A STUDY OF ELECTRIC PROPERTIES
OF FIBER FABRIC BASED FILLED EPOXY COMPOSITES

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ABSTRACT

Electric and magnetic properties of laminate carbon fiber fabric based epoxy composites are investigated through experimental techniques. Various concentrations of powder fillers were used in order to change the basic properties of standard composite. Also effects of an electric or a magnetic external field over the mentioned properties are investigated. Electric conductivity is evaluated across and along reinforcement and at the surface of the samples.

KEYWORDS: Laminate Composite, Ferrite, CNT, Electric Properties, External Electric and Magnetic Fields.

1. Introduction

In recent years there are more and more researches about the electric and magnetic properties of composite materials based on the need of metal replacement in aircraft and spacecraft industries. There are many researches and also many results published in various journals covering a range of interests from physics to engineering. In the majority of the cases the approach is connected to a certain problem, for a certain application. There are also many papers concerning the modeling of electric properties of composites in order to ensure the design of composites [1]. However it is considered that such an approach is just a partial one because the design has to take into account not only those properties but also the mechanical and thermal properties. Obviously this is a very difficult approach and it can be found an extensive study over its complexity [2]. One of the cheapest and most convenient method is to fill the polymer with various powders (metal powders, CNT, carbon black, clay, ferrites etc.) [3]. The cited paper is an excellent review of actual orientations and results in the domain of filled polymer composites and emphasizes the importance of filler dimensions and shapes bringing in attention the importance of interface. One of the most important assessments in last years is the highly contribution of interfaces at the macroscopic properties of composites [4]. A composite material is made up of at least two components. The electric and magnetic properties of the finite material depend essentially on the same properties on the components but also of external conditions of composite forming. Taking into account a woven fabric reinforced composite with filled polymer matrix the problem becomes more complex. As we mentioned above there are many papers concerning modeling of electric properties of composites but they are often limited to a particular structure of a bi-composite [5], [6]. It is not our intention to develop, at this very moment, a model for multi-composites but we consider that it is important to know, even just qualitative, the influence of various fillers over electric properties of a composite with a certain reinforcement, in various external conditions. This study is based on the idea that using different fillers in different concentrations for the same reinforcement we might establish the macroscopic properties of multi-composites. However electric magnetic properties of composites, as manifestations at the external changes, have to be averaged manifestations of the components. As it was mentioned already it is not the intention of the research, at this point, to test one model or other or to build up a new model. This is just a "trial and error" approach viewed as a starting point both for further studies and decision making in forming a composite with certain properties. It is extremely difficult to mathematically describe a four component composite even if there are various models for bi-component composites. The aim of this study, based on intuition, is to present some empirical results in order to help the manufacturers in decision making of forming a special composite.

2. Samples

Plates of four components composites with a 4 mm thickness and 120 mm x 250 mm as planar dimensions were formed, in glass moulds using polyvinyl alcohol 20% as unmoulding agent. As basic matrix for composite was used the bi-component epoxy resin EPIPHEN 4020 and it was used in order to obtain the reference samples for two types of reinforcements. Both reinforcements are realized from carbon fiber fabric with an arrangement of alternate 0 and 45 degrees sheets. For the magnetic field samples had been used 15 sheets of reinforcements while the electric field samples containing 13 sheets of reinforcements.

The orientation of reinforcement sheets is been given relatively to the sample's edges: 0 degrees means that the yarn and the fill of the fabric are parallel to the length and the width of the sample and 45 degrees means that the yarn and the fill of the fabric are oriented at 45 degrees relatively to the same dimensions of the sample. In the case of the electric field samples it had been used a simple type fabric wile in the case of magnetic field samples a satin type fabric had been used. Both fabrics were prepared for cutting in order to avoid the tear. In order to obtain the filled resin certain quantities of ferrite and CNT were dispersed in the A-component of the resin using a mixer at a temperature of 85 Celsius. For the sample realization amounts of filled A-component were mixed with specified quantities of B-component and the mixture was used in 15 minutes, 10 minutes after the mixture was made.

