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INFLUENCE OF CARBON FIBER ON PROPERTIES OF GRAPHITE/EPOXY COMPOSITES

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Abstract. *The wide use of polymeric composite requires a greater understanding of their characteristics. These materials have attractive combination of properties, it can replace with lower cost and greater efficiency, metallics components. The basic requirement is that the composite must possess adequate electrical and mechanical properties for the particular application. One of the many examples in which the using of polymer is of prime importance is in Industrial applications, mainly in automobile industries. For instance, bipolar plates, for polymer electrolyte fuel cell, in automobile applications. Such composites combine low cost, reasonable conductivity. In this work, epoxy/graphite composite reinforced with fiber carbon was investigated. The influence of the addition of carbon fibers on the mechanical and electric behavior of the composite and the microscopic structure were analyzed. The goal of the present paper is to relate the macroscopic mechanical properties and electrical conductivity of graphite/epoxy composites filled with the weight percentages of graphite powder and reinforced with carbon fiber. The conductivity tests and tensile testing applied to the material with or without carbon fiber, showed that the addition of carbon fiber in the array significantly increased the conductivity and the stiffness and ductility of the material.*

Keywords: *conductivity; carbon fiber; polymeric composite.*

1. INTRODUCTION

Intrinsically (or inherently) conducting polymers (ICPs) are organic polymers that conduct electricity (Shirakawa *et al.* 1977, Liu *et al*. 2003). Such compounds may have metallic conductivity or can be semiconductors. Conductive polymers are generally not plastics, i.e., they are not thermoformable. But, like insulating polymers, they are organic materials. They can offer high electrical conductivity but do not show mechanical properties as other commercially used polymers do.

One way of classifying solid materials is according to the ease with which they conduct an electric current; within this classification scheme there are three groupings: conductors, semiconductors, and insulators. Metals are good conductors, typically having conductivities on the order of 10^7 $(\Omega.m)^{-1}$. At the other extreme are materials with very low conductivities, ranging between 10^{-10} and 10^{-20} $(\Omega.m)^{-1}$ these are electrical insulators. Materials with intermediate conductivities, generally from 10^{-6} to 10^4 $(\tilde{\Omega}m)^{-1}$ are termed semiconductors. (Callister,W. D., 2000).

An interesting alternative to the ICPs may be the addition of conductive filler into non conducting polymers. Such composites combine low cost, reasonable conductivity, processability and good mechanical strength. One of the most promising applications of such kind of composite are in fuel cells (Lee *et al*. 2007).

The bipolar plate cost is a considerable part of the cost of a polymer electrolyte fuel cell stack. Especially for automobile applications, it is necessary to strongly reduce this cost. A combination of a minimum mechanical strength with a reasonable conductivity is a basic requirement. Generally, carbon nanotubes, carbon blacks or carbon fibers are added to the matrix.

The mechanical and electrical properties of the composite with different graphite powder weight percentages (0, 5, 10, 15, 30, 50 wt.%) and with 30%, 40%, 50%, 55% and 60% of graphite powder with carbon fiber addition have been investigated, as shown at the tab. 2.

The goal is to study the effect of adding carbon fiber in the epoxy/graphite composites, analyzing both the mechanical behavior and electrical properties.

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2. EXPERIMENTAL PROCEDURES

2.1 MATERIAL

In this study, one type of epoxy resins was selected as the polymer matrix. Commercial powder graphite and carbon fiber were chosen as the conductive fillers. Epoxy resin has several advantages, including exceptional combination properties such as hardness, chemical resistance, high heat distortion temperature, thermal stability and weather properties. Powder graphite was incorporated into this resin to increase electrical conductivity, both at ambient and high temperatures. The composites were manufactured in the Laboratory of Pipeline Testing (LED-LMTA) at the Universidade Federal do Rio the Janeiro (UFF). We used two kind of carbon fiber: Unidirectional and bidirectional-0°/90˚ fibers. Information provided by the supplier is showing at Tab. 1:

Table 1. Carbon fiber properties**.**

Properties	Carbon fiber
Density (g/cm^3)	1.76
Elongation (%)	1.90
Elastic Modulus (GPa)	234.00
Ultimate Tensile Strength (MPa)	3530.00

