

Improvement of mechanical properties of carbon/glass fiber reinforced polymer composites through inter-ply arrangement

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Abstract. Fibrous reinforced polymer composites are used in automobiles, aerospace, railway, marines, construction and mega structures like airport infrastructure and olympics. Carbon fiber reinforced polymer composites (CRPC) are stronger than glass fiber reinforced polymer composites (GRPC). However, the cost of carbon fiber is around four times than glass fiber. Therefore, there is a need to evaluate the mechanical properties of glass/carbon hybrid composites to meet the design requirements and reduce the cost. In this article the effect of glass/carbon fiber ply sequence on mechanical properties were investigated experimentally. Two types of hybrid composites were considered; i.e [G3C2]_s & [C2G3]_s and mechanical properties were evaluated. The composites were fabricated by hand-layup method. The results revealed that the tensile strength has been improved in [G3C2]_s hybrid composite by 11.5% as compared to [C2G3]_s composites. The fracture toughness and flexural strength of [C2G3]_s has been improved by 52.4% and 22.9% respectively as compared to [G3C2]_s composites. Hence, the mechanical properties are sensitive to inter-ply sequence even if the weight fraction of each fiber types is constant.

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

1. Introduction

For high end engineering and conventional applications, the polymer matrix composites have gained popularity in recent times. Nowadays multifunctional and light-weight composite materials are being utilized across fields of engineering industry. Design aspects stress on high-performance and multifunctional composites possessing superior strength, impact resistance, heat resistance, stiffness and abrasion resistance. Fiber reinforced polymer (FRP) composites are 30–40% lower in weight than steel. FRP composites are flexible and adoptable to design considerations and have lower tooling cost. GRPC can reduce the weight of components. However, carbon fibers can further cut down weight and enhance strength. CRPC materials are preferred as they are ultra light-weight while possessing superior strength and stiffness but have lower elongation [1-4]. Due to its high specific modulus, carbon fiber is widely utilized in aerospace applications. Sudden and catastrophic failure occurs without warning and little



residual load carrying capacity makes them unreliable. The strain and impact properties of hybrid composites can be improved by addition of fibers having moderate modulus and better strain like E-glass [5-9]. The high modulus fibers will act as the major load bearing constituent whereas low modulus fiber like E-glass fibers are of moderate strength and lower stiffness with higher elongation. The mechanical properties of the resulting composite are dependent on volume fraction and stacking sequence of different fiber layers. The presence of both of these reinforcements in a polymer matrix combines the benefits of individual fibers and at the same time gets rid of their shortcoming when the fibers act alone and resulting properties may be better or worse than individual fibers that is termed positive or negative hybrid effect respectively [9-13]. Czél and Wisnom [8] have reported for unidirectional glass and carbon hybrid composites pseudo-ductile failure achieved by thin carbon layer. Pandya *et al.* [9] investigated hybrid woven carbon and glass fabric composites and reported of enhancement of tensile strength and strain by having central carbon layers in the hybrid composite. Naik *et al.* [14] experimented with hybrid composite by drop-weight impact test machine and reported of enhanced impact energy. Lopez-Puente *et al.* [15] performed medium and high velocity impact tests on carbon fiber reinforced polymer composites and observed the damage to depend on temperature, impact velocity and the laminate. Li and Xian [16] studied the effect of addition of carbon fibers in ultra-high-modulus polyethylene which showed improved flexural modulus. Onal *et al.* [17] observed volume fraction of carbon fiber in hybrid glass carbon composites to affect flexural strength.

The effect of glass/carbon sequence on hardness, tensile, flexural and impact strength has not been evaluated comprehensively. Therefore, in this article two types of hybrid composites were considered and fabricated by hand lay-up technique. There were total 10 layers of fibers considered for the composites. Out of 10 layers, 6 layers of glass and 4 layers of carbon fibers were considered for hybrid composites. The mechanical properties of pure glass, carbon and hybrid composites were evaluated at room temperature and compared with each other. The evaluated properties will be definitely helpful for different design requirements.

2. Experimental Work

2.1. Materials

In the present investigation, the carbon fiber is bidirectional of 200 gsm, 2×2 twill woven roving of density 1.76 g/cm³ were procured from Soller Composites, India. The plain woven E-glass fiber of 360 gsm and density 2.52 g/cm³ were procured from Owens Corning, India. Composites were fabricated using epoxy (Diglycidyl ether of Bisphenol A) having density 1.16 g/cm³ marketed as Lapox L-12 and hardener (Triethylene tetra amine) marketed as K-6 by Atul Industries, India. The properties of the fibers and polymers are given in Table 1.

Table 1. Materials Properties

Property	Glass fiber	Carbon fiber	Epoxy
Tensile modulus (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, carbon fibers and epoxy polymer matrix. The ratio of epoxy to hardener was 10:1. 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 were $[G3C2]_s$ RPC and $[C2G3]_s$ RPC 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 fiber and carbon fiber of the composites in the current study. Specimens were cut to dimensions as per test specifications and then post cured in oven at 140 °C for duration of 6 hours before testing [12].