The forming of samples were made using a combined method, first a "layer-by-layer" adding of resin imbued sheets of reinforcement. After the mould was closed the excess of resin was extracted through application of a mechanical effort, then the mould was introduced in a rubber bag.

The air and other gases from the bag were removed using a small vacuum pump in order to avoid the gas intrusions in the sample. One hour after the described above technique the moulds were introduced in electric or magnetic field and kept there for 12 hours. One of the goals of this experiment was to investigate the influence of external fields over the electric properties of composite.

The idea is not new but it is possible to improve such properties using electric and magnetic fields or their superposition [4]. The electrostatic field was obtained using a plan-parallel plates capacitor. The magnetostatic field was obtained inside of a tubular wrapping of coils. After the extraction the samples were prepared for electric measurements.

First the edges were rectified by abrasion in order to ensure the contact of electric plungers, then they were cleaned using alcohol.

3. Measurements

Measurements were performed in order to determine the electric conductivity. In this case because of sample's anisotropy, we have to make distinction between transversal conductivity (measured between the large faces of the sample) and longitudinal conductivity (measured along the yarn or the fill of the external sheets of reinforcement). It is expected a high anisotropy for electric properties of the material because both the presence of reinforcement and the action of external fields [7]. It is obvious that the ferrite particles will be aligned along the magnetic field (for example). Those orientations have to have effects in electric properties magnitude [8], [9], [10].

Fig. 1. *Image of sample's surface after extraction and preparation*

The resistivity measurement techniques are described in [11] and [12]. In [11] is described the van der Pauw technique in order to determine the resistivity which had been used for the longitudinal resistivity by measuring voltages and intensity for dc.

Figure 2 shows the experimental setup for the van der Pauw technique.

Fig. 2. *The experimental arrangement for van der Pauw Technique*

For the others measurements it had been used the same experimental setup, described for two distinct applications [12]. It is about the volume

resistivity of plates and, also about surface resistivity of plates. Both methods are based on the use of a measuring cell (three electrodes) and an apparatus able to measure electric resistance. For this purpose it had been used a *RLC-meter* at $1kHz$. In order to perform those measurements a measuring cell was realized according to [12]. Figure 3 shows the main characteristics of measuring cell as they are described in [11]. In order to respect all the geometric conditions (imposed by the sample thickness) the cell was designed in accordance to [11].
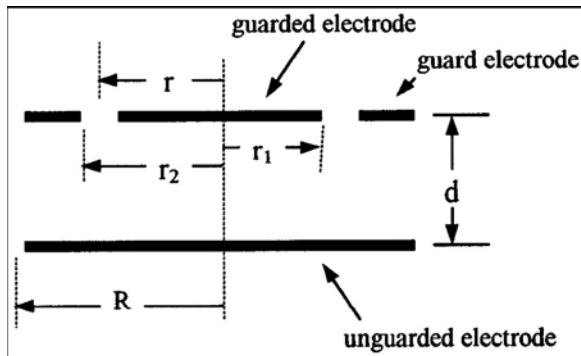
Fig. 3. *Geometric characteristics of the measurement cell*

The cell is of next dimensions: $R = 47.85mm$, $r_2 = 34.5mm$, $r_1 = 32.45mm$.

The value of r is given in [11] and is $r = r_1 + \Delta$ where

$$\Delta = \frac{1}{2}(r_2 - r_1) - \frac{2d}{\pi} \ln\left(\cosh \frac{\pi(r_2 - r_1)}{2d} \right) =$$

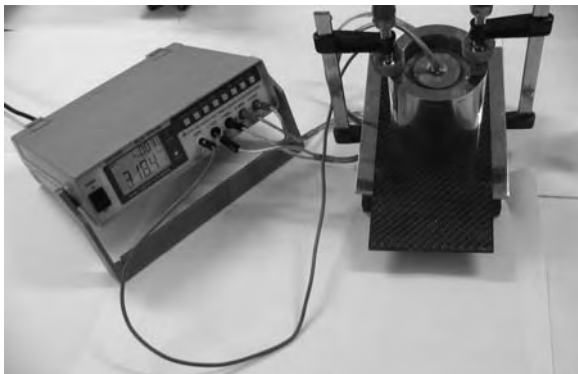$$= \frac{1}{2}(r_2 - r_1) - 1,4659d \ln\left(\cosh 0,7854 \frac{r_2 - r_1}{d} \right).$$

