23rd ABCM International Congress of Mechanical Engineering
December 6-11, 2015, Rio de Janeiro, RJ, Brazil

Flexural and Tensile Behavior of Graphite/epoxy Composite Reinforced with Carbon Fiber

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Abstract. *Most of the currently available technologies require the use of materials with unusual combinations of properties that cannot be met by the metallic alloys, ceramic or conventional polymeric materials. The polymer composites are designed to meet the requirements and challenges of the industry, where there is an increasingly growing demand for special materials, involving the best cost-benefit relationship. The aim of this work was to study the effect of carbon fiber in relation their ability to reinforce the composite. Experimental testing was carried out on specimens of composites with different graphite fraction, with and without carbon fiber. Since, the graphite addition at the epoxy causes a decrease on the mechanical properties, the carbon fiber come to reinforce the material.*

Keywords: *Epoxy Composite, Carbon fiber, mechanical properties.*

1. INTRODUCTION

The wide use of polymeric materials requires a greater understanding of their characteristics, mainly mechanical properties. It is necessary to know the behavior of these materials when subjected in their use conditions. Whatever the application, it is also necessary to know the durability of these materials so to evaluate the service life and proper maintenance procedures (Berry e*t al.*, 2007).

Nowadays, polymers are widely used in many applications that range from everyday household goods to matrices for advanced composites. One of the many examples in which the using of polymer is of prime importance is in Industrial applications, mainly in automobile industries (Callister, 2000).

Epoxy-based thermosets are versatile materials, which have important applications as structural adhesives, surface coatings and matrices for composites and nanocomposites, as well as in electrical devices (Da Costa Mattos and Martins, 2013). Their highly crosslinked structure imparts high stiffness, high glass transition temperature and high chemical resistance, but decreases their toughness (Soares *et al*., 2011) This material has attractive combination properties such as hardness, chemical resistance, high heat distortion temperature, weather and thermal stability.

This kind of composite can replace with lower cost and greater efficiency metallic component. The basic requirement is that the composite must possess adequate mechanical properties for a particular application. In some case, such compounds 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 electrical conductivity but do not show mechanical properties as other commercially used polymers do.

In this work was studied an epoxy/graphite Composites reinforced with carbon fiber tissue and compared the mechanical behavior in relation of the graphite and carbon fiber influence. Tensile tests and flexural tests were applied to the material with and without graphite and carbon fiber. The graphite addition is used to improve the electrical conductive properties, but in this work are studied the effects on mechanical behavior of the composite.

2. EXPERIMENTAL PROCEDURES

In this work were prepared an epoxy/graphite composites, some of the specimens were reinforced with carbon fiber tissue. These composites were performed in tensile and flexural tests. In the this section are presented the materials and how were the tests performed.

2.1 Materials

In this study, one type of epoxy resins was selected as the polymer matrix. Commercial powder graphite and carbon fiber were chosen as the 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 and then the carbon fibers tissue were interspersed in these matrices composites. We used and bidirectional- 0°/90˚ carbon fiber. Information provided by Carbon fiber's supplier is showing at Tab. 1 and information about the powdered graphite at Tab. 2:

Table 1. Carbon fiber properties.

Properties	Value
Density (g/cm^3)	1.76
Elongation (%)	1.9
Elastic Modulus (GPa)	234
Ultimate Tensile Strength (MPa)	3530

Table 2. Graphite properties

Graphite (G)	
Properties	Value
Melting point (°C).	Above 3338
Vapor Pressure	760 mm Hg at 4.200(°C).
Apparent density (g/cm^3)	2.1 to 2.3
Actual density (g/ cm^3)	1.30

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 5 min, in order to obtain 30 wt. % and 50 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, as shown at Fig. 1 and 2. For to prepare the higher fraction of graphite composite, 50 wt. % 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 carbon fiber layers between them. Tab. 3 shows the samples manufacture.

Figure 1: Mold where were manufactured the specimen

Figure. 2 Some specimens manufactured.

Table 3. Manufactured samples.