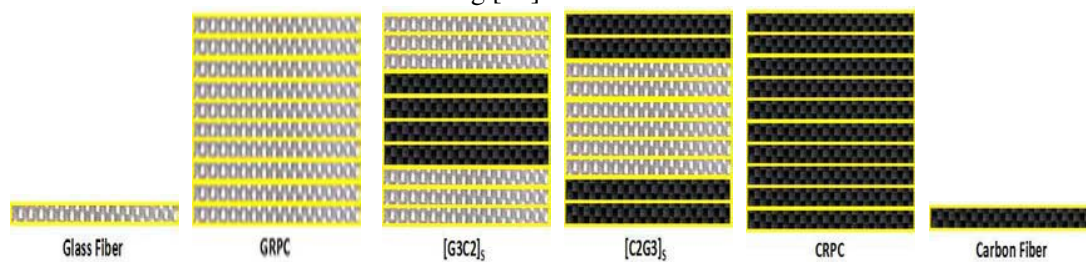


Figure 1. Composite laminates

3. Results and Discussions

3.1 Hardness

The hardness of the composites was evaluated as per the ASTM D2583 standard using Barcol hardness tester. Figure 2 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 $[C2G3]_s$ was improved by 13% as compared to $[G3C2]_s$. This may be due to high stiffness of carbon fiber on the outer surface of $[C2G3]_s$.

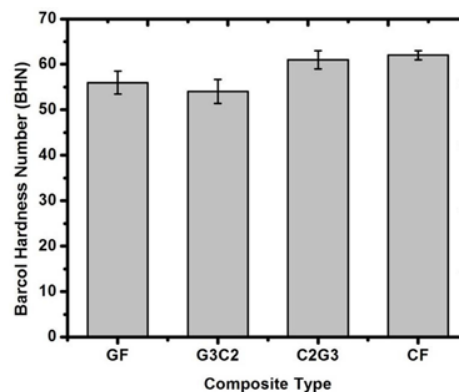


Figure 2. Comparison of Hardness of the composites

3.2 Tensile Strength

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

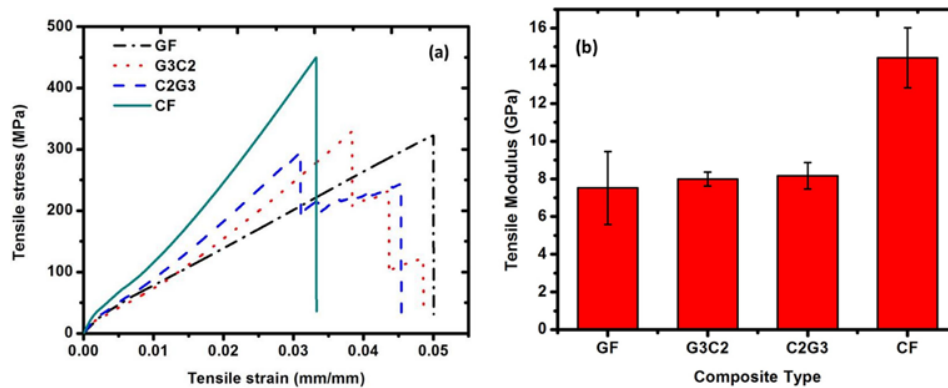


Figure 3. (a) Tensile stress versus strain and (b) tensile modulus of different composites

Figure 3(a) shows tensile stress versus tensile strain and 3(b) shows tensile modulus versus composite type. It was observed that tensile strength is maximum at 450 MPa for CRPC and tensile strength was lower for GRPC. However, the optimum tensile strength and strain were observed for $[G3C2]_s$ as compared to $[C2G3]_s$. It was observed that $[G3C2]_s$ has tensile strength of 329.5 MPa which is enhanced by 11.5% and tensile strain by 23.8% than that of $[C2G3]_s$. This may be due to high stiffness of carbon fiber at the center of the hybrid composite. Pandya *et al.* [9] have reported of improved tensile strength and strain by inner carbon layers in hybrid composite. However, tensile modulus of $[C2G3]_s$ is 8.16 GPa which is slightly more than $[G3C2]_s$ by 2.2%.

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) \times 12.7 mm (width) \times 3 mm (thickness) were cut as per the ASTM D256. Figure 4 shows the impact specimens before and after testing of different composites.

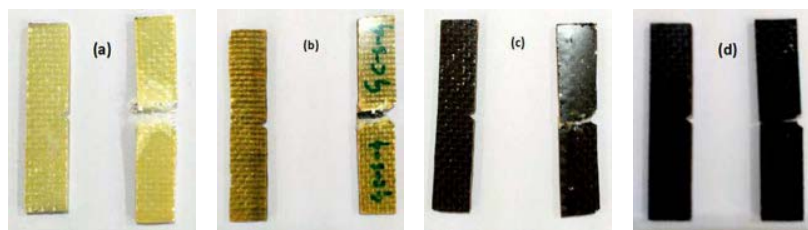


Figure 4. Before and after impact test of (a) GRPC, (b) $[G3C2]_s$, (c) $[C2G3]_s$ and (d) CRPC specimens.

