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# Tensile and Flexural Properties of Hybrid Graphene Oxide / Epoxy Carbon Fibre Reinforced Composites

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**Abstract.** In this study, nano-sized graphene oxide sheets were homogenously dispersed via sonication methods in epoxy followed by vacuum resin infusion for the fabrication of the epoxy, graphene oxide (GO) and micro-sized carbon fibre reinforced nanocomposites (EP/CF/GO). Graphene oxide concentrations ranging from 0.1 – 0.5 wt. % were studied to investigate the effect on tensile and flexural strength. It was observed that the tensile strength of the EP/CF decreased with the addition of GO but increased with GO weight concentration in the nanocomposites studied from 498MPa to 519 MPa for the inclusion of 0.1 to 0.5 wt.% GO respectively. The 0.5 wt. % EP/CF/GO recorded a 10% increase in Young's modulus compared to the classical epoxy / carbon fibre composites, and similar trend was observed for the flexural properties. However flexural strength of the GO samples did not surpass the control sample (epoxy /carbon fibre composites) with the 0.3 wt.% GO samples (EP/CF/GO) providing the greatest flexural strength of >580 MPa compared to the 0.1 wt.% and 0.5 wt.% GO samples.

## 1. Introduction

The development in carbon based fillers since the discovery of graphene has demonstrated significant improvement over the past decade. This has triggered interest and increasing implementation within commercial applications for both textile and engineering hybrid composites [1-4]. Use of reduced graphene and graphene oxide (GO) in epoxy-carbon fibre reinforced composites is still at infancy stages has been limited however due to the challenges in processing and dispersion of the fillers along with the high price associated therewith [5]. Homogeneous dispersion of the filler within the polymer and the strong interfacial interactions required between the filler and the matrix are the two biggest concerns when fabricating polymer nanocomposites [6].

The oxygen groups within GO offer and allow for a versatile, less fastidious and enhanced chemical cross-interlocking with the polymer chains [7]. The oxygen functional groups that GO possesses on its basal planes and edges permit it to be manipulated, exfoliated and functionalised to yield well-dispersed solutions of graphene oxide sheets [8-10]. Various studies have already presented GO to improve the polymer matrix material mechanical properties [11-13], and have struggled so far to achieve a superior dimensional performance and relative cost benefit to micro sized carbon fibre composites (CFCs) [14]. Since the inclusion of GO in epoxy has presented improved mechanical and electrical properties with reference to the unreinforced epoxy, the filler will potentially carry improvements in a fibre composite

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depending on the interfacial interaction. Researchers have therefore started to investigate combining GO nanofillers with the micro sized carbon fibre fillers [15-17]. This aim of this study is to experimentally investigate the combination of established carbon fibre reinforcement with graphene oxide to further enhance the hybrid material mechanical properties.

## 2. Methodology

### *2.1. Materials and Samples Manufacturing*

A commercially available high performance bisphenol-A-(epichlorhydrin) based epoxy resin specifically formulated for use in vacuum resin infusion from Easycomposites (IN2 Epoxy Infusion Resin[@]) combined with a polyoxypropylendiamin based hardener from Easycomposites (AT30 Epoxy Hardener – Slow[@]) was chosen for the matrix. Graphene oxide (GO) flakes, 15-20 sheets with 4-10% edge-oxidized from Sigma-Aldrich (796034 Aldrich) was employed in this investigation. The 3k 2/2 Twill Carbon Fibre was obtained from Easycomposites.

The composite samples were manufactured through the vacuum resin infusion method. Concentrations of 0.1 wt. %, 0.3 wt. % and 0.5 wt. % were initially dispersed within methanol with the use of a sonication bath for 1 hour to allow for later dispersion of the GO in the Epoxy. Once fully dispersed, the solution was then homogenously dispersed within the bisphenol-A-(epichlorhydrin) based epoxy together with the hardener using a magnetic stirrer and manual mixing to allow for slow solvent evaporation. This was followed by the vacuum resin infusion process with 6 layers of the carbon fibre textile layered within a mould and left to cure. A reference sample without any GO was also manufactured, that is, EP/CF, EP/CF/GO with 0.1 wt. % GO, EP/CF/GO with 0.3 wt. % GO and EP/CF/GO with 0.5 wt. % GO.

### *2.2. Mechanical Testing*

The manufactured samples were machined to 250x25mm for the tensile test and 100x15mm for the flexural test in accordance to the respective standard regulation ISO 527-4 tensile test [18] and ISO 178 3-point bend test [19]. The samples underwent a 3-point bend flexural test in accordance to ISO 178 at 2 mm/min and tensile test in accordance to ISO 527-4 at 1 mm/min [18-19]. We used a Instron Model 3382 universal testing machine to carry out the tensile and flexural testing.

