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# Evaluation of mechanical properties of hybrid composite laminates reinforced with glass/carbon woven fabrics

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**Abstract.** Polymer composites are sought for their enhanced properties and performance over conventional materials for diverse applications. Glass and carbon fibers are popularly used in polymer composites for their improved properties and lower weight. But carbon fiber being much stronger and costlier, the cost effectiveness of these composites can be ensured by optimal inclusion of carbon fiber in glass fiber composites to achieve requisite performance. This article examines the influence of stacking arrangement on mechanical properties of hybrid composite containing glass and carbon fiber of different strength and stiffness. Two hybrid composites of symmetrical pattern were fabricated; i.e. $[GCGGC]_S$ and $[CGGCG]_S$ having a fixed proportion of carbon fiber and glass fiber. Mechanical characterization was done by hardness, impact, tensile and flexural tests. It is found that hybrid composites with $[GCGGC]_S$ stacking sequence have tensile strength and flexural strength which are marginally more than $[CGGCG]_S$. The $[GCGGC]_S$ lay-up has higher impact strength by 22.8%. However $[CGGCG]_S$ lay-up has higher hardness. The tensile modulus and flexural modulus of $[CGGCG]_S$ are higher by 20% and 36.2% respectively.

*Keywords*: glass/carbon composites, hybrid composites, tensile, flexural and impact strength

## 1. Introduction

Composites are being used in aerospace, automobile, structural, industrial and related applications. Since weight is of concern, so its reduction is necessary across domains of industry; in order to decrease dependence on heavier conventional materials and to achieve greater efficiency. Polymer composites exhibit superior properties such as strength, heat resistance, toughness and abrasion resistance and are lighter than conventional materials such as metals and alloys. They are also more flexible in terms of design and manufacturing. Plastic and composite materials are paving their way into automobile industries usually for nonstructural usage. Light weight composite components can lead to improved fuel efficiency and lower cost in automobiles. Glass fiber reinforced polymer composites (GRPC) reduce weight. Carbon fiber reinforced polymer composites (CRPC) will improve strength and result in additional cut in weight. Fiber glass polymer composite materials have been used for wind turbines, but carbon fibers are being incorporated now. Thus interest in hybrid glass and carbon fiber polymer composite is growing [1-5]. The carbon fibers are expensive which is a major obstacle for its usage. Although being lighter, stronger and stiffer than glass fiber, carbon fibers have lower strain-to-failure compared to glass fibers. Hence, improvement of strain-to-failure can be obtained by adding carbon fibers with glass fibers by means of hybridization. Hybrid composites consist of different reinforcements within the same matrix. Inclusion of carbon fiber in

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glass fiber composites by different stacking sequence have led to enhancement of mechanical performance [6–10]. Czél G and Wisnom MR [11] outlined the influence of carbon layer thickness on failure of unidirectional glass and carbon hybrid composites. Song [12] investigated hybrid carbon/glass and carbon/aramid composites and reported of central carbon layers improving the tensile strength. Zhang *et al*. [3] found that for hybrid composites with carbon layer on the exterior improve the flexural stiffness. Giancaspro *et al.* [13] reported that the flexural strength of glass fibre polymer composites being enhanced by placing carbon fiber at the tensile region. Gomez-del RT *et al.* [14] carried out low impact velocity test on carbon fiber reinforced epoxy composites and observed the mechanical properties to depend on temperature and stacking arrangement. Thomason [15] performed impact test on long glass-fiber reinforced polyamide composites and reported increase in improved impact resistance by increasing the fiber content.

From literature, it is seen that the variation of mechanical properties with stacking sequence of glass and carbon fibers have not been assessed extensively. In this article, two pure composites and two different hybrid composites having different stacking sequence are fabricated with ten layers each by hand lay-up technique. The hybrids have a fixed ratio of carbon and glass fibers consisting of six layers of woven E-glass fibers and four layers of woven carbon fibers. These composites are investigated to determine the hardness, impact, tensile, flexural properties and compared with each other. The different properties of hybrid composites can serve towards specific design requirements.