Specimens	Graphite	Carbon Fiber
0%	0%	No carbon fiber
0%+CF	0%	Bidirectional Carbon Fiber (2 Layers)
30%	30%	No carbon fiber
30 %+CF	30 %	Bidirectional Carbon Fiber (2 Layers)
50%	50%	No carbon fiber
50%+CF	50%	Bidirectional Carbon Fiber (2layers)

2.3 Mechanical Test

Specimens were submitted to Tensile and Flexural tests.

2.3.1 Tensile Test

Tensile tests were performed at the composites, following the recommendations of ASTM D 3039 Standard. These tests were conducted until the specimen fracture using a servo-electric Universal test 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.

2.3.2 Flexural Test

Flexural tests were performed at the composites, following the recommendations of ASTM D 790 Standard.

The three point bending flexural test provides values for the modulus of elasticity in bending, flexural stress, flexural strain and the flexural stress-strain response of the material. The main advantage of a three point flexural test is the ease of the specimen preparation and testing.

The experiments were carried out under displacement controlled conditions at a constant cross head rate in a servo hydraulic Universal testing Machine EMIC Model DL500, with 5KN load cell applied on the loader to record the force, Fig. 3, Stress and strain behaviors were determined throughout the test following ASTM D 790, as mentioned before.

Fig.3 Flexural tests performed in a servo hydraulic Universal testing Machine EMIC Model DL500.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Tensile Test

The experimental curves stress-strain for the composites are presented in Fig. 4, 5 and 6. Fig. 4 shows the performance of the composites with different graphite fractions. Tensile stress-strain curves for composites with 0% wt. graphite fraction with carbon fiber and without carbon fiber are shown in Fig. 4. In Fig. 6 it can be observed the performance comparation of Tensile stress versus strain curves for 0, 30 and 50% wt. graphite fraction with and without carbon fiber. At Tab. 4 is presented the average elastic modulus, elongation at break, the ultimate tensile strength and the tensile fracture strength.

Comparing the tensile tests response (in figure 4, 5 and 6) 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. Then, the mechanical tests results showed that the graphite addition made a small increase in the stiffness until 1% of strain. The results show also that with the graphite added a reduction of the material stiffness occurs when the strain exceeds a value of approximately 1.0%, Fig.4. Therefore, with the carbon fiber addition, the mechanical properties, strength as well as elastic modulus, increased considerably, recovering and making better these properties.

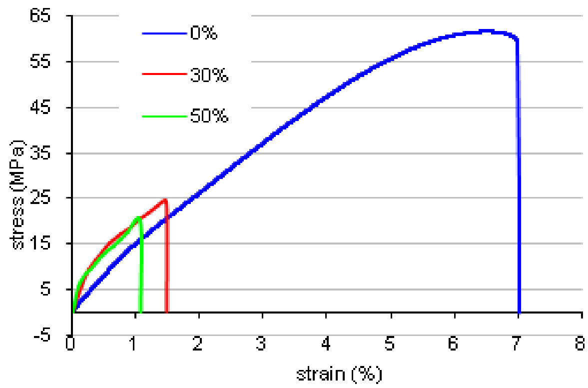

Figure 4: Tensile stress-strain curves for 0 wt% (line blue), 30 wt % (line red) and 50% wt.(line green) graphite fraction, until fracture.

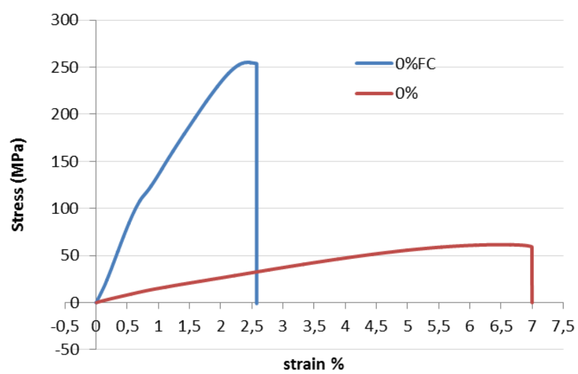

Figure 5: Tensile stress-strain curves for composites with 0% wt. graphite fraction with carbon fiber (line blue) and without carbon fiber (line red) addition, until fracture.

