Mechanical Characterization of Carbon Fibre and Graphene Oxide Reinforced Epoxy Hybrid Composite

Md. Nazmus Sakib, AKM Asif Iqbal, and Dewan Muhammad Nuruzzaman

Abstract In this study, graphene oxide (GO) and carbon fibre (CF) reinforced epoxy hybrid composite has been fabricated by vacuum resin infusion method and the influence of GO reinforcement on the tensile and flexural properties has been investigated. Three different concentration of GO 0.2, 0.4 and 0.6 wt% were used to develop hybrid composite samples. The results show that both the tensile and flexural strength increase once GO is added to the epoxy-CF composite. Among the three different concentration of GO, 0.4 wt% GO reinforced hybrid composite exhibits superior mechanical properties and can be considered as the optimum value in augmenting the mechanical performance of the hybrid composite.

Keywords Graphene oxide (GO) · Epoxy · Nanocomposite · Mechanical properties · Tensile strength

1 Introduction

Graphene, as stated as the "wonder material" has demonstrated its potential in developing high strength structural composites [1]. Since its invention, significant improvement is observed in the carbon-based fillers that usually use to develop composites. This accelerates the interest to the industries in developing hybrid composite based on graphene materials for commercial applications [2–5]. However, due to the challenging processing techniques and the high fabrication cost, the use of graphene and graphene derivatives are still limited [6]. Epoxy resin possesses outstanding mechanical and thermal behaviour. These thermoset polymers are chemically resistant and considerably cheap, therefore, can be used as the matrix of the composite [2]. Yet, the inherent brittleness characteristics make epoxy vulnerable to produce crack and restrict its application in structure. To overcome this challenge, researchers employed fillers in epoxy to make it composite and found tremendous

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improvements in its mechanical properties [7–10]. Nevertheless, uniform distribution of the reinforcing fillers within the polymeric base is a major concern while developing epoxy-based polymer matrix composite [8]. This affects the uniformity of strength over the composite surface. Moreover, the strong interfacial interaction is another important requirement for successful composite fabrication [11]. Due to the 2-dimensional nature of the graphene and its atomic level layer, this material exhibits its potential to disperse uniformly to the epoxy matrix. Graphene also possesses high surface area, therefore, a small amount of graphene can cover to the whole surface of the composite which also benefits to obtain strength evenly to the entire composite surface [1]. Among the different graphene derivatives, graphene oxide (GO) is one of the popularly used material to develop polymer composite. The oxygen functional groups exist within GO enhances the chemical bonding with the polymer due to its flexible nature [12]. The oxygen groups usually exist on the basal planes and edges of the GO that eventually help to occur the manipulation, exfoliation and functionalisation to produce evenly-distributed solutions of GO on the polymer matrix [13–15]. Various studies have already demonstrated the positive impact of using GO fillers on the polymer materials in terms of enhancement of mechanical and functional properties, however, its impact on developing hybrid composite with carbon fibre is still a matter of concern [16–18]. This is because the desired dimensional properties have not been achieved yet once GO is used to micro-sized carbon fibre composites (CFCs). Moreover, the cost-benefit is another important issue for developing such hybrid composite [19]. According to the previous research, the addition of GO filler to epoxy exhibits its superiority over the unreinforced resin in terms of mechanical and electrical properties [20–22]. Therefore, it is expected that the filler may potentially improve the properties of the fibre composite if a proper interfacial interaction is achieved. Therefore, in this study, GO filler and carbon fibre (CF) reinforced epoxy matrix hybrid composites have been developed by vacuum resin infusion method and their mechanical properties such as tensile and flexural properties have been determined.

2 Experimental

Epoxy resin bisphenol-A and a curing agent (Hardener HY 956) were used in this study. Graphene oxide (GO) powder and 3 k 2/2 twill carbon fibre were used as the reinforcement materials. At first, three different concentrations of GO of 0.2 wt%, 0.4 and 0.6 wt% were dispersed in the acetone. Once the GO is fully dispersed, a specific amount of epoxy and curing agent was added into the mixture. The mixture was then mixed manually and by using magnetic stirrer followed by sonication process for one and half hour. The mixture was then placed on top of a hotplate at the temperature of 50 °C for two hours to remove the solvent by evaporation. The epoxy-GO solution with different concentration of GO was then obtained.

