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Comparative study on the enhancement of thermo-mechanical properties of carbon fiber and glass fiber reinforced epoxy composites

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ABSTRACT

This work is the part of a study on the enhancement of thermo-mechanical properties of Epoxy by incorporating carbon and glass fiber and preparing epoxy composites and are rarely used before. The composite/laminates of Carbon fiber/Epoxy (CFE) and Glass fiber/Epoxy (GFE) having 1.5 mm thickness were prepared by hand layup vacuum bagging technique. The fiber-epoxy ratios for preparation of CFE and GFE were 40:60, 50:50 and 60:40 by weight percent. Thermal properties of the composites were investigated using Differential Scanning Calorimetry (DSC), while mechanical properties were examined using Universal testing machine (UTM) in terms of tensile strength and Young's modulus. The tensile strength of CFE were enhanced to 844.44%, 951.11% and 1122.22% by incorporation of carbon fiber having 40, 50 and 60 wt%, respectively. While the increase of 156.66%, 171.10% and 197.77% in tensile strength of GFE was noticed when 40, 50 and 60 wt% of glass fiber was incorporated. The glass transition temperature (Tg) increased from 71 °C of neat epoxy to 110 °C for both the epoxy composites. Overall, the properties of CFE were found to be much superior to that of GFE.

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1. Introduction

Epoxy resin is very significant as a matrix-binder in composites. The addition of fillers and fibers in it as reinforcements improves its mechanical and thermal properties [1]. It has been reported that the addition of carbon fibers increases its mechanical and thermal properties significantly [2]. Generally, such composites are made by conventional techniques without having negative effects on density and ageing of matrix phase [3]. In addition, these exhibit high strength to weight ratio, better fatigue life, corrosion and wear resistance and environment constancy. Owing to such engineering features, these materials are widely used in automotive, packaging, electronics and aerospace industries [4].

There is a susceptibility of mechanical damage when laminated composites are subjected to tension, flexural and impact loads [5]. It can be minimized by improving their inter-laminar properties when the resin matrix along with fiber reinforcement is toughened [6]. Rahmani et al. examined effect of fiber orientation, fiber content, and sum of plies on mechanical properties of various epoxy [7]. Therefore, the co-relation of fiber orientation and resin on laminates with respect to thermo-mechanical properties has also been established by various researchers before.

Keeping all previous work in view, focus of the present study was to investigate thermal and mechanical properties of laminates of Carbon/Epoxy and Glass/Epoxy composites using a particular epoxy, grade of Araldite® LY-5052 which was rarely used earlier. Also, optimizing and identifying ratio of fiber-cloth to resin which may express better mechanical and thermal properties was main task of the study.

2. Experimental

2.1. Preparation of composite laminates

The composite laminates of Carbon/Epoxy and Glass/Epoxy having 1.5 mm thickness were prepared by hand layup vacuum bagging technique [8], using woven fiber-cloths and epoxy resin.

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The laminates were prepared using fabric to resin ratios of 40:60, 50:50 and 60:40 by weight percent. Epoxy wetted pieces of each type of fiber-cloth were placed on each other in a metal mold coated with releasing agent to avoid their sticking. A metal scraper was used for proper wetting of pieces in the mold. In vacuum bagging unit, vacuum of −27 mm of Hg was employed for 5 h and laminates were left in the setup for 24 h. Then, post curing was carried out at 80 °C for 2 h.

2.2. Characterization

The influence of varying weight percent of fibers and epoxy in laminates on mechanical and thermal properties in terms of, Tensile strength (Ts), Tensile modulus (Tm), Strain % and glass transition temperature (Tg) was evaluated. The samples for mechanical testing were prepared as per ASTM standard D-3039. Tensile testing was done with heavy universal testing machine at room temperature. The strain rate was 1 mm/min. This machine can be utilized for tensile, compression and bending testing. Mechanical test was operated along with PC software test Xpert. For Differential Scanning Calorimetry (DSC) testing, DSC 6000 calorimeter equipment was utilized and the samples of each composite sheets were tested from ambient temperature up to 250 °C under inert atmosphere. The inert atmosphere of N_2 was applied for avoiding oxidation and reduction and other environmental factors. The temperature was raised at 10 °C per minute.

3. Results and discussion

3.1. Mechanical properties of composite

The tensile strength, modulus and tensile strain of neat epoxy and its composites are given in Table 1. The laminate having greater fiber to resin ratio i.e. 60:40 shows better strength as compared to others. The higher tensile strength with increasing fiber content indicates proper wettability of the carbon fibers with epoxy. This has caused an increase in inter-laminar strength of the laminates. It happened because of the optimized ratio of fiber to resin was achieved in laminate. And, resulted due to better wettability of fibers with resin. However, the strain of epoxy was also increased interestingly at all ratios with increase of strength [7].

Table 1
Mechanical Properties of Carbon and Glass fibers laminated composite.