## 3. Results and Discussion

### *3.1. Tensile Properties*

The results from the tensile test conducted on the EP/CF composites with different wt. % of GO is displayed in Figure 1. The data represented is an average from the test samples recorded from the repeated tests. The concentrations of GO can be seen to have little or contrasting effects on the EP/CF based composite performance. Figure 1 indicates the non-reinforced EP/CFC sample to have the highest tensile strength. However, the Young Modulus can be seen to improve for the 0.3 wt. % and 0.5 wt. % concentrations of GO relative to the EP/CF sample. A comparison of the ultimate tensile strength (UTS) and Young's modulus is illustrated on Figure 2.

The increase in concentration of GO observed a decreasing effect on the extension of the specimen at the point of failure. The EP/CF ruptured after an extension of 5.35mm in comparison with the EP/CF 0.1 wt.%, 0.3 wt.% and 0.5 wt.% EP/CF/GO samples breaking at 4.73mm, 4.57mm and 4.51mm respectively. The materials are therefore appearing to become slightly more brittle with increase in GO concentration. This is shown in the increase of Young's Modulus results illustrated in Figure 2 for the 0.3 wt.% and 0.5 wt.% EP/CF/GO reinforced samples.

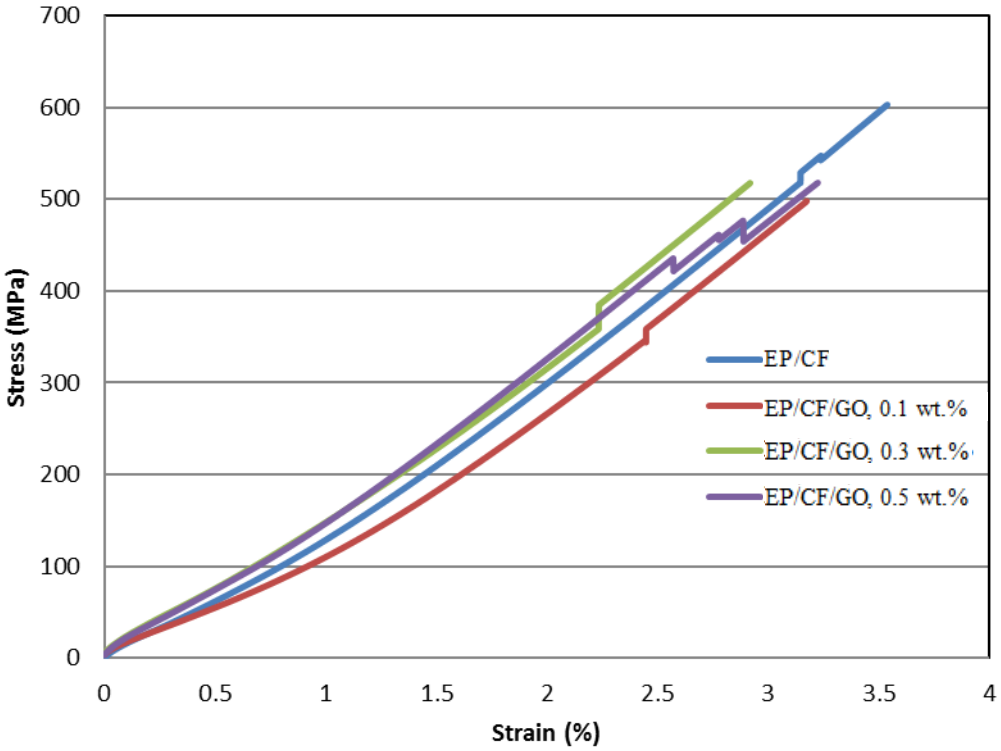


Figure 1: Stress vs strain from tensile test carried out on EP/CF based composites with varying GO concentrations