2.2 PROCEDURES

The procedure to manufacture graphite/epoxy composites consists in mixing the graphite powder and the base resin, which consists in a diglycidyl ether bisphenol A, with a spatula for approximate 15 min, in order to obtain 5, 10, 15, 20, 30, 40, 50, 55 and 60 (wt.%) of graphite in the composite. After homogenization, the aliphatic amina hardener was added to start the polymerization process. Then, the produced composite is pored into the mold. For to prepare the higher fraction of graphite composite, such as 50, 55 and 60 % was added also acetone for to facilitate the mixture dissolution. (Loos *et al.*, 2008). For the composite with carbon fiber, graphite/resin epoxy mixed was interspersed with two or three carbon fiber layers between them. The tensile specimens were prepared according to ASTM D 638. Tab. 2 shows the samples manufacture.

Table 2. Samples Manufacture.

Graphite (%)	Carbon Fiber
0.0	No carbon fiber
5.0	No carbon fiber
10.0	No carbon fiber
15.0	No carbon fiber
30.0	Bidirectional Carbon Fiber (2 Layers)
30.0	No carbon fiber
40.0	Bidirectional Carbon Fiber (2 Layers)
50.0	Bidirectional Carbon Fiber (2layers)
50.0	No carbon fiber
55.0	Bidirectional Carbon Fiber (2 Layers)
60.0	Bidirectional Carbon Fiber (3 Layers)

2.3 MECHANICAL TESTING

Tensile tests were performed at the graphite/epoxy composites, following the recommendations of ASTM D 638 Standard. A prescribed stroke speed of 5mm/min was adopted. These tests were conducted until the specimen fracture using a servo-electric test Universal machine, Shimadzu-100kN. Five specimens were tested for each fraction of powder graphite. The procedure adopted as a criterion for determining the Proportional limit establish as Proportional limit the value of stress to corresponded to the point where a straight line cuts the abscissa axis at 0.02% strain, tangent to stress-strain curves.

ISSN 2176-5480

2.4 CONDUCTIVITY TEST

The high through-plane electrical conductivity of the composite is more important for the application of these materials as bipolar plates in PEMFC (Ling Du, 2008).

The through-plane conductivity of the composite was measured by using a fixture design whereby the specimen was kept under pressure in the measurement setup Fig. 1. This figure show the apparatus composed, first more externally, two acrylic plates, between these, two rubbers layers and then two layers of conductive metal, in this case, we used Aluminum, and finally the specimen is insert between these aluminum plates. The specimens' area dimensions are equal to about 75x45mm and the thickness varies from 1.0mm until 4.0mm (depending on the number of carbon fiber layers). Before the tests, both sample's surface were painted using graphite ink or silver ink to homogenize the surface and have more precision on the conductibility results.

The conductivity tests was performed at Laboratório de Processamento de Sinais (LPS), at Universidade Federal do Rio de Janeiro (UFRJ), using a The Agilent 34401A digital multimeter , Fig. 1.

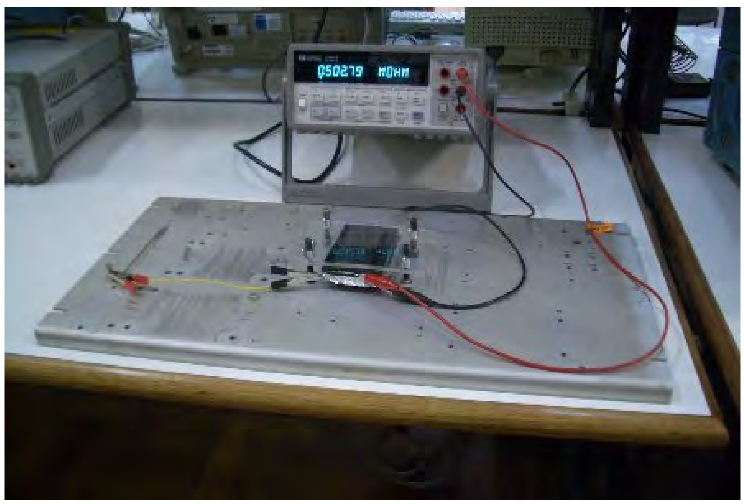

Figure 1: The specimen connected to digital multimeter**.**

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 TENSILE TESTS

The experimental stress-strain curves for different graphite fractions are shown in Fig. 2 and 3. At Tab. 3 is presented the average elastic modulus, the proportional limit, the ultimate tensile strength and the tensile fracture strength.