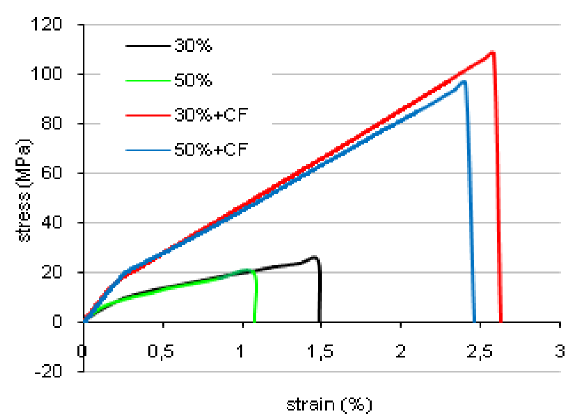

Figure 6: Tensile stress-strain curves for 0, 30 and 50% wt. graphite fraction with and without carbon fiber addition, until fracture.

Table 4. Tensile properties, experimental results

Properties[1]	Graphite fraction [wt.%]					
	0	30	50	0 + CF	30+CF	50+ CF
Elastic Modulus (GPa)	1.6 ±0.3	4.2±0.2	5.6±0.2	15.9±3.0	7.7 ±0.6	7.8 ±0.5
Elongation at break (%)	7.0 ±1.8	1.5±0.	1.1±0.3	2,6±1.2	2.6 ±0.5	2.4 ±0.4
Ultimate Tensile Strength (MPa)	61.6 ±1.9	24.3±0.8	20.2±1.5	255.2±3.5	108.0 ±15.0	96.0±10.0
Tensile Fracture Strength (MPa)	59.3 ±1.2	24.3±0.8	20.2±1.5	253.3±4.0	108.0 ±15.0	96.0±10.0

[1]: measured at room temperature. CF=Carbon Fiber

3.2 Flexural Test

The experimental curves stress-strain for different graphite fractions with and without carbon fiber are shown in Fig. 7 and 8. At Tab. 5 is presented the average of maximum stress (σ_{max}), maximum strain (ε_{max}) and Flexural modulus (E_F), it have been used as mechanical parameters to compare the tested composites and measure the efficacy of Carbon fiber addition. It can be observed at the stress versus strain curves that flexural strength and ductility was improved with carbon fiber addition and decrease with graphite fraction. Therefore, the Elastic Modulus increased with graphite, it was more than 100% with 30% of graphite as shown in Tab. 5 and in the Fig.8.

Stress, strain and flexural modulus were determined accord next equations following the ASTM D790, as shown above.

Flexural stress (σ_F):

$$\sigma_F=(3.F.L/2.b.h^2) \tag{1}$$

Flexural strain (ε_F):

$$\varepsilon_F= (6.D.h/L^2) \tag{2}$$

And Flexural Modulus of elasticity (E_F):

$$E_F=(L^3.M/4.b.h^3) \tag{3}$$

F=load;
D=displacement;
L= Support span;
b, h are width and thickness respectively;
M= the gradient (i.e., slope) of the straight line portion of the load deflection curve (*F/D* [N/mm])

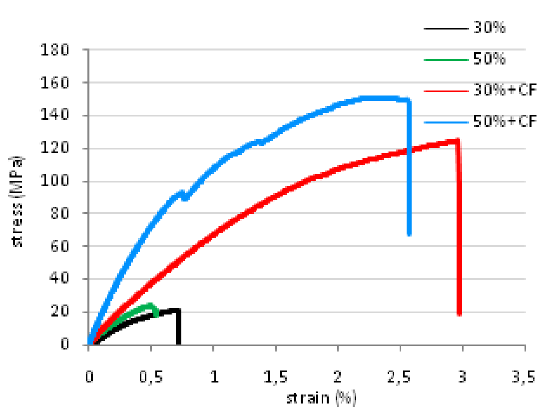

Figure 7: Flexural stress-strain curves for 30 wt.% of graphite (line black and red) and 50 wt.% graphite fraction (line green and blue) with carbon fiber and without carbon fiber addition, until fracture.

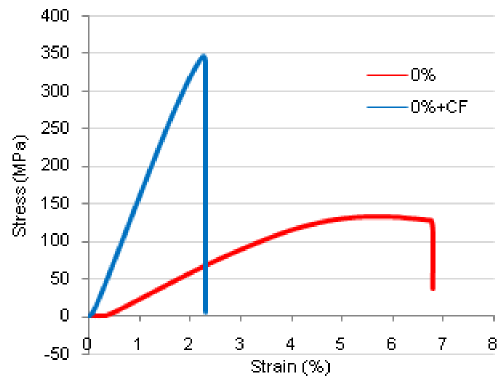

Figure 8: Flexural stress-strain curves for 0 wt. % graphite with carbon fiber (line blue)and without carbon fiber addition (line red), until fracture.