## 2. Experimental Work

### *2.1. Materials*

For the current investigation, the carbon fiber is bidirectional of 200 gsm, 2×2 twill woven roving of density 1.76 g/cm$^3$ procured from Soller Composites, India. The glass fiber of 360 gsm, plain woven E-Glass of density 2.52 g/cm$^3$ was procured from Owens Corning, India. Composites were fabricated using epoxy having density 1.16 g/cm$^3$ (Diglycidyl ether of Bisphenol A) marketed as Lapox L-12 and hardener (Triethylene tetra amine) marketed as K-6 by Atul Industries, India. The fiber and polymer data are outlined in Table 1.

Table 1. Materials data

| Property | Glass fiber | Carbon fiber | Epoxy |
|---|---|---|---|
| Tensile stiffness (GPa) | 76 | 230 | 4.1 |
| Tensile strength (MPa) | 3100 | 3530 | 110 |
| Strain to failure (%) | 4.5 | 1.5 | 4.6 |

### *2.2 Fabrication of Composite Laminates*

The hybrid composites were fabricated by reinforcement of glass and carbon fibers in epoxy polymer matrix. The ratio of epoxy to hardener was 10:1. The hybrid glass and carbon fiber reinforced epoxy laminates were made of ten layers of which six layers were of glass fibers and four layers of carbon fibers fabricated by hand lay-up method. Roller was used to reduce voids and air bubbles during fabrication of laminates. The composites were kept under a load of 10 kg for 24h at room temperature for initial curing. Uniform thickness was obtained by applying both load and roller.Two laminates of different stacking sequence were fabricated. The hybrid stacking configuration are $[CGGCG]_S$ and $[GCGGC]_S$, where G denotes plain woven bi-axial E-glass fiber and C denotes 2×2 twill woven bi-axial T200 carbon fabric. Figure 1 shows the sequence of glass and carbon fiber of the hybrid composites. Specimens were cut to dimensions as per test specifications and then post cured in oven at 140 $^{O}$C for duration of 6 hours before testing [16].

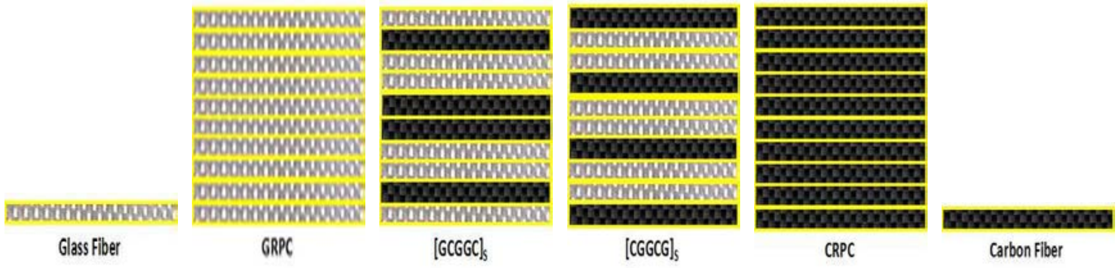


**Figure 1.** Composite laminates

## 3. Results and Discussions

### *3.1 Hardness*

The hardness of the composites was evaluated as per the ASTM D2583 standard using Barcol hardness tester by Barber Colman, USA version GYZJ-934-1. Three specimens were tested and their average value was taken. Figure 2(a) shows the Barcol Hardness Tester and Figure 2(b) shows the hardness of glass, carbon and hybrid composites. It was observed that the hardness of CRPC was maximum and GRPC was minimum. However, the hardness of $[CGGCG]_S$ was higher as compared to $[GCGGC]_S$ . This may be due to higher stiffness of carbon fiber on the outer surface of $[CGGCG]_S$.