Comparing the tensile tests response, it can be seen, that there was a performance variation with the powder graphite addictions, the fracture strength was reduced and the ductility too, but there was a small increase in the elastic modulus. It can observe that between 5, 10 and 15 wt.% of graphite fraction, the mechanical properties variation is smaller, it means, the mechanical tests results showed that the graphite addition decrease the strength limit, but the difference behavior between the composites with the graphite fraction are smaller, however there are a small increase in the stiffness until 1% of strain. The results show also with the graphite added a reduction of the material stiffness occurs when the strain exceeds a value of approximately 1.0%, Fig.8. With the addition of carbon fiber, the composite present a high rise on the mechanical properties, such as elastic modulus, stretch, stiffness and Tensile Fracture Strength. But, with 60 wt.% of graphite fraction there was a degradation in properties such as. The high concentration of graphite and the addition of acetone caused high porosity and roughness on the material and increase its fragility drastically, decreasing the adhesion of carbon fiber added, so it was not possible to make this test in these samples.

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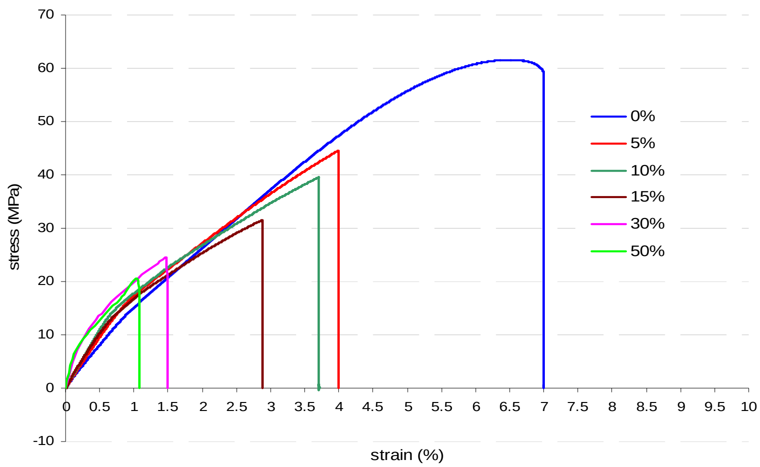

Figure 2: Tensile stress-strain curves for 0, 5, 10, 15, 30 and 50% wt. graphite fraction until fracture

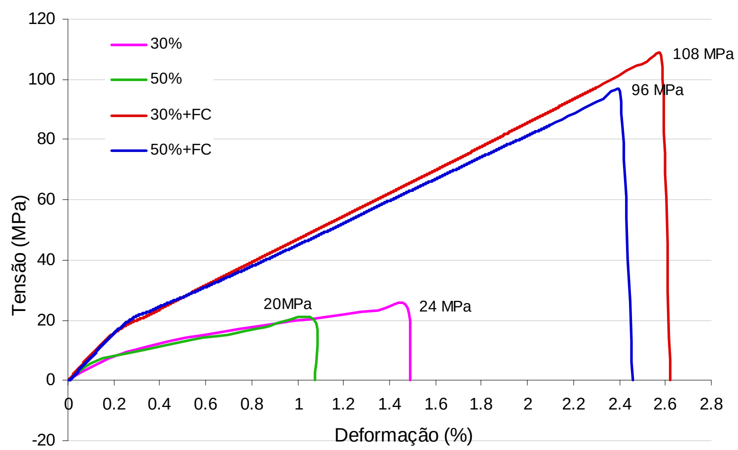

Figure 3: Tensile stress-strain curves for, 30 and 50% of graphite with and without Carbon Fiber (CF).

In general, to determine Yield stress in polymeric materials is not obvious. The plateau region of instability with constant stress does not appear in the tensile tests curves. Moreover, using the stress value associated with 0.2% strain, usually applied to metals is unrealistic for the polymers. Thus, it was adopted as a criterion for determining the Proportional limit, the procedure in which establish as Proportional limit the value of stress to corresponded to the point where a straight line cuts the abscissa axis at 0.02% strain, tangent to stress-strain curves.