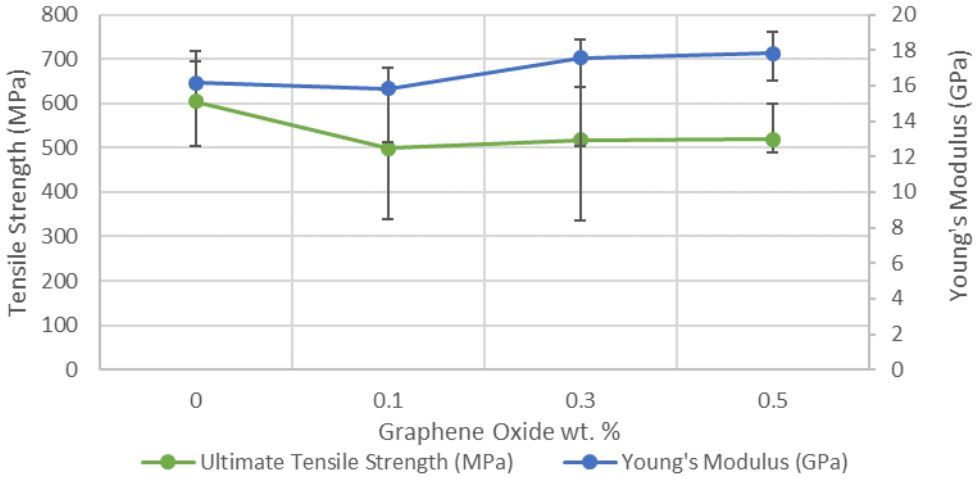


Figure 2: Tensile strength and Young's modulus of EP/CF based composites with varying GO wt.% concentrations

Figure 1 and Figure 2 both demonstrate the minimal effect the GO concentrations appeared to have on the EP/CF based material performance. Furthermore, the significant error bars indicate a high variety in the specimen performance. There was therefore a limitation with the material fabrication consistency. Further analysis is required to analyse the samples and the fabrication process. A possible reason could be due to poor or inconsistent bonding between the GO and CF, which is subject to further investigations. The slight increase of 11% in Young's modulus and UTS increase from 498.2MPa for the 0.1wt.% sample to 518MPa for the 0.5wt.% sample clearly demonstrates a potential material augmenting tensile strength performance.

### *3.2. Flexural Properties*

The results from the varying concentrations of GO reinforcement on the EP/CF composite from the 3-point bend flexural technique are illustrated in Figure 3. The data represented is an average of the repeated tests for each sample. The EP/CF sample without GO reinforcement displayed the best flexural performance for the EP/CF sample. However, the flexural modulus displayed a marginal improvement with the addition of GO filler. The effect of GO concentration on flexural strength and flexural modulus is illustrated in Figure 4.

The flexural stress vs strain relationship is displayed on Figure 3. The EP/CF sample demonstrated the best performance and the EP/CF with 0.1 wt.% GO clearly demonstrated best performance for the grapheme reinforced composites. The 0.3 wt. % GO and 0.5 wt. % GO samples are seen to only differ marginally.

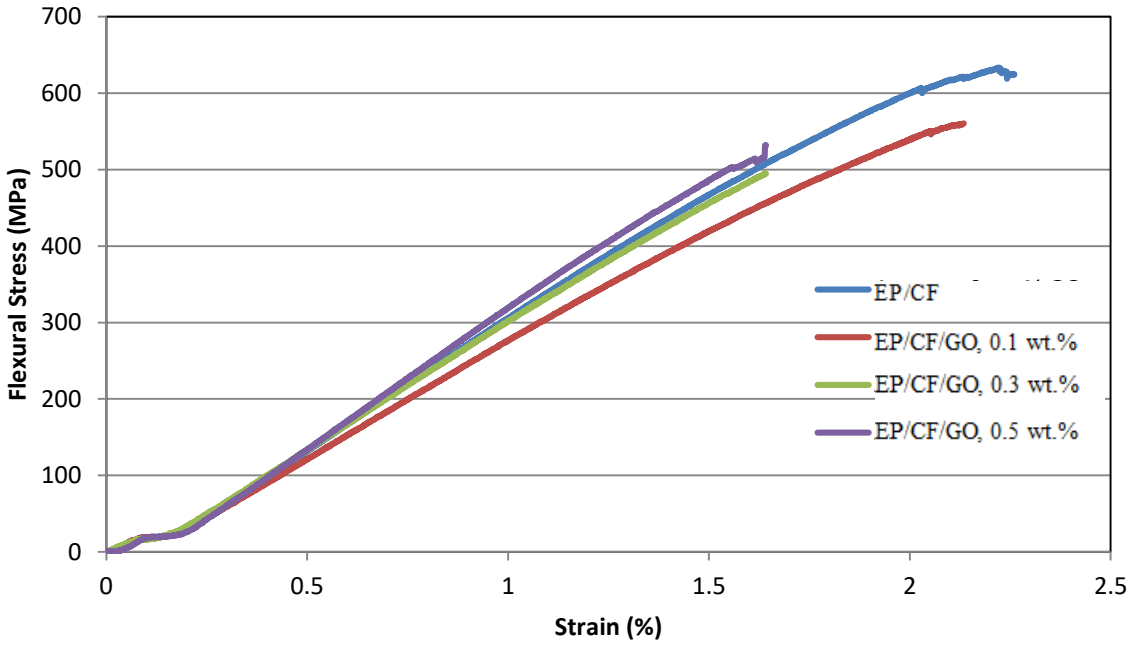


Figure 3: Flexural stress vs strain plot from 3-point bend test of EP/CF based composites materials with varying GO concentrations