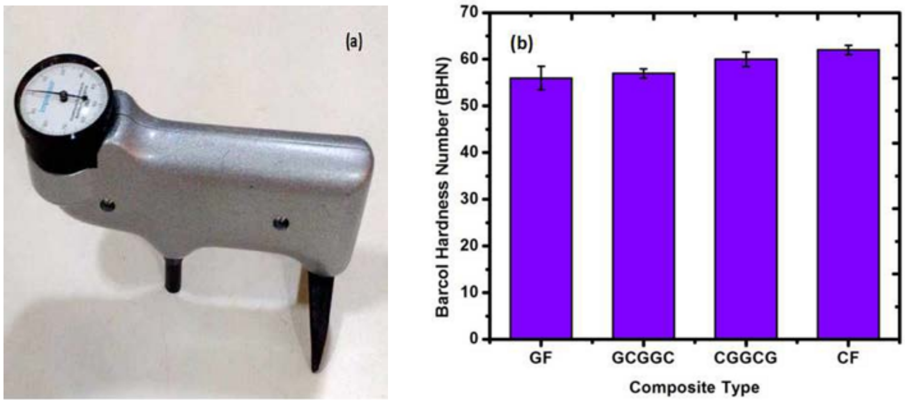


**Figure 2.** (a) Barcol Hardness Tester and (b) Hardness of different composites

### *3.2 Tensile Strength*

Tensile strength and modulus were measured according to ASTM D3039-76 standard. The specimen dimensions were 250 mm (length) × 25 mm (width) × 3 mm (thickness). The tensile test was carried out using Instron 3382 Universal Testing Machine (UTM) at room temperature. The gauge length of 150 mm and cross head speed of 2 mm/min were considered during the test. Three specimens were tested and their average value was taken.

In Figure 3, the tensile stress versus strain and tensile modulus of different composites were shown. It was observed that tensile strength was the highest for CRPC and it was lower for GRPC. However, $[GCGGC]_S$ had higher tensile strength and strain as compared to $[CGGCG]_S$.

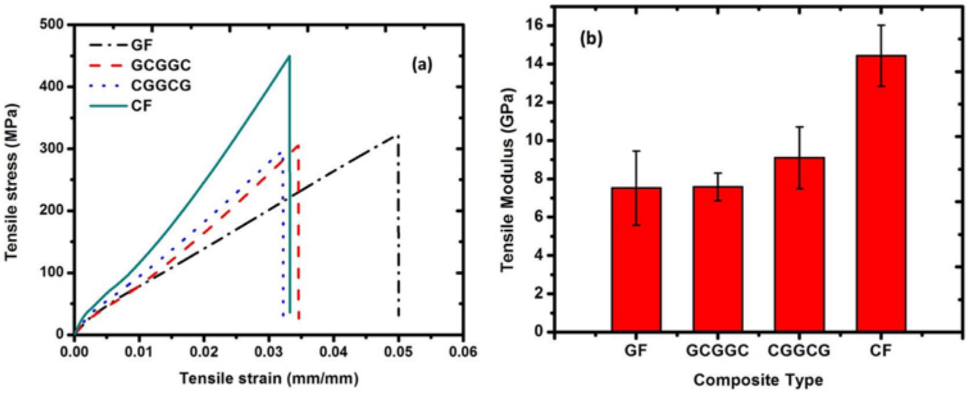


**Figure 3.** (a) tensile stress versus strain curve and (b) tensile modulus of different composites

It was observed that $[GCGGC]_S$ had tensile strength of 305.5 MPa which was enhanced by 2.6% and tensile strain by 7.1% than that of $[CGGCG]_S$. This may be due to high stiffness of carbon fiber at the center of the hybrid composite that improves the strength of the composites. Song [9] reported of enhanced tensile strength by central carbon layers in hybrid composite. However, the tensile modulus was found to be maximum for $[CGGCG]_S$ and higher by 20% as compared to $[GCGGC]_S$.