In the second stage of fabrication of hybrid composite, 4 layers of 3 k 2/2 twill carbon fibre were placed in a mould and then the epoxy-GO solution was added

Table 1 Composition of different composite materials

Sample	Composition
S1	Epoxy + Carbon fibre (EP + CF)
S2	Epoxy + Carbon fibre + 0.2% GO (EP + CF + 0.2% GO)
S3	Epoxy + Carbon fibre + 0.4% GO (EP + CF + 0.4% GO)
S4	Epoxy + Carbon fibre + 0.6% GO (EP + CF + 0.6% GO)

over the carbon fibre through the vacuum infusion technique. The prepared hybrid composite was kept in the mould for 24 h to be cured. Besides, a sample with only epoxy and carbon fibre (without any GO) was prepared as a reference. The compositions of the samples are shown in Table 1. The fabricated hybrid composite was cut to prepare samples in conducting tension and bending test. Both the tensile and bending tests were performed in a universal testing machine as per the guidelines provided in ASTM D3039 and ASTM D7264 respectively. For the tensile test, a 100 kN load cell was used and a deflection of 0.5 mm/min was maintained while 1 mm/min deflection was maintained for the 3-point bending test.

3 Results and Discussion

Figure 1 depicts the tensile test result of the CF and GO reinforced epoxy composites with different wt% of GO while Fig. 2 illustrates the comparison of tensile strength and elastic modulus of different types of samples. Three tests for each sample has been performed and the mean value is taken and presented in the result. The results in

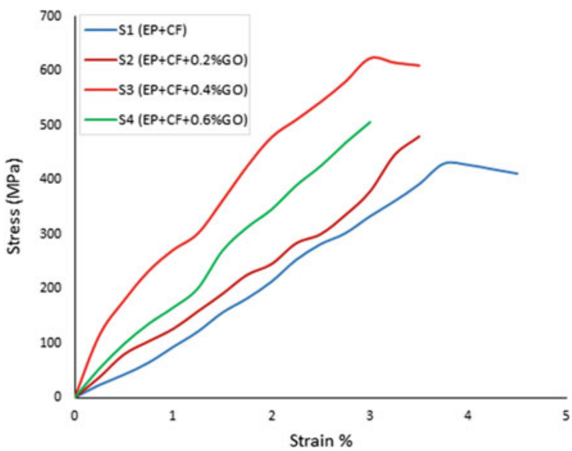

Fig. 1 Tensile stress-strain diagram of hybrid composite with different wt% of GO

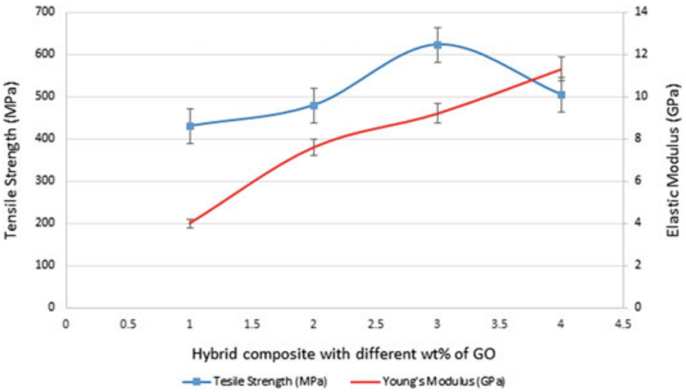

Fig. 2 Tensile strength and elastic modulus of hybrid composite with different wt% of GO

Figs. 1 and 2 demonstrate that the hybrid composite possesses greater strength once GO is added to the epoxy system. The increase of strength becomes in the range of 3–44.8% depending on the wt% of the GO. Among the three hybrid composite samples, sample S3 which is composed of 0.4 wt% of GO exhibited superior strength in tensile loading in comparison to other compositions. This hybrid composite exhibited around 44.8% increment of tensile strength than that of the epoxy-carbon fibre composite. Besides, this composite sample showed considerably higher elastic modulus than S1 and S2 samples but lower than that of the S4 sample. From Fig. 1, it is observed that the increasing percentage of graphene oxide results in an elongation reduction of the materials at the fracture point. The epoxy-carbon fibre composite sample S1 exhibited the highest elongation of 4.25 mm before it ruptured while the breaking of hybrid composite samples S2, S3 and S4 were observed at the extension of 3.5 mm, 3.5 mm and 3 mm respectively. This indicated that the materials are losing ductility with an increase in GO concentration. Among all the samples, hybrid composite sample S4 which is composed of 0.6% GO demonstrated the lowest elongation at the point of fracture indicated that the materials gained the highest brittleness. The above results clearly indicate that the concentration of GO above 0.4% degrades the materials mechanical properties in terms of tensile strength and ductility. The existence of a higher percentage of GO reduces the ductility of the material that severely affects the tensile properties of the hybrid composite materials. Therefore, the percentage of the materials used in sample S3 may be considered as the optimum value in such composites.