Fig. 4. *The experimental arrangement for standard method for determination of ρ_V and ρ_S*

With those we have: $\rho_V = \frac{RS}{d}$ where R is the read value of resistance. $S = \pi r^2$ and d is the

sample's thickness (all the dimensions are according the I.S.). Figure 4 shows the experimental setup of the cell method.

4. Results

The epoxy resin, as well as all the polymers, is a dielectric so its resistivity has high value and, of course, its conductivity has a small value.

On the other hand we used as reinforcement sheets of carbon fiber fabric which is an excellent conductor so, the standard plate (a laminate composite) looks like a sandwich of alternate conductor and dielectric layers. To improve the electric conductivity of such a material we may spread in dielectric a powder with high value of conductivity, this is the case of CNT used as filler.

In such conditions the composite's resistivity along the reinforcement has to be smaller than the across one.

There are not reasons to consider that the matrix (filled epoxy) is influencing the natural conductivity of carbon fiber increasing or decreasing its resistivity. In fact, the yarn and the fill will act as insulated conductors.

Adding fillers to the resin we can improve its conductivity and, as an effect, we can have an improvement of composite's conductivity as a consequence of superposition principle.

Figure 5 shows the across resistivity $\rho_V [\Omega m]$, surface resistivity $\rho_S [\Omega]$, along resistivity $\rho_L [\Omega m]$ for standard sample and CNT filled epoxy composite (electric type sample).
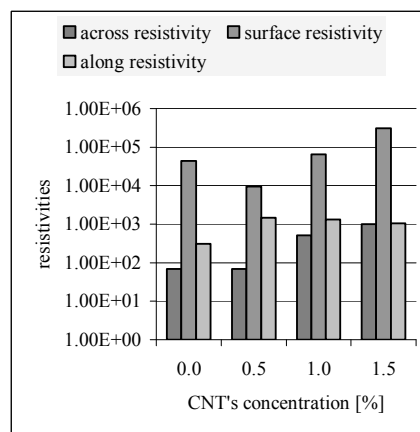

Fig. 5. *Influence of CNT's concentration on samples' resistivities (13 sheets of reinforcement)*

Figure 6 shows the $\rho_V [\Omega m], \rho_S [\Omega], \rho_L [\Omega m]$ for standard sample and CNT filled epoxy composite (magnetic type samples).
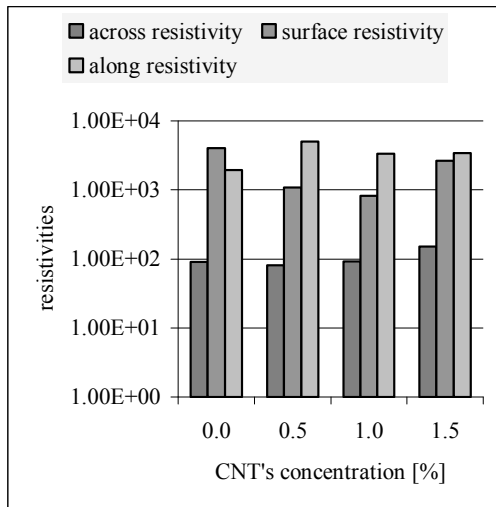
in the polymer structure.