Table 3. Experimental results to composite tensile properties(1).

Graphite (wt.%)	Elastic Modulus(GPa)	Proportional limit (MPa)	Ultimate Tensile Strength (MPa)	Tensile Fracture Strength (MPa)
0	1.6 ±0.3	3.0 ±1.0	61.6±1.9	59.3±1.2
5	2.0 ±0.2	3.5 ±0.8	44.5±1.1	44.5±1.1
10	2.2 ±0.3	5.5 ± 0.5	39.2±1.2	39.2 ±1.2
15	2.2 ±0.2	4.5 ±0.5	31.5±0.9	31.5 ±0.9
30	4.2 ±0.2	7.1 ±0.3	24.3±0.8	24.3±0.8
50	5.6 ±0.2	6.8 ±0.4	20.2±1.5	20.2±1.5
30+CF	7.7 ±0.6	14.0 ±1.8	108.0±15.0	108.0±15.0
50+CF	7.8 ±0.5	18.0 ±2.0	96.0±10.0	96.0±10.0

(1): measured at room temperature. Average results of 5 tests.

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The next Fig.4 and 5 shows the experimental Parameters results with the trend line and curve equation. Fig.4 shows that Ultimate Tensile Strength decreases with graphite increase, nearly, in the linear way; it shows the mechanical behavior trend with the powder graphite addition.

The Elastic Modulus increased with graphite addition, it was around 20% with 5% of graphite as shown in Tab. 3 and in the Fig.5, tending to the linear way, with this equation is possible also forecast the material behavior.

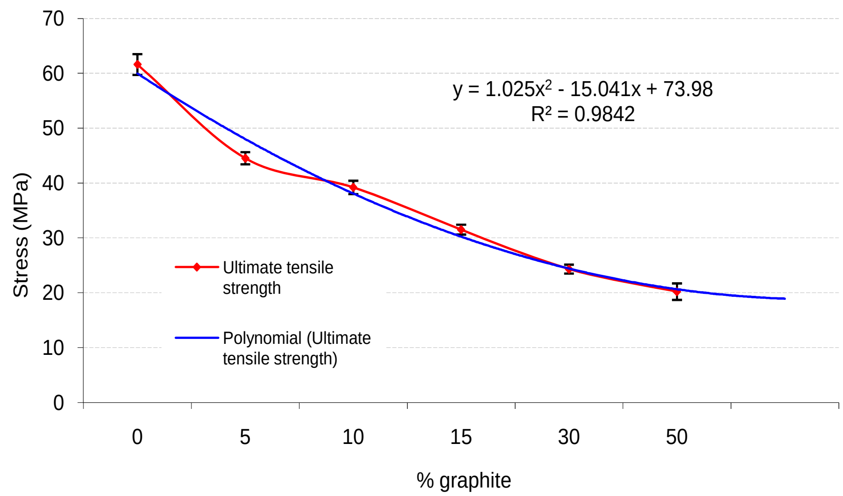

Figure 4: Ultimate Tensile Strength versus % graphite, with the trend line and curve equation

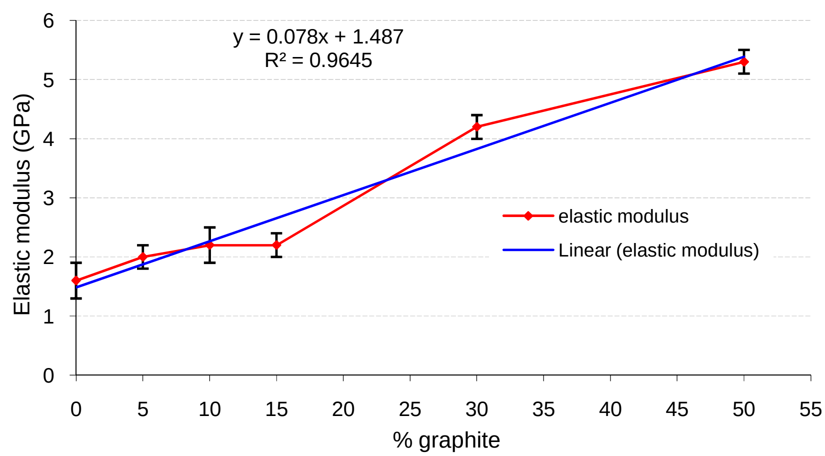

Figure 5: Elastic Modulus versus % graphite, with the trend line and curve equation.

