IMPROVING BENDING PROPERTIES OF CARBON/EPOXY COMPOSITES BY CARBON BASED NANOPARTICLES DISPERSION

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Abstract. This work studies the effects of graphite nanoparticles on the bending properties of hybrid carbon fiber reinforced composites materials. The analyzed hybrid composite was a carbon/nanomodified epoxy system laminate. The reinforcement was a plain carbon fiber with density f 200 g/m^2. The epoxy system was DGEBA, from Hunstman Inc. The carbon fiber volume fraction was around 50%. The graphene sheets were obtained from an expandable graphite (HC 11 IQ) supplied by Nacional Grafite. The nanoparticles concentrations were 0 wt%, 1 wt%, 2 wt% and 3 wt%, respectively. Nanocomposites were made using a high shear mixer and ultrasound. Mechanical characterization was performed considering the ASTM D 790 three point bending test. Results show that the graphene based hybrid composites obtained have much better values than the conventional composites. 1wt% graphene based composites had an increase of almost 80% in bending strength and 16% in flexural modulus in comparison to 0 wt% based composite.

Keywords*: graphene nanosheets, carbon , composites, hybrid composites, bending test*

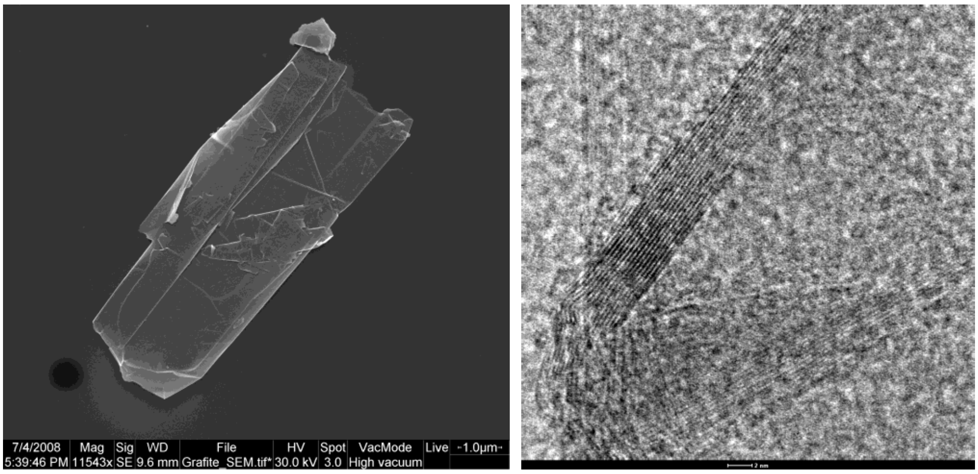
1. INTRODUCTION

Composites are engineering materials composed by two or more phases, in macroscopic scale. Their mechanical properties and features are different from those listed for each of its components (Daniel e Ishai, 1994). This class of material shows higher specific mechanical properties, i.e. stiffness-to-weight and strength-to-weight than conventional materials. For this reasons, it has being widely used in various engineering applications.

Polymer nanocomposites are a new class of composite materials containing extremely small particles with thickness around 1nm, dispersed in a polymeric matrix. Polymeric nanocomposites possess unique properties that are not shared by conventional composites, because of their large interfacial area per unit volume (Chen *et al.*, 2003; Luo e Daniel, 2003).

Fibrous composites and nanocomposites can be associated, forming a new type of composite, named hybrid nancomposite. As described by Ávila et al. (2007), hybrid nanocomposites can be defined as multi-reinforced laminated composites. Such multi-reinforcement can be divided in three different levels: the first one is due to nanostructures formation when nanoparticles were dispersed into the polymeric matrix. The second level of reinforcement can be described as the bonds formed between clusters of nanostructures and the macroscopic fibers. Finally, fibers themselves can be defined as the last level of reinforcement. The combination of nanocomposites and fibrous composites improves composites materials properties (Carvalho *et al.*, 2009; Vlasveld *et al*., 2005; Vlasveld et al., 2007).

Graphite nanoparticles have attracted increasing interest, being a promising and cheaper alternative to carbon nanotubes in nanocomposites fabrication. This kind of nanoparticles consists of a stacking of nanosized graphene sheets formed by sp^2 carbon atoms, while the carbon sheets are bounded by van der Waals forces (Li *et al.*, 2007, Chen *et al*., 2004). Figure 1, clearly shows the several layers of graphene nanosheets.