### *3.3 Impact Strength*

Impact strength of the composites was evaluated by Izod test. In Izod test, the test specimen is placed in vertical position where the hammer (pendulum) strikes the upper tip of specimen. Rectangular specimen of 65 mm (length) × 12.7 mm (width) × 3 mm (thickness) were cut as per the ASTM D256. Three specimens were tested and their average value was taken. Figure 4 shows the impact specimens before and after testing of different composites.

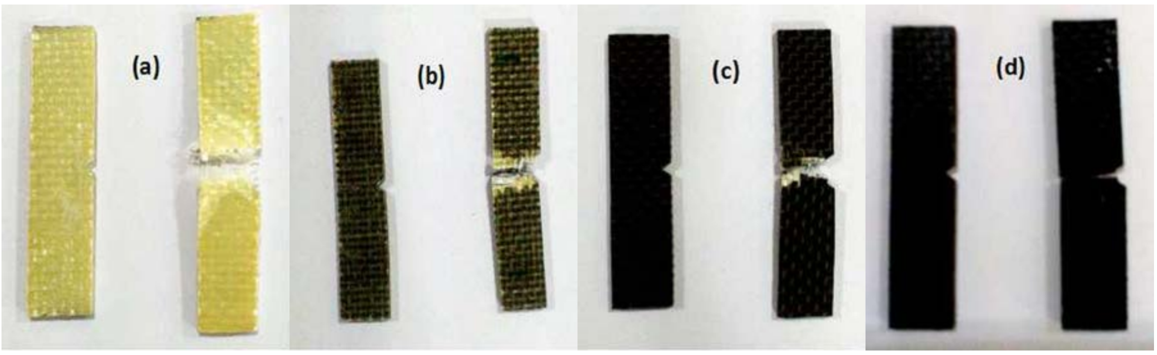


**Figure 4.** Specimens of (a)GRPC, (b)$[GCGGC]_S$, (c)$[CGGCG]_S$ and (d)CRPC before and after impact test.

The Izod test was evaluated using Impact testing machine by S.C. Dey & Co, India shown in Figure 5(a). The toughness of pure glass, pure carbon and hybrid composites are shown in Figure 5(b). The toughness of GRPC is the highest and CRPC is the lowest because of brittleness of carbon fiber. The toughness is 112.8 $KJ/m^2$ for $[GCGGC]_S$ which is higher by 22.8% as compared to $[CGGCG]_S$. This may be due to tougher glass layers absorbing more energy.

