Analysis on mechanical and thermal properties of glass-carbon/epoxy based hybrid composites

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Abstract. The primary purpose of this study is to analyze, evaluate and compare the mechanical and thermal properties of epoxy based composites with different fiber reinforcements. Fabrication of Glass fiber, carbon fiber and hybrid composites was one by Hand lay-up technique. Tensile test, Three point bend test, Inter-laminar shear test and Compression Test were done on the composite laminates as per the ASTM Standards to obtain mechanical properties such as tensile strength, transverse strength, peak load, compressive strength. Thermal properties such as Glass Transition temperature, melting and decomposition peaks were investigated by Differential Scanning Calorimeter (DSC); Thermo Gravimetric Analysis (TGA) was done to study the decomposition behavior of the composites. Results are tabulated and the comparison is drawn between the laminates.

Key words: Glass fiber, Carbon fiber, Hybrid, Epoxy Polymer Resin, Mechanical properties, Thermal properties, DSC and TGA analysis

1. Introduction
Composite materials can be defined as a combination of two or more materials resulting in better and enhanced properties than those of the individual materials when used. The major constituents are reinforcement fiber and a matrix [1,2]. The main characteristics of composite materials are their high strength to weight ratio and when compared with bulk materials the composite material has good stiffness, combined with low density, allowing reduced weight in the finished part [3,13-15]. The reinforcement in composite provides the required strength and stiffness. In most cases, the reinforcing phase is stronger, harder, and stiffer than the base matrix [4]. Epoxy matrix has been increasingly used in various fields as it has got superior strength for its light in weight and exceptional functional characteristics at elevated temperatures. Composites differ from alloys in a way that they are made from two or more separate materials bonded in such a way as to form one solid piece of material, on the other hand alloys are mixtures of primarily metal atoms which form a continuous solid solution [5-7].
Typical fibers include glass, kevlar and carbon etc. The main matrix is the continuous phase, which can be a polymer, metal, or ceramic. Ceramics matrix have high strength and stiffness but are brittle, Polymer matrix have low strength and stiffness and metals matrix have intermediate strength and stiffness but are highly ductile in nature. Carbon fiber is available in different weave pattern such as unidirectional, plain weave patterns, 2X2 twill weave and many more. It is also differentiated according to the number of strands such as 3K, 6K, 12K and 24K. Chopped strand matt is a type of reinforcement used in glass fiber. CSM consists of fibers laid arbitrarily across each other and held intact in the base matrix by a binder. Using CSM in fiber glass induces isotropic in-plane material properties.

The mechanical properties of polymer based hybrid composite and found that the stacking sequence has more impact on the results obtained [8]. The tensile properties and fracture behavior of the hybrid rods for varying composition and found out that controlling the void were very difficult and tensile strength and modulus increases with increasing with increase of carbon fiber[9]. The flexural properties of glass and carbon fiber rein-forced epoxy hybrid composites were studies using FEA and found that there is 20 to30% lower flexural strength and models failed by shear [10]. Glass fibers have very less shear modulus, Young’s modulus, and Poisson’s ratio where as carbon fiber which is very costly has excellent mechanical properties. The orientation of the fibers plays a vital role and the hybrid composite is used to achieve desired Mechanical properties [11]. FEA was used to obtain flexural strength and failure occurs due to shear failures, the flexural strength is 20 to 30% lower compared to other failure modes[12].

From the above literature survey it has been found that though there are more works for hybrid composite, not much work has been carried on for CSM woven glass fiber and unidirectional carbon fiber. The cost of these two fibers are comparatively cheap and an effort has been made to study and analyze on mechanical and thermal properties of the individual fiber composite and epoxy based hybrid composite.

2. Experiments

2.1 Elements and Specification of Composites

The reinforcement materials used in present study are carbon fiber and glass fiber. For reinforcement the glass fiber is available as yarn, continuous fibers, chopped strands, and mat form. In this study chopped strands are used as reinforcement for glass and unidirectional plane weave pattern of carbon fiber is used. Glass fiber and carbon fiber used for preparing the composites are shown in figure 1a and 1b. To fabricate the polymer composite carbon fiber, glass fiber, epoxy resin, hardener, and releasing agent are used.

![Figure 1. Fibers used a) Glass b) Carbon.](image)

Epoxy resin has been used in this study though they are much more expensive than polyester. However, the polymers have more complex polymer chain reaction and controlling the cross linking reaction of these polymers gives much more improved matrix in terms of rigidity, strength and performance. To
control the curing action and the reaction taking place in the polymer composite hardener is added. The degree of hardness can also be controlled in the cured composite. Semi-solid wax has been used as a releasing agent to avoid sticking of the polymer on the surface of layup.