3.2 CONDUCTIVITY TEST

The electrical conductivity tests results, for different graphite fractions, are presented in Tab. 4 and Fig. 6. It can be observed that the conductivity increases with the graphite fraction, very fast after carbon fiber addition and about 50% of graphite, showing that there is influence of the powder graphite and carbon fiber, modifying the conductivity of the resin and mechanical properties.

Table 4. Composites conductivity properties, experimental results [(1)].

Graphite (%)	Conductivity (S/cm)
0.0%	$<6.6x10^{-13}$
5.0%	$<1.3x10^{-13}$
10.0%	$<1.3x10^{-13}$
15.0%	$1.5x10^{-10}$
30 %	$3.75x10^{-9}$
40%	$2.2x10^{-6}$
30% + bidirectional carbon fiber (2 layers)	$2.08x10^{-4}$
40.0% + bidirectional carbon fiber (2 layers)	$1.72x10^{-5}$
50%	$2.95x10^{-4}$
50% +bidirectional carbon fiber (2layers)	$1.5 x10^{-2}$
55%+bidirectional Carbon Fiber (2 Layers)	$2.0 x10^{-2}$
60.0%+ bidirectional carbon fiber (3 layers)	$7.5 x10^{-2}$

[(1)]Measured at room temperature.

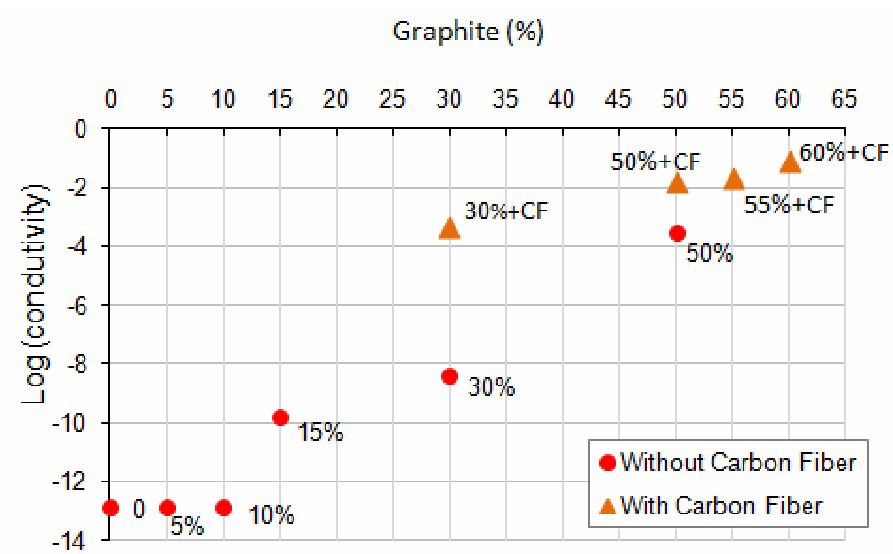

Figure 14: Log Conductivity versus % graphite curves, with and without Carbon Fiber (CF).

4. CONCLUSION

The mechanical and electrical properties of the composite, with different graphite powder fraction (0, 5, 10, 15, 30, 50, 60 wt.%) and carbon fiber have been investigated. The study has demonstrated that reasonably small quantity addition of graphite powder can modify the mechanical behavior of a polymer matrix. A challenge is that the mechanical strength of the epoxy matrix strongly decreases with the initial addiction of graphite, but with the addition of carbon fiber this problem can be solved. The conductivity increased firstly very slowly then from 50% it was very fast mainly with the addition of carbon fiber, we had the best conductivity results. The conductivity of a semiconductor is in a range of 10^{-4} to 10 S/cm. From this study, it is achieve a semiconductor behavior for a graphite weight fraction around 50 wt.% reinforced with carbon fiber, reaching around 10^{-2} Siemens/cm, that is enough for bipolar cell application, since it is necessary at last a conductivity around 10^{-2} Siemens/cm. So, the Carbon Fiber addition increased the mechanical and electrical properties considerably.

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7. RESPONSIBILITY NOTICE

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