Figure 5 shows the toughness of pure glass, carbon fiber and hybrid composites. It was observed that the toughness of GRPC is the highest and CRPC is the lowest because of brittleness of carbon fiber. The toughness of $[C2G3]_s$ is 137.36 KJ/m² which is significantly higher by 52.4% as compared to $[G3C2]_s$. Out of the two hybrid composites, $[C2G3]_s$ has stiffer outer carbon layers which initially absorb some energy. This allows the inner ductile glass layers to expand and delaminate by absorbing more energy. Thus energy absorption of $[C2G3]_s$ is greater than $[G3C2]_s$ because of higher resistance towards penetration. The results were in agreement with investigation by Reddy *et al.* [18].

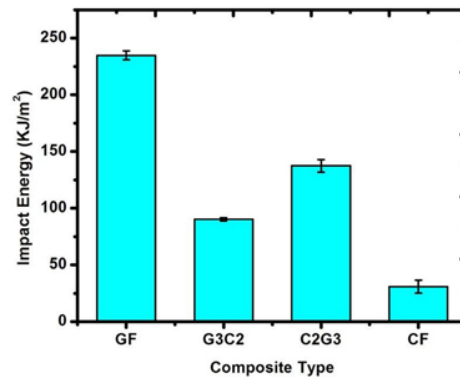


Figure 5. Impact energy of composites

3.4 Flexural Strength

The flexural strength has been determined as per ASTM D7264 standard. The span length of the specimen was 60 mm and cross head speed was 2 mm/min. Figure 6 shows the flexural strength versus extension of pure glass, pure carbon and hybrid composites. It was observed that GRPC has the lowest flexural strength but highest flexural extension with gradual failure. CRPC shows moderate flexural strength and fails catastrophically. However, [C2G3]_s shows the highest flexural strength of 465.7 MPa which is higher by 22.9% than [G3C2]_s but has lower extension. Whereas [G3C2]_s displays higher extension with stress reducing slightly gradually before sudden failure. This may be due to ductile glass layers at outer region improving strain. Similar results were obtained by Zhang *et al.*[3].

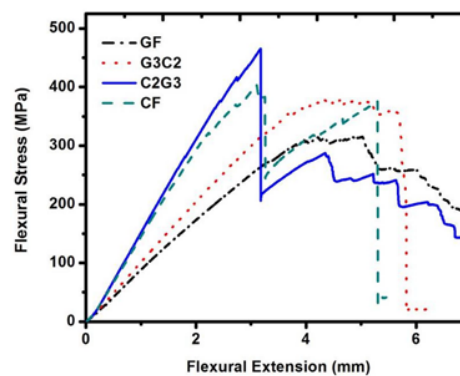


Figure 6. shows flexural stress versus extension behavior of different composites.

Figure 7 shows flexural modulus and extension of glass, carbon and hybrid fiber reinforced polymer composites. [C2G3]_s has higher modulus by 64% as compared to [G3C2]_s because of high stiffness of outer carbon layers. However, [G3C2]_s has higher flexural extension by 38.9% as compared to [C2G3]_s due to higher ductility of outer glass layers.

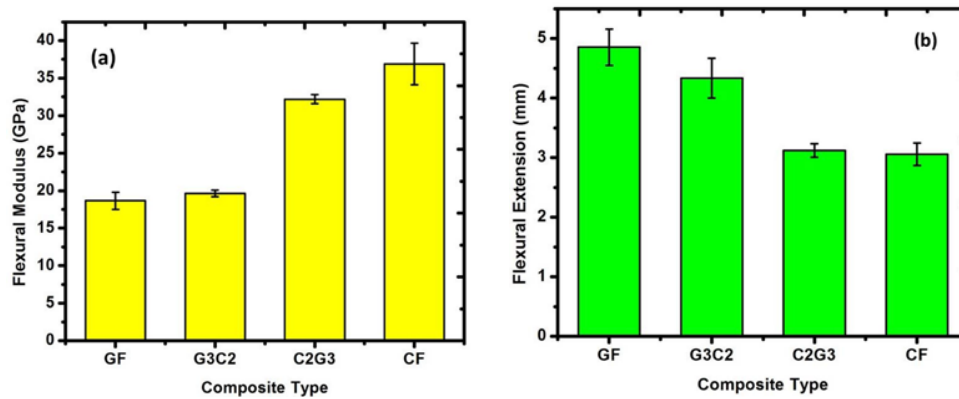


Figure 7. (a) Flexural modulus and (b) Flexural extension of different composites.

4. Conclusion

The following conclusion may be drawn.

1. The tensile strength, strain and flexural extension of [G3C2]_s has been improved by 11.5%, 23.8% and 38.9% respectively as compared to [C2G3]_s composites.
 2. The fracture toughness, hardness, flexural strength and flexural modulus of [C2G3]_s has been improved by 52.4%, 13%, 22.9% and 64% respectively as compared to [G3C2]_s.
- Therefore, there is need to explore other interply sequence to optimize the mechanical properties of the hybrid composites.

5. References

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