Fig. 6. *Influence of CNT's concentration on samples' resistivities (15 sheets of reinforcement)*

Comparing the two diagrams above it can be noticed also the influence of reinforcement over the resistivity of the samples.
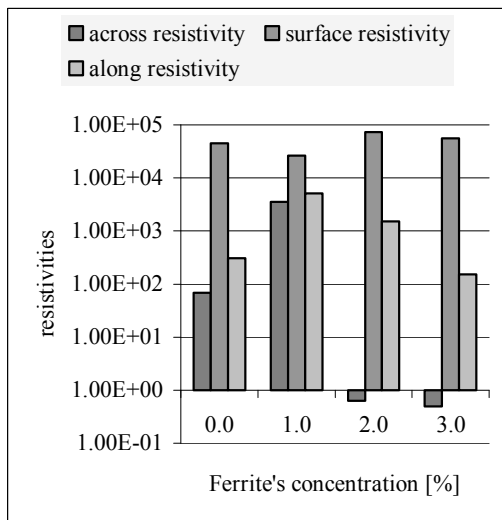

Fig. 7. *Influence of ferrite's concentration on samples' resistivities (13 sheets of reinforcement)*

There are small values for the 15 sheets of reinforcement samples than the 13 sheets ones. We can also notice that only small amounts of CNT can bring benefits in terms of resistivity. A soft decreasing of the value of bulk resistivity in both cases for 0.5% concentration of CNT can be noticed.

Figure 7 and 8 shows the influence of ferrite over the samples' resistivities.

When a composite material is formed with filled polymer it is expected that it is sensitive to external electric or magnetic field. Under these fields actions there is possible that small particles of fillers to suffer an alignment so some kind of order may be installed
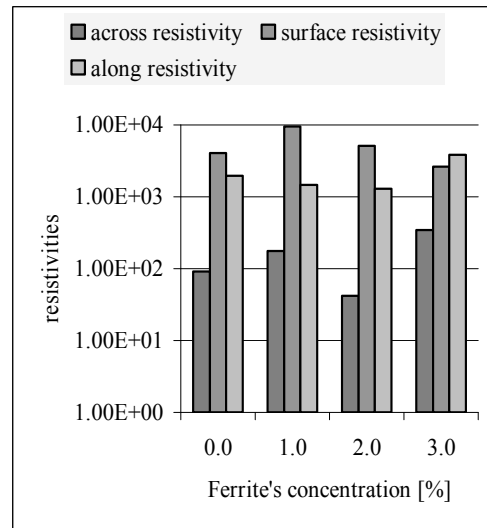

Fig. 8. *Influence of ferrite's concentration on samples' resistivities (15 sheets of reinforcement)*

The electric and the magnetic fields were parallel to the reinforcement so it is expected that the across resistivity to increase and also the surface resistivity in the case of CNT used as filler.

In the case of the magnetic field the ferrite particles are expected to be aligned along the magnetic field lines. Figure 9 shows the variations of samples' permitivities with the intensity of the electric field for the 0.5 % CNT filled epoxy matrix.
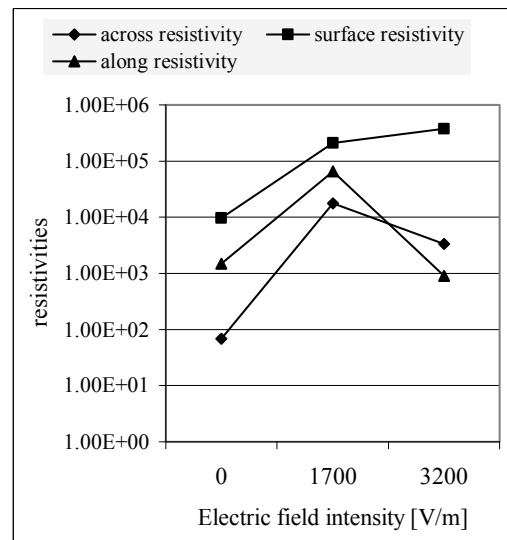

Fig. 9. *Resistivities' variations with electric field intensity (CNT 0.5%)*

Figure 10 present the variations of permitivities in electric field for the 1% ferrite filled epoxy matrix.