(a) (b)

Figure 1. Graphene nanosheets. (a) SEM analysis; (b) TEM analysis
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Graphene nanosheets have excellent electrical properties (Santovich *et al.*, 2006) and the same stiffness as single walled carbon nanotubes, which is around 1.0 TPa (Koo, 2006). Despite these properties, the use of graphite nanoparticles in hybrid nanocomposites is restricted. Therefore, more studies on the development and assessment of this kind of composites materials are necessary. This work focuses on the synthesis and study of the effects of graphite nanoparticles on the bending properties of hybrid carbon fiber reinforced composites materials.

2. METHOD

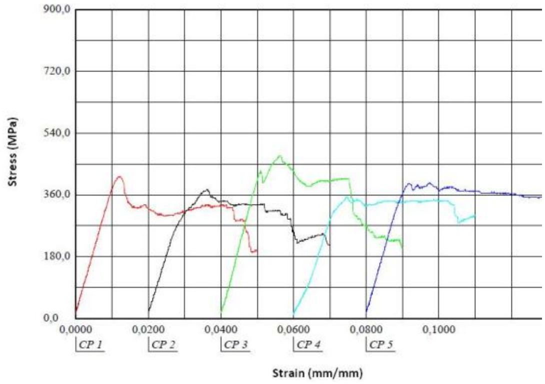
This study focused on a carbon/nano-modified epoxy system laminates. The fiber reinforcement was a plain carbon fiber with density of 200 g/m^2. The epoxy system was DGEBA, from Hunstman Inc. The graphene nanosheets was obtained from an expandable graphite (HC 11 IQ) supplied by Nacional Grafite. The nanoparticles concentrations in were 0 wt%, 1 wt%, 2 wt% and 3 wt%. To properly disperse graphite nanosheets stacks into the polymer, it was used a high shear mixer and an ultrasound. A degassing stage was required to eliminate bubbles generated during the shear mixing.

Hand lay-up technique was used to impregnate and laminate the composite structures. The carbon fiber volume fraction was around 50%. Twelve carbon fiber plies were impregnated with graphene nanocomposites and stacked. After the lamination procedure, composites were cured at 80^o and then, a post cure at 100^o, was applied for 1h.

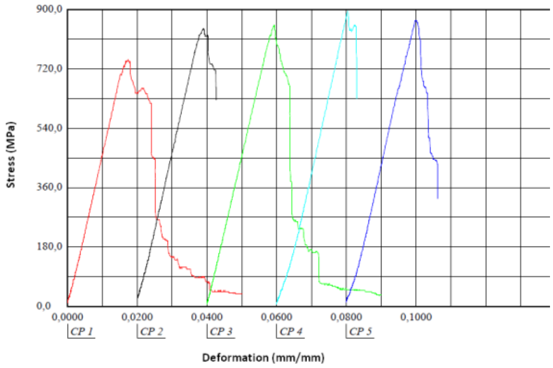
Mechanical characterization was performed considering the ASTM D 790 three point bending test. Ten specimens of each experimental condition were tested. Statistical analysis – One-Way Analysis of Variance (ANOVA) and *Bonferroni* test - was performed to verify if there was significant difference regarding the experimental conditions.

3. RESULTS AND DISCUSSION

Three sets of bending tests were performed on the hybrid composites laminates to observe the effect of graphene nanosheets on the flexural behavior of the composites. Figure 2 shows stress-strain curves for three-point bending tests of some specimens in each condition: (a) 0wt%; (b) 1wt%; (c) 2wt%; (d) 3wt%.



(a)



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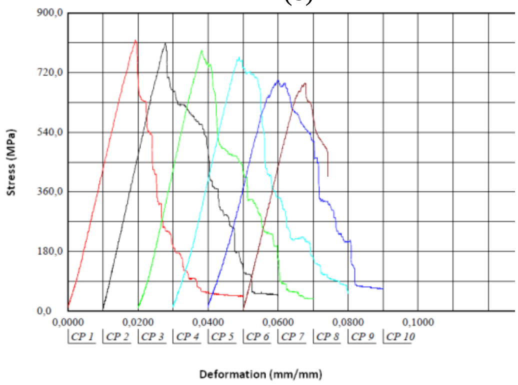