2.1.1 Composition of Polymer Composite.
In this study to fabricate the composite, the composition of different materials used to make samples for all the tests are given in the below mentioned table 1.

| Materials     | Specification                  | Mix ratio by weight |
|---------------|---------------------------------|---------------------|
| Epoxy Resin   | Nitobond EP Base resin          | 1litre              |
| Hardener      | Aradur 955                      | 100ml               |
| Carbon fiber  | Unidirectional plane weave      | 50gms per sample    |
| Glass fiber   | CSM/Woven roven                 | 50gms per sample    |
| Hybrid fiber  | Woven roven/ Unidirectional plane weave | 50gms per sample |

2.2 Fabrication of Composite material
The composite laminates were manufactured using hand lay-up technique. The entire fabrication was carried out at room temperature. The required mixture of hardener and resin were made by mixing them in (1:10) parts in a beaker by stirring the mixture using a glass stirrer and it should be mixed in same direction to avoid air entrapment inside the solution. Wax was used as a releasing agent. The polymer was uniformly spread with the help of brush. The prepared samples were then cured for approx. 24 hours at room temperature.

2.3 Testing of composite material
Universal testing machine TUE-CN-200 as shown in figure 2a was used to carry out tensile and compressive test. All the tests were conducted at room temperature. The three point bending test equipment is shown in figure 2b to find out the flexural strength of the composites specimens and the tests were performed according to ASTM D790 in the displacement-controlled mode. During the test progress, the load values and cross-head travel were recorded simultaneously. The specimens were subjected to load until rupture of the specimen occurred on the outer surface. The samples were tested for load at peak, cross-head travel at peak, maximum elongation, maximum load before failure and the transverse strength. The sample test samples are shown in figure 2c.

When any homogenous elastic material is tested in three point bend test as a simply supported beam and loaded at the midpoint, the maximum stress is observed in the middle at the outer surface of the test specimen.
Figure 2. a) Tensile Test.  b) Bending Test.  c) Test Sample.

The tensile test process was carried out by placing the samples to be tested in Universal Testing Machine and extending it slowly until it the test sample fractures. The tensile strength of the composite laminates under static longitudinal loading was determined by ASTM D 3379 standards. Once the specimen was clamped in the grip of the tensile testing machine it was pulled in either direction to failure. The entire process was recorded for the load and elongation and the tensile strength, breaking strength, yield stress, load at yield, load at peak, elongation at peak, load at break, percentage reduction in area and percentage elongation were recorded.

Inter-laminar shear test was done according to ASTM D732 standards. The test was performed by clamping between two metal fixtures and the test sample is attached to a punch. In the metal fixture shearing along the edge of the hole takes place when a male punch is forced through the hole. The compressive force or crush resistance of the composite and the ability of the composite to recover the applied force after holding over a period of time compression testing was carried out. The maximum stress a material can withstand over a period of time under a load (constant or progressive) was determined. The laminates were subjected to compression loading to determine the compressive strength in accordance to ASTM D3410 standards. The tests were performed in Universal Testing Machine.

2.4 Thermal Properties testing of composite Material
The thermal properties and the behavior of the composites were measured using both Differential Scanning Calorimeter (DSC) and Thermo-Gravimetric Analysis (TGA). The procedure included curing the laminates using a SDT Q600 Differential Scanning calorimeter from TA instruments. The process was carried by ramping of approx. 4miligram of sample from room temperature to 600°C, 900°C and 1000°C for Carbon fibre, Glass fibre and hybrid composites respectively. The heating rate was 20°C/min. All DSC and TGA test used aluminum Pans and air is the testing atmosphere. All the thermo-grams reported for DSC where upward peaks that are exothermic.

In Thermo-Gravimetric analysis the physical properties and chemical properties are recorded and analysed as a function of increasing temperature and time. This test was done to study the thermal stability of the composites. The changes in the mass of the samples were studied when the samples were
subjected to ramping heat input. It also helped in analysis of volatile products, gaseous products lost during the reaction in composites.

3. Results and Discussion

3.1 Tensile properties
The ultimate tensile strength of carbon reinforced composite was higher as compared to the other composites. It is because the strength of the carbon fiber is higher and it behaves like elastic material during tensile loading. Figure 3, figure 4 and figure 5 shows the tensile curve obtained for carbon fiber, glass fiber and hybrid composite respectively. The yield stress for Carbon fiber composite is 27% more than hybrid composite and 24% less for Glass fiber composite. Carbon fiber has 40% more yielding when compared to glass fiber composite. The reason for such behavior of carbon composite can be attributed to its elasticity and glass fiber is brittle in nature. The percentage elongation is also 1.5 times more for carbon fiber composite when compared with hybrid or glass fiber composite. There is no much difference for hybrid and glass fiber composite. As the glass fiber is of CSM woven the impact of elongation in hybrid is negligible. Tensile strength of carbon fiber composite is 29% more when compared with hybrid composite and 23% less for glass fiber composite when compared with hybrid composite. But the Carbon fiber composite has 40% more strength when compared with glass fiber composite. As the carbon fiber has good load bearing capacity and elastic in nature the tensile strength of the carbon fiber composite is more compared to other composites. Similarly the breaking strength of Carbon fiber composite is approximately twice when compared with hybrid or glass fiber composite whereas, there is no much difference between hybrid and glass fibre composite.

