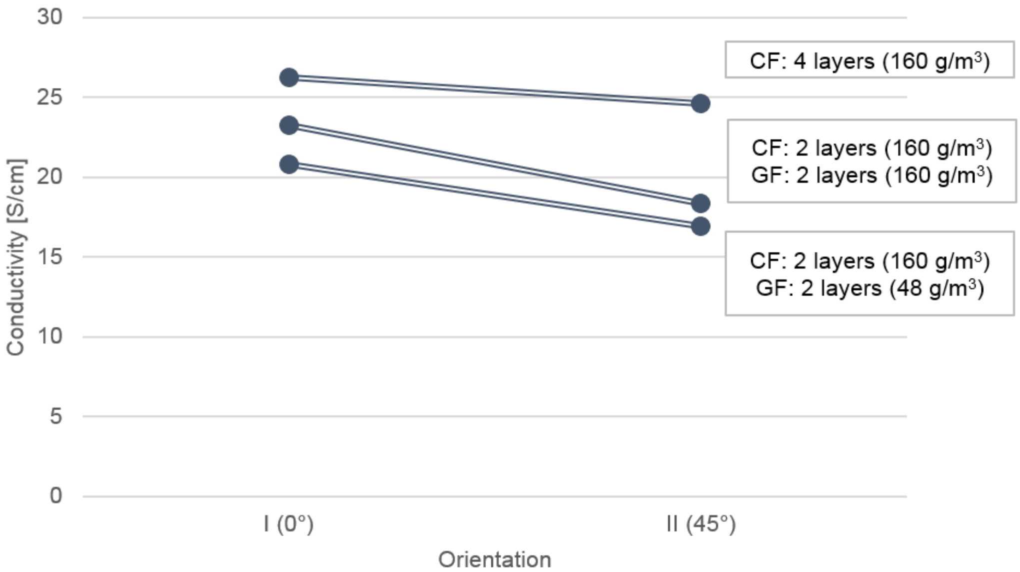


*Fig. 6. Electrical conductivity depending on the fibre orientation, CF density of 160 g/m$^3$*

After placing the third electrode between the first two, there was no change in the conductivity measured between the outer electrodes. In addition, the measurement results between the outer electrode and the centre electrode did not differ significantly regardless of whether the left or right electrode was chosen. By measuring the electrical conductivity for the 5 cm distance, lower results were obtained than for the 10 cm distance, which can be seen in Fig. 7. This may be due to an incorrectly assumed cross-section of the conductive element or due to not included resistance between the electrode and reinforcement layers.

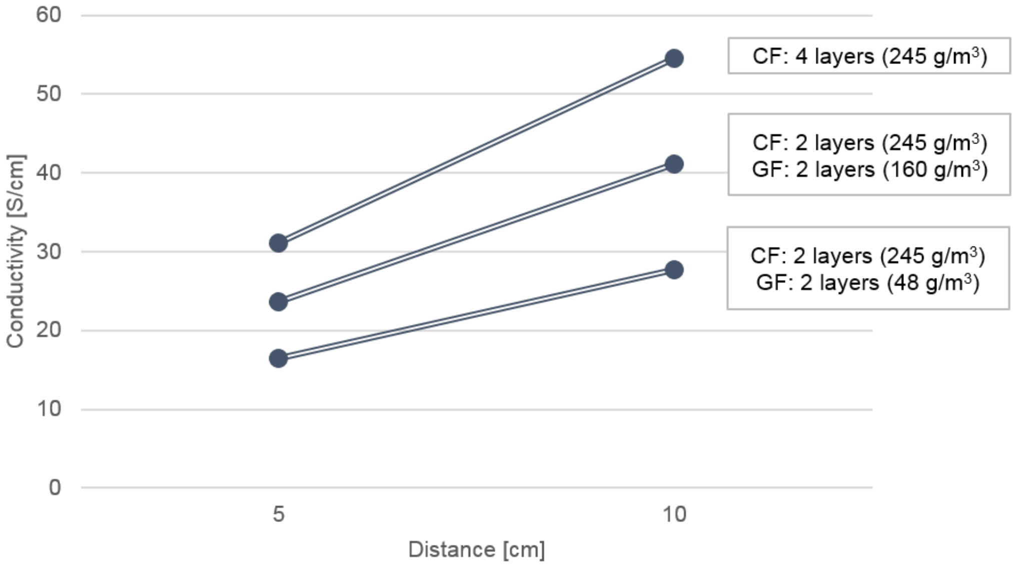


*Fig. 7. Electrical conductivity depending on the distance between electrodes, CF density of 245 g/m$^3$*

## 4. Conclusions

Numerous publications on increasing the electrical conductivity of epoxy resin composites are a consequence of the present situation in the aviation industry. One of the factors affecting the electrical conductivity of the laminate is the structure of its reinforcement. The aim of the research was to determine the possibility of influencing the electrical conductivity of the composite through appropriate selection of reinforcement. The following conclusions can be drawn:

1) The electrical conductivity along the reinforcement increases as the number of CF reinforcement layers increases.
2) The electrical conductivity along the reinforcement increases as the density of the CF reinforcement layers increases.
3) Laminates have poorer conductivity in the orientation of 45º in relation to the direction in which CF are laid.
4) Measurement of the conductivity of the layered composite along the reinforcement may be subject to error due to the way in which the electrodes are connected to the CFs.

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