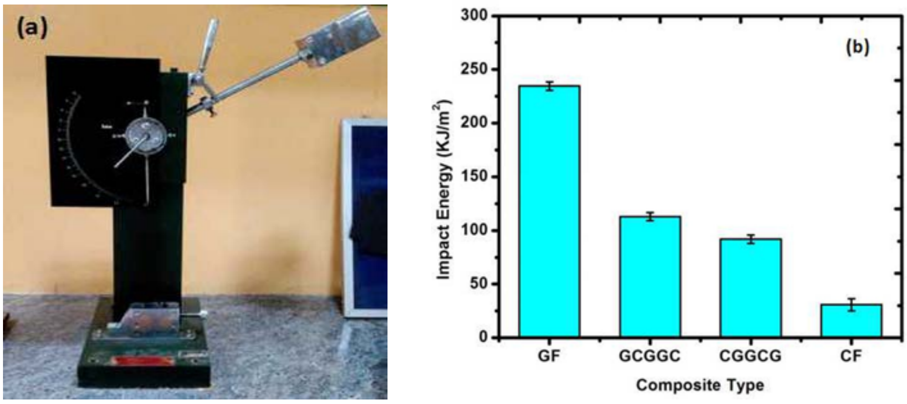


**Figure 5.** (a) Izod Impact Testing Machine and (b) Impact Energy of composites

*3.4 Flexural Strength*

Flexural strength and modulus were measured according to ASTM D7264 standard. The rectangular specimen dimensions were 70 mm (length) × 13 mm (width) × 3 mm (thickness). The flexural test was carried out using Instron 3382 Universal Testing Machine (UTM) at room temperature. The span length of 60 mm and cross head speed of 2 mm/min were considered. Three specimens were tested and their average value was taken. Figure 6 displays the flexural strength versus extension of pure glass, pure carbon and hybrid composites. GRPC shows the lowest flexural strength but has the highest flexural extension whereas CRPC displays moderate flexural strength and lower extension with catastrophic failure. The flexural strength of $[GCGGC]_S$ is 494.1 MPa which is marginally more than $[CGGCG]_S$. However, $[GCGGC]_S$ displays higher flexural extension. $[CGGCG]_S$ displays lower flexural extension with stepped failure. This may be due to bridging action of glass fibers which continue loading even after outer carbon layer has failed.

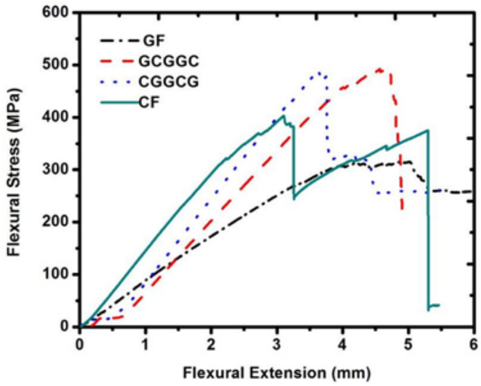


**Figure 6.** flexural stress versus extension behavior of different composites.

In Figure 7, the flexural modulus and flexural extension of pure glass, pure carbon and hybrid composites are shown. $[CGGCG]_S$ has higher flexural modulus by 36.2% than $[GCGGC]_S$ because of higher stiffness of outer carbon layers. Similarly $[GCGGC]_S$ has larger flexural extension by 21.7% compared to $[CGGCG]_S$ due to higher ductility of outer glass layers.

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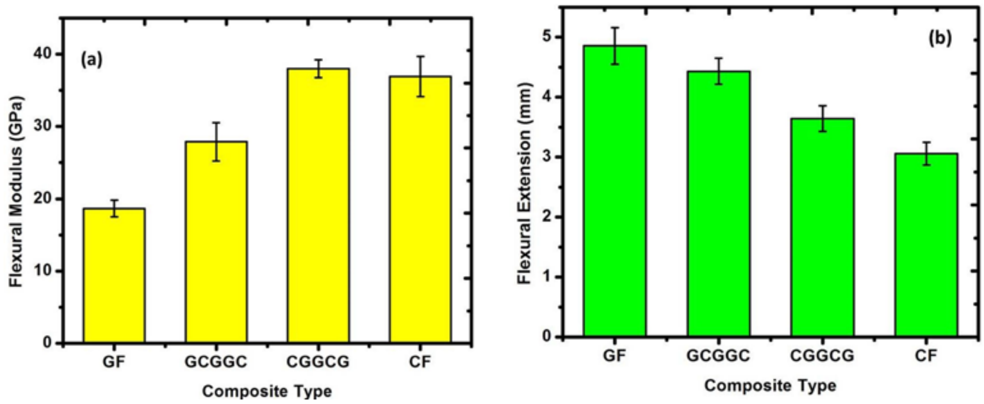


**Figure 7.** (a) flexural modulus and (b) flexural extension of different composites.

## 4. Conclusion

The mechanical properties of hybrid composites $[CGGCG]_S$ and $[GCGGC]_S$ were evaluated and compared with each other. The results are shown below.

a) The tensile strain, toughness and flexural extension of $[GCGGC]_S$ are higher by 7.1% , 22.8% and 21.7% respectively than that of $[CGGCG]_S$.
b) The tensile modulus and flexural modulus of $[CGGCG]_S$ are higher by 20% and 36.2% respectively as compared to $[GCGGC]_S$.
c) The tensile strength and flexural strength of $[GCGGC]_S$ are marginally more than $[CGGCG]_S$.

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