Figure 3 demonstrates the flexural stress-strain relationship of all the fabricated hybrid composites samples. The results presented in the figure is the average of three repeated tests. All the hybrid composite show higher flexural strength than that of the epoxy-carbon fibre composite. The addition of GO to the epoxy-carbon fibre composite increases the flexural strength from 13.7 to 50.3%. Moreover, among the different hybrid composite samples, sample S3 which is composed of 0.4 wt% of GO demonstrated greater flexural strength in comparison to other samples. This

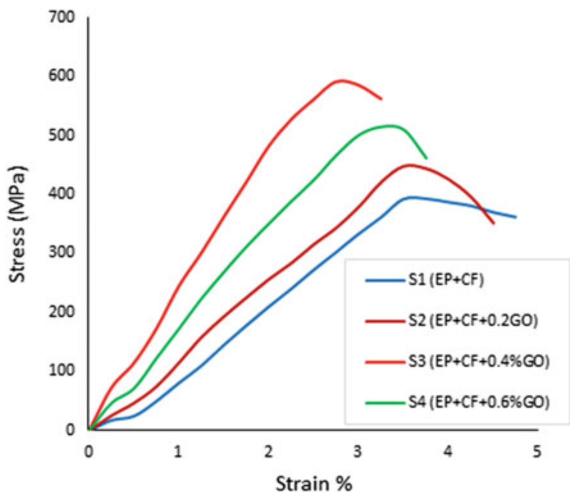

Fig. 3 Fexural stress-strain diagram of hybrid composite with different wt% of GO

composite exhibited a 50.3% flexural strength enhancement than that of the epoxy-carbon fibre composite. Figure 4 represents the comparison of flexural strength and flexural modulus of all the fabricated composite samples. It is observed in Fig. 4 that the hybrid composite sample S3 demonstrated greater flexural modulus as compared to other composite samples.

From the above results, it is certain that the inclusion of GO to the epoxy-carbon fibre composite helps to increase the mechanical properties. Besides, the addition of 0.4% GO demonstrated the superior tensile and flexural strength. It is also clearly seen that the concentration of GO beyond 0.4% reduces the ductility of the material and degrades its mechanical properties. Therefore, it can be concluded that the concentration of GO of 0.4 wt% is the optimum value that is useful in augmenting the mechanical performance of the hybrid composite.

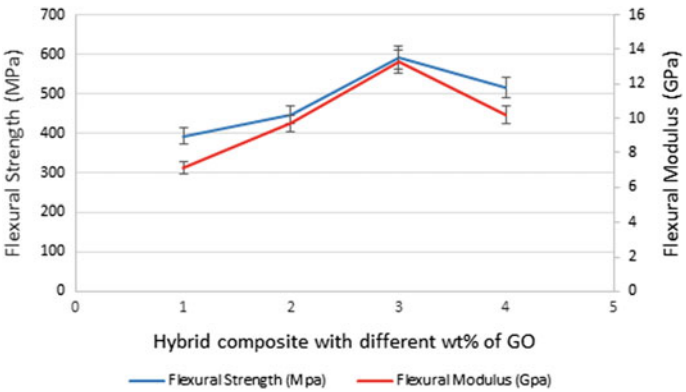

Fig. 4 Fexural strength and flexural modulus of hybrid composite with different wt% of GO

4 Conclusions

This study investigated the mechanical characterization especially the tensile and flexural strength of the epoxy-carbon fibre-GO hybrid composite with different concentration of GO. The hybrid materials were fabricated through a vacuum resin infusion method. The results showed that the addition of graphene to the epoxy-carbon fibre composite significantly improved the mechanical properties. Besides, the hybrid composite sample S3 which is composed of 0.4 wt% GO exhibited superior tensile and flexural strength in comparison to other composite samples. This hybrid composite also showed greater tensile and flexural modulus. Therefore, it can be concluded that the concentration of GO to 0.4 wt% is the optimum value which provides a positive impact and augments the overall mechanical performance of the hybrid composite.

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