Next section is about the magnetic field effects over resistivities of samples and we will present just the results for 0.5 % CNT and 1 % ferrite filled epoxy matrix composites.
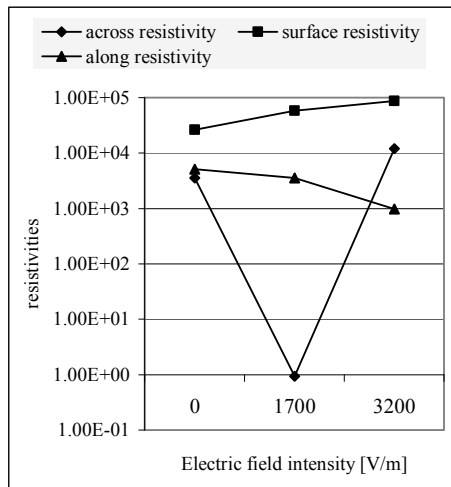
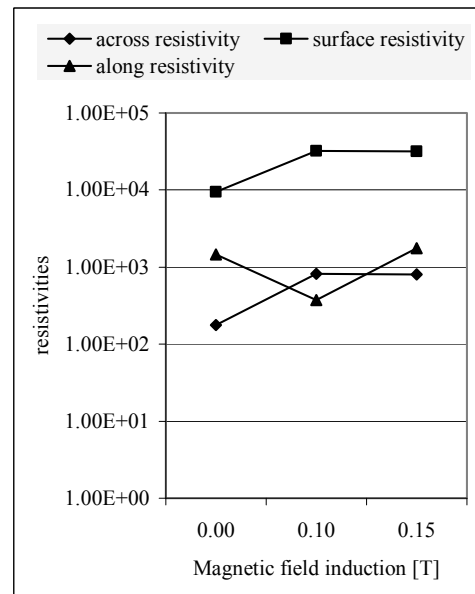***Fig. 10**. Resistivities' variations with
electric field intensity (ferrite 1%)*

Figure 11 present the variations resistivities for 0.5% CNT filled epoxy composite with 15 reinforcement sheets in external magnetic field and the figure 12 for 1 % ferrite filled epoxy matrix, 15 reinforcement sheets of carbon fiber fabric.
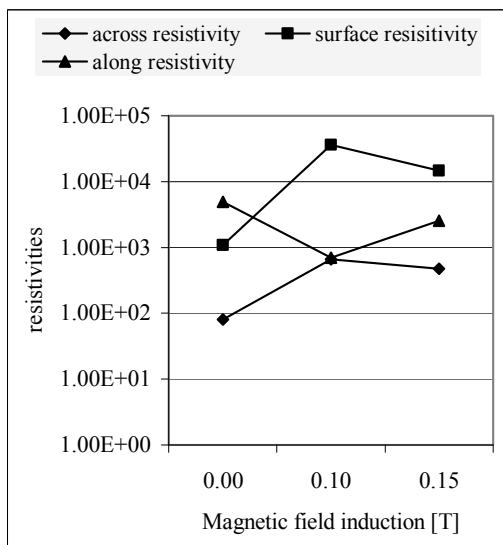

***Fig. 11.** Resistivities' variations with
magnetic field induction (CNT 0.5%)*

***Fig. 12**. Resistivities' variations with
magnetic field induction (Ferrite 1%)*

5. Conclusions

Based on above presented results - it is possible to design a fiber fabric based filled polymer composite with certain values of surface resistivity and across resistivity in order to avoid the electric charging.

The above presented results allow the conclusion that it is possible to form a composite based on a certain geometry of reinforcement (fiber fabric) using various types of filled polymers. It is clear that these results are just a part of an exhaustive characterization of samples. Mechanical, thermal and thermomechanical analysis are necessary.

Another aspect to be taken into account is the fact that because of the fillers and of the reinforcement such a composite material is frequency sensitive *i.e.* the electric and electromagnetic properties depend on the frequency of measuring signal.

The study of mechanical and thermal properties will allow manufacturers to make the right decision about the best reinforcement, best geometry of the reinforcement, best fillers' concentrations for a given application. Based on these results it is possible to start verifying some models regarding electric and electromagnetic properties of complex composites.

Acknowledgments

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