As shown in Figure 4, the addition of 0.1 wt. % of GO in the EP/CF composite presented a decrease of 7% in flexural strength from neat EP/CF sample from 602MPa to 560MPa. The slight increase of 0.3 wt. % GO displayed an increase of 4% from the 0.1 wt. % GO sample to 582MPa, which is however still a decrease from the EP/CF sample. The then 9% decrease to 0.5 wt.% GO sample would indicate a performance threshold in GO concentration. Although the flexural strength between the GO reinforced samples displayed a slight increase, no sample improved performance from the EP/CF sample.

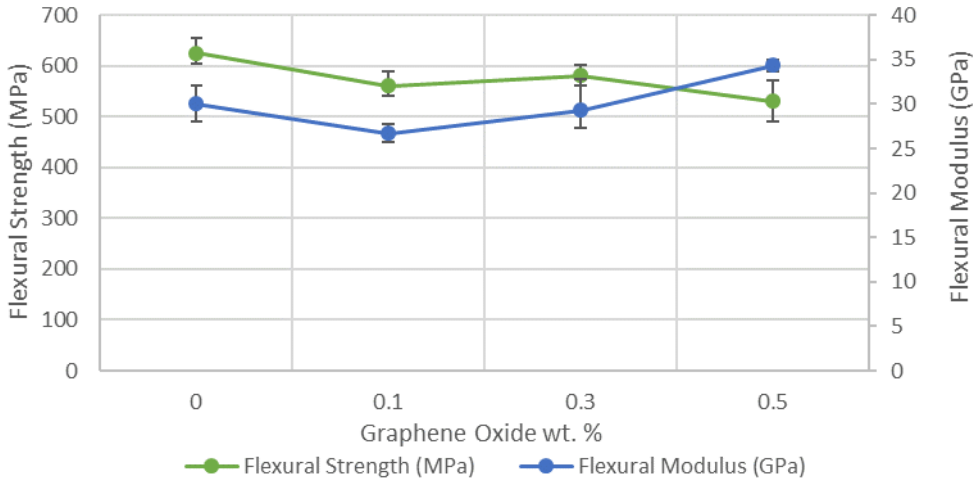


Figure 4: Flexural strength and modulus of EP/CF based composites with varying GO wt.% concentrations

However, as shown in Figure 3 and Figure 4, the use of GO as a filler displayed an increase in flexural modulus. Initially the 0.1 wt. % GO sample displayed a decrease in bending modulus from the EP/CF sample, but the 0.3 wt. % GO and 0.5 wt. % GO samples revealed a 10% and 30% increase from the 0.1 wt. % GO sample respectively. The 0.5 wt. % GO sample with a flexural modulus of 34.3GPa demonstrated a 14% increase from the reference EP/CF sample. The increase in stiffness however displayed a decrease in overall flexural strength from the EP/CF sample.
This is part of an ongoing study. The analysis will further comment on microstructures on broken surfaces, microscopy on samples surface, thermal and electrical conductivity all due to the varied concentration dispersions of the GO on epoxy samples.

## 4. Conclusion

The initial findings from this study have appeared to show little effect from the incorporation of GO in a EP/CF composite. In comparison to the reference EP/CF material, the GO samples did not show any improvement in tensile strength or flexural strength. However, a minor improvement in Young's modulus and flexural strength were observed with the addition of the GO into the EP/CF sample. The increase in GO concentration did have a marginal effect on tensile and flexural strength when solely comparing the different GO concentrations. A limitation with the bonding difficulty and interfacial interaction between the GO dispersed within the epoxy and the CF textile is blamed for the decrease in tensile and flexural strength. This is an ongoing study and these early stage results eludes to the potential to improve the epoxy/carbon fibre composites both tensile and flexural strength while still opening material tailoring opportunities for toughness and ductility improvements. Further investigation into the fabrication method is required to improve bonding and interfacial interaction between the GO dispersed within the epoxy and the carbon fibre textile.

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