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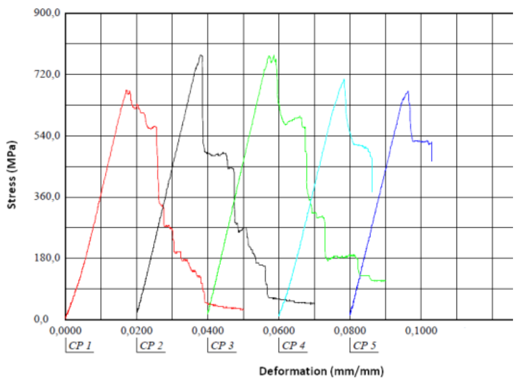

(d)

Figure 2. Stress-strain curves for three-point bending tests. (a) 0wt%; (b) 1wt%; (c) 2wt%; (d) 3wt%

Table 1 shows the maximal strength and flexural modulus values for the experimental conditions. ANOVA was conducted to verify statistical difference among the experimental groups and *Bonferroni* test was performed to localize these differences. The results for the *Bonferroni* statistical test are summarized in Tab. 2 and 3.

Table1. Experimental results for bending properties (n=10)

Experimental Condition	Maximal strength (MPa)	Standard Deviation	Flexural Modulus (MPa)	Standard Deviation
0 wt%	158.6	10.72	14010	815.1
1 wt%	285.6	12.19	16300	570.0
2 wt%	277.2	14.34	16069	349.4
3 wt%	292.1	15.03	15890	649.9

Table2. Bonferroni statistical test for maximal strength

Group (A)	Group (B)	α value
0 wt%	1 wt%	0.00
0 wt%	2 wt%	0.00
0 wt%	3 wt%	0,00
1 wt%	2 wt%	1.00
1 wt%	3 wt%	0.65
2 wt%	3 wt%	1.00

Table 3. Bonferroni statistical test for flexural modulus

Group (A)	Group (B)	α value
0 wt%	1% wt	0.00
0 wt%	2% wt	0.00
0 wt%	3% wt	0.00
1 wt%	2% wt	1.00
1 wt%	3% wt	1.00
2 wt%	3% wt	0.07

As shown in Tab. 2, significant increase (α=0.00) in the composites maximal strength was observed for all hybrid composites when compared to the control group (0 wt%). These results show that the addition of small concentrations of graphene nanosheets in polymeric matrix of fibrous composites can improve maximal strength. This improvement may be related to the presence of nanosheets located at the surface of the carbon fibers, which can enhance the interfacial properties between the matrix and the fibers (Carvalho *et al.*, 2009; Kornmann *et al.*, 2005). The increase observed in this study, related to maximal strength, was 80%, 75% and 84% with the dispersion of 1 wt%, 2 wt% and 3 wt% of graphene nanosheets, respectively. These values are better than those observed by Carvalho *et al*. (2009) that verified a maximal improvement of 1.78% in peak stress. This difference can be due the dispersion method. According to Yasmin *et al.* (2006), the dispersion method of nanosheets in a matrix plays a key role in the improvement of both physical and mechanical properties of the resultant nanocomposite. While Carvalho *et al*. (2009) used a high shear mixing to disperse nanoparticles, we performed a combination of high shear mixer and ultrasound. The association of the methods lead to better nanoparticle dispersion and, thus, better mechanical properties.

From the data described in Tab. 3, it is clear that all hybrid composites showed significant (α=0.00) improvement in flexural modulus when compared to the control group (0 wt%). By the dispersion of 1 wt%, 2 wt% and 3 wt% of graphene nanosheets, respectively, the increase of flexural modulus was almost 16%, 15% and 13%. Probably, graphene nanosheets restricted the mobility of polymeric chains in the interface between the fiber and the matrix, allowing better stress distribution to carbon fibers (Lin et al., 2006).

Among hybrid nanocomposites (Tables 2 and 3), there is no significant difference on the maximal strength and flexural modulus values. This can be due to the fact that the same dispersion process were performed in all cases. There, the dispersion process parameters has to be modified according to the graphene concentration, allowing better nanoparticles dispersion.

4. CONCLUSIONS

This work focuses on the study of effects of graphite nanoparticles on the bending properties of hybrid carbon fiber reinforced composites materials. High shear mixer and ultrasound were used to disperse the carbon based nanoparticles into polymeric matrix. The results showed that small weight percentages of this kind of nanoparticles (1 wt%) lead to an exceptional improvement on maximal strength - 80% - and flexural modulus - 16%. These improved properties of hybrid composites can be attributed to the presence of nanoparticles at the surface of carbon fibers, since it helped increase interfacial properties between the matrix and fibers.

5. ACKNOWLEDGEMENTS

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