Table 5. Experimental results to composite, Flexural properties.

Properties(1)	Graphite					
	0wt.%	30 wt.%	50 wt.%	0 wt.%+ CF	30wt.%+CF	50 wt.%+CF
Flexural Modulus (GPa)	2.5±0.5	6.2±1.0	7.5±1.5	16.0±3.0	7.8±1.5	16.7±2.8
Maximum stress (MPa)	132.0±24.0	20.6±6.0	23.6±4.5	345.0±65.0	125.0±15.0	151.0±20.5
Maximum strain (%)	6.7± 1.2	0.72±1.3	0.53±0.1	2.13±0.4	2.96±0.6	2.56±0.5

CF=Carbon Fiber

Next Fig. 9, 10 and 11 show the experimental Parameters results of flexural tests : maximum stress, maximum strain and flexural modulus respectively. And Fig. 12 show the maximum flexural stress Versus maximum tensile stress curves to composite with carbon fiber and without carbon fiber.

Comparing tensile and flexural tests response (figure 9, 10, 11 and 12) it can be seen that with the addition of 30% of graphite, decreased substantially the maximum stress obtained in comparing with the specimens without graphite addition, but from 30 wt. % to 50 wt. % of graphite it made a small performance variation at the test results, in relation of tensile maximum stress, these results were more evident after addition of carbon fiber. Considering the maximum strain, it is possible to observe that the ductility decreases strongly, to the samples without carbon fiber, after 30 wt.% of graphite addition. About elastic modulus, it was upper at the samples with carbon fiber addition, in flexural and tensile tests. Therefore, these properties improved linearly with the graphite fraction increased, in specimens without carbon fiber. But the better results were obtained in specimens with carbon fiber, that presented the superior modulus of elasticity. The specimens with carbon fiber presented the better results in stress and strain, showing best ductility and strength except for the composites with 0wt.% of graphite. As was observed in tensile and flexural tests, fig. 12, samples with the carbon fiber addition, the mechanical properties increased considerably, recovering and making better these properties, in both tests. But as was mentioned before, the strength and modulus of elasticity results obtained in tensile and flexural response were considerably superior between the samples with carbon fiber. Comparing the response of the composite in these two tests it can be observed that these composites presented perform better in flexion, but at the specimens without graphite addition it was more considered.

Legend:

	tensile test of specimens without carbon fiber (T)		tensile test of composite with carbon fiber added (T+CF)
	Flexural test of specimens without carbon fiber (F)		Flexural test of composite with carbon fiber added (F+CF)

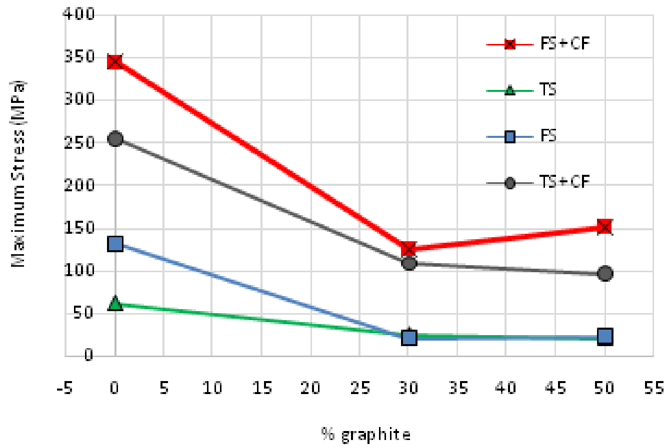

Figure 9: Maximum stress versus graphite fraction curves, in tensile (TS) and Flexural test (FS) of composite with and without carbon fiber (CF)