![Tensile curve for carbon fiber, glass fiber and hybrid composite](image_url)

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*Figure 3: Tensile curve for carbon fiber composite. Figure 4: Tensile curve for glass fiber composite. Figure 5: Tensile curve for hybrid composite.*
Figure 3. Tensile test curve for a) Carbon  b) hybrid  c) glass  d). Comparison of Tensile strength for the three composites

3.2 Compression Test
Compression failure is mainly due to buckling followed by breakage. There is an initial compression stress at the inner layer of laminate, transmitting stresses through the interface, inducing fiber, getting delaminated one by one. Test results show that the compressive strength for hybrid composite has 31% less strength than carbon fiber composite and is 51% more for glass fiber composite. The compressive strength for Carbon fiber composite is 66% more when compared with glass fiber composite. When the compressive load is applied the carbon will buckle more when compared to glass fiber as its more brittle and has less yielding strength.

Figure 4. Comparison of Compression load
3.3 Three-point bending test

Bending properties are one of the most important properties in any structural elements. Composite material used in structural application mostly fail in bending. Test results shows that transverse strength of carbon fiber composite test better than the Glass fiber composites and hybrid composite. Figure 5a-c shows the transverse test curve for the three laminates and figure 5d shows the comparison graph for all three types of composite.

![Three-point bending test curves](image)

**Figure 5.** Three point bending test curve for a) Carbon fiber composite b) glass fiber composite c) hybrid composite d) comparison for Flexural strength for all three composites.

Hybrid composite has 1.3% lesser strength than Carbon fiber composite and has 30.5% higher strength for Glass fiber composite. Whereas carbon fiber has 31% more traverse strength than Glass fiber composite. The reason for such behavior is that the carbon fiber has more elongation and yielding property. The Flexural strength for hybrid composite is observed to be more than carbon fiber composite and glass fiber composite though there is not much variation in the flexural strength of hybrid with carbon fiber composite.
3.4 Inter-laminar Shear test
The Inter-laminar shear test results shows that ultimate stress in shear was maximum in the case of hybrid composite and it was minimum for the carbon-fiber composite, while the Glass-fiber composite was intermediate of both. Ultimate stress for the above test were obtained as 120.556 N/mm², 115.370 N/mm² and 105 N/mm² respectively for Hybrid composite, Glass fiber composite and Carbon fiber composite. This shows that there is good bonding strength for the hybrid hen compared to glass or carbon fiber composite.

3.5 DSC Characterization
Thermographs obtained for the laminates are showing an exothermic behavior. Figure 6a-c shows the DSC temperature ramp curve for the composites. The glass transition temperature of the composites is depending upon the resin used. It is almost equal to 240°C for all the three cases since the epoxy decomposes at same temperature in the entire three situations. Crystallization peak was obtained at 330°C, 640°C and 600°C respectively for carbon fiber composite, Glass fiber composite and Hybrid composite respectively. Whereas, melting of Carbon fiber, glass fibers and hybrid composite was obtained at 540°C, 960°C and 750°C respectively. Specific heat capacity for Carbon fiber, glass fibers and hybrid composite were 0.1625J/°C, 0.34J/°C and 0.2J/°C and is shown in figure 7.
Figure 6. DSC &TGA Curve for a) Carbon fiber composite b) Hybrid composite c) Glass fiber Composite
3.6 TGA Characterization

The TGA curve for all the three samples indicates the decomposition of the sample in the single stage. It also shows that there is no volatile substance present in the sample. Reduction in mass obtained after the thermal test were 48%, 30% and 75% respectively for carbon fiber composite, Glass fiber composite and Hybrid composite respectively as shown in figure 8. Procedural decomposition occurred at 270°C, 275°C and 280°C respectively for the three composites.

4. Conclusion

This study reveals that an effort has been made to analyze the mechanical and thermal properties of Glass fiber, carbon fiber and hybrid composites. The results showed superior mechanical property in the form of higher inter-laminar shear strength for hybrid composite was obtained.
The Tensile strength and yield strength of hybrid composite was 29% and 27% less when compared with carbon fiber and has 23% and 24% more strength with respect to glass fiber. The breaking strength and % elongation was found to be almost twice more for carbon fiber and not much difference when compared to glass fiber. The flexural strength of hybrid is higher than the carbon and glass fiber composite. The transverse strength of hybrid and carbon fiber was found to lie in same line where as the glass fiber shows 30.5% less strength.

The DSC results shows that the Glass transition temperature for all the three composites. The crystallization temperature and melting temperature for the hybrid composite is nearer to Glass fiber composite. This indicates that the hybrid composite is more stable. TGA analysis also reveals that the hybrid composite is more stable than the other laminates.

5. References

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