Samples	Tensile Strength (MPa)	Tensile Modules (GPa)	Tensile Strain
Neat Epoxy	45	1.84	2.69
Carbon/Epoxy (40:60)	425	8.66	4.95
Carbon/Epoxy (50:50)	473	11.39	4.12
Carbon/Epoxy (60:40)	550	10.62	4.97
Glass/Epoxy (40:60)	111.5	2.89	3.95
Glass/Epoxy (50:50)	122	2.99	4.69
Glass/Epoxy (60:40)	134	3.49	3.54

The tensile strength of pure epoxy enhanced significantly in its laminates with carbon and glass fiber reinforcements. In case of Carbon/Epoxy laminate with fiber to resin ratio of 50:50, it increased from 45 MPa to 473 MPa. The reason for such enhancement implies because carbon fibers are strongly stiff in nature and with proper wettability of fiber and matrix give rise to strong bonding. The fibers restricted the entanglement between the chain of the thermosetting polymer. Furthermore, with the same ratio, the Glass/Epoxy laminate showed value of 122 MPa. The increase in tensile strength was due to the constraining effect of fibers on movement of polymer chains of epoxy. Similarly, the tensile modulus increased remarkably for both the composites. Comparatively, the Carbon/Epoxy composite exhibited tensile modulus much better than Glass/Epoxy laminate because carbon fibers are more stiff and light weight in nature then glass fibers. The tensile strength of Carbon/Epoxy 60:40 increases while the tensile modulus decreases because at this ratio, the tensile strain has also been increased along with tensile strength interestingly. It can be concluded easily that at this ratio the material is more tough along with strength. This is because of the better bonding adhesion between the fiber and matrix interface due to entanglement of polymer chains by fibers and proper wettability of fibers at this ratio. Generally, the tensile modulus is increased by increasing the amount of carbon due to stiff properties of carbon, while carbon interaction between epoxy is not improved reflecting to tensile strength. This is also attribute to the increment of tensile strain.

The strain percentage or elongation of pure epoxy improved much when it formed laminates with Carbon and Glass fabrics. There was an increase of more than 80% in both types of laminates; as presented in Table 1. The drop of tensile strain for Glass/Epoxy (60:40) and Carbon/Epoxy (50:50) was observed because glass fiber need higher percentage of epoxy for its proper wettability to make stronger bonding and the epoxy was not enough at this ratio while the epoxy was higher than optimum requirement for the carbon fiber at this ratio due to which it shows small decrease in tensile strain. The results of tensile properties are in agreement with the work of Rahmani et al. [9] and Cai et al. [10].

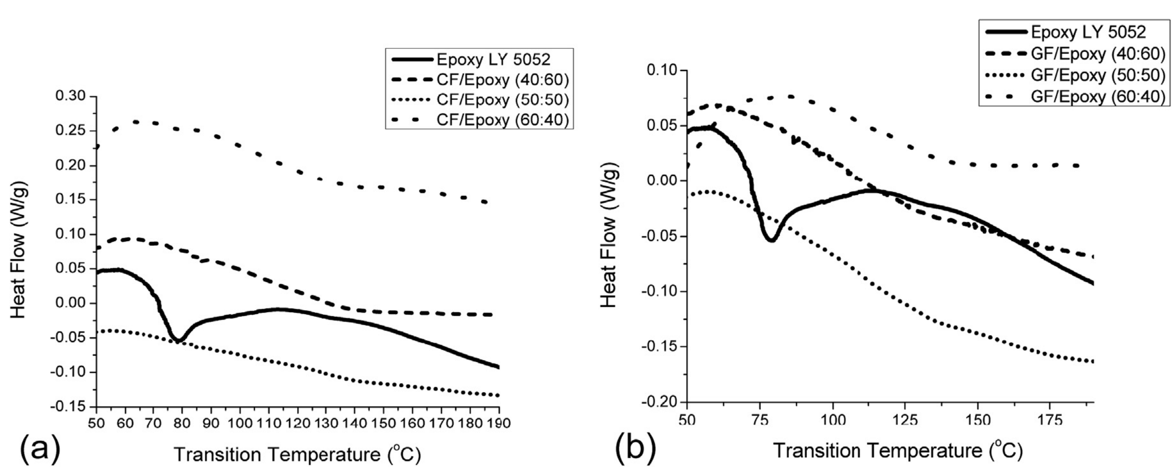

Fig. 1. Plots change in glass transition temperature with different fiber to resin ratios in laminates of (a) Carbon/Epoxy and, (b) Glass/Epoxy.

3.2. Thermal properties of composite

Fig. 1(a, b) shows change in thermal properties of Carbon/Epoxy and Glass/Epoxy laminates due to difference in fiber to resin ratios. The glass transition temperature (Tg) of Carbon/Epoxy laminates increased with increasing wt. % of carbon fibers. The Tg of the pure epoxy-Ly5052 was 71 °C whereas it was found 115 °C for Carbon/Epoxy laminate having fiber to resin ratio 60:40, see Fig. 1(a). Almost, similar change in Tg was noticed for Glass/Epoxy laminates; it can be seen in Fig. 1(b). The increase in Tg of epoxy was due to the incorporation of fibers which have restricted movement of its polymer chains. The restriction movement is attributed by good interaction between fibers and matrix. As a conclusion, this designates that interfacial adhesion between fibers and matrix, which permits efficient stress transfer from matrix to fibers. Similar findings were obtained Chen and co-workers [11] and showed that the binder has successful functioned and contributed to the enhancement of thermal properties of carbon/epoxy composites.

Though, there was no remarkable change in Tg noticed, however Carbon/Epoxy laminates exhibited comparatively better Tg than Glass/Epoxy laminates due to stronger interfacial adhesion between matrix and carbon fibers as compared to glass fibers and matrix. The results are well supported by theory and mechanism explained by Chen et al [11].

4. Conclusions

Mechanical and thermal properties of Carbon/Epoxy and Glass/Epoxy laminates having different fiber to resin ratios were evaluated. In Carbon/Epoxy laminates, both tensile strength and modulus as well as strain% increased with increasing fiber content. Whereas in Glass/Epoxy laminates, the same trend was found. The tensile strength and modulus of Carbon/Epoxy laminates were remarkably higher than Glass/Epoxy laminates regardless of their compositions. The glass transition temperature of both types of laminates irrespective of their mixing ratios, was much better than pure epoxy.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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