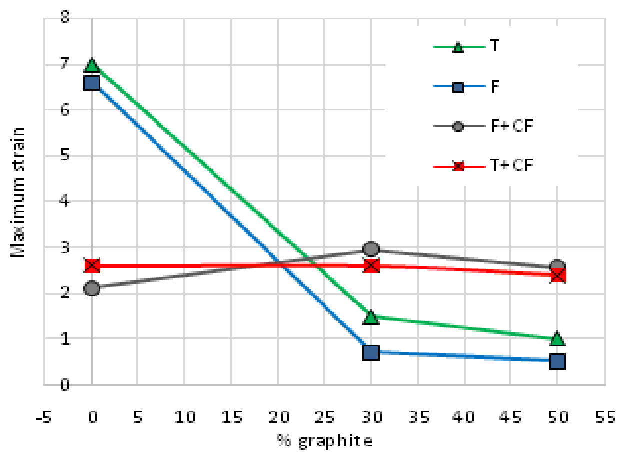

Figure 10: Maximum strain versus graphite fraction curves, in tensile (TD) and Flexural test (FD) of composite with and without carbon fiber (CF)

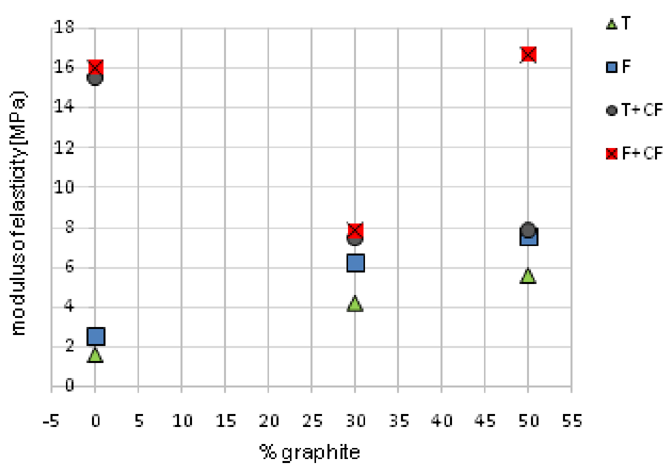

Figure 11: Modulus of elasticity versus graphite fraction curves, in tensile (ET) and Flexural test (EB) of composite with and without carbon fiber (CF)

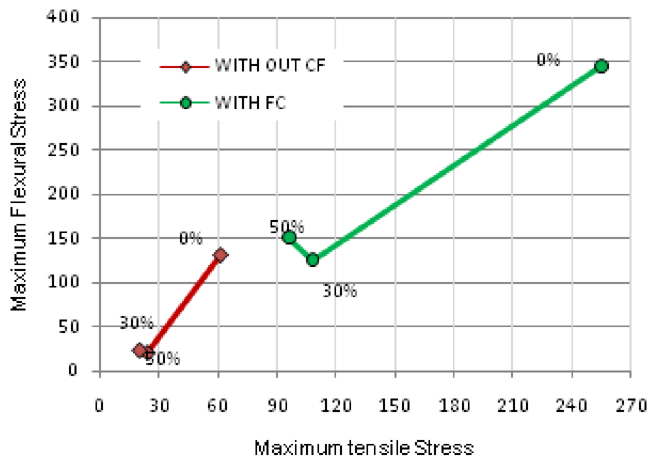

Figure 12: Maximum flexural stress Versus Maximum tensile stress curves to composite with carbon fiber (green line) and without carbon fiber addition (orange line).

4. CONCLUSION

Mechanical properties of the composite, with graphite powder fraction (30 and 50 wt.%) and carbon fiber have been investigated in tensile test and flexural test. The study has demonstrated that:

- addition of graphite powder can modify considerably the mechanical behavior of a polymer matrix, the mechanical strength of the epoxy matrix strongly decreases with the addiction of graphite, but with the addition of carbon fiber this problem can be solved.
- Comparing tensile and flexural tests response, it is possible to observe that the strength and ductility decreases strongly, to the samples without carbon fiber, after 30 wt.% of graphite addition. About elastic modulus was upper at the samples with carbon fiber addition, in flexural and tensile tests.
- Specimens with carbon fiber presented the better results in stress and strain, showing best ductility and strength except the ductility of the composites with 0wt.% of graphite.
- Comparing the response of the composite in these two tests it can be observed that these composites presented perform better in flexion, but at the specimens without graphite addition it was more visible.

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