Processing and Flexural Strength of Carbon Fiber and Glass Fiber Reinforced Epoxy-Matrix Hybrid Composite

Prashanth Turla , S. Sampath Kumar, P. Harshitha Reddy, K. Chandra Shekar
Department of Mechanical Engineering, Vignan Institute of Technology and Science, Hyderabad, India.

***Abstract---*Polymer matrix composite materials have extensive engineering application where strength to weight ratio, high dimensional stability, high chemical resistance, low cost and ease of fabrication are required. Hybrid composites (dual reinforcement) provide combination of properties such as tensile modulus, compressive strength and impact strength that cannot be realized in composite materials. In recent times hybrid composites have been established as highly efficient, high performance structural materials and their use is increasing rapidly. Hybrid composites are usually used when combinations of properties of different types of fibers have to be achieved, or when longitudinal as well as lateral mechanical performances are required.**

In this study, the flexural strength of glass and carbon fiber reinforced epoxy matrix hybrid composite was studied and to know the influence of glass and carbon fibers individually on flexural strength carbon fiber epoxy composite and glass fiber epoxy composite were also prepared and studied extensively. The results show that the flexural strength of hybrid composite is significantly improved as compared to glass fiber reinforced composite / carbon fiber reinforced composite.

Keywords- Hybrid composites, Flexural strength, Filament winding

I. INTRODUCTION

A composite is a structural material that consists of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is called reinforcing phase and one in which it is embedded is called the matrix. The reinforcing phase material may be in the form of fibers, particles or flake. The matrix phase materials are generally continuous [1,2].

In recent years, the fiber reinforced polymer composites are now finding suitable materials for various application in automobile, building, electrical, and packaging sectors because of their several practical advantages like ease of processing, fast production cycling, and low processing cost over traditional materials[3]. One of the major sciatic challenges for the composite engineers is the development of new stronger and tougher lightweight structural materials supporting latest technologies and design concepts for the complex shaped structures like aircraft, automotive structures, and large wind turbine blade structures [4].

Hybrid composite materials are consisting of two constituents at the nanometer or molecular level. Commonly one of these compounds is inorganic and the other one organic in nature [5]. Thus, they differ from traditional composites where the constituents are at the macroscopic (micrometer to millimeter level) [6]. Mixing at the microscopic scale leads to a more homogeneous material that either shows characteristics in between the two original phases or even new properties.

The flexural test measures the force required to bend a beam under three point loading conditions. The data is often used to select materials for parts that will support loads without flexing. Flexural modulus is used as an indication of a material's stiffness when flexed. Since the physical properties of many materials (especially thermoplastics) can vary depending on ambient temperature, it is sometimes appropriate to test materials at temperatures that simulate the intended end user environment.

Artmenko [8] reported that the hybridization of carbon fiber with basalt fiber significantly increased the production of carbon fiber reinforced plastics. Park and Jang [9] examined the effect of the addition of polyethylene fibers on the mechanical properties of a carbon fiber/epoxy composite. Dong et al. [10] investigated the flexural properties of hybrid composite by comparing experiment and finite-element analysis. Their result showed a decrease in flexural modulus of carbon fiber reinforced plastic (CFRP) with an increase in glass fiber content. Assie et al. [11] reported that the loading conditions significantly affect the optimum weight of laminated plates. In addition, the ply orientation affects the optimum weight design of the laminate.

Many research aspirants on these composites based on these fibers have done a lot of work. But little work was explored about the glass-carbon-epoxy hybrid composites as these offers a range of properties that cannot be obtained with a single kind of reinforcement.

In this study glass fiber reinforced composite, Carbon fiber reinforced composite and glass/carbon/epoxy hybrid composite are manufactured by filament winding process with a curing in a high pressure environment using hydraulic press.

II. EXPERIMENTAL

In this present study, glass and carbon fiber reinforced epoxy matrix hybrid composite, glass fiber reinforced epoxy matrix composite and carbon fiber reinforced epoxy matrix composite were fabricated and tested according to ASTM D790.

The laminas in a composite laminate can be laid up in different orientations based on the properties required. In this, the properties of a laminate with laminas in different orientations are studied to obtain a laminate with optimum properties in all directions. The properties for various combinations of lamina orientations for the hybrid composite laminate are obtained by AUTODESK software.

The optimum ply orientation for the hybrid composite is decided as $(0^0{}_C/45^0{}_G/45^0{}_C/-45^0{}_G/-45^0{}_C/90^0{}_G/90^0{}_C/)_S$.

A. Synthesis of Materials

The materials used in the manufacturing are listed in the Table 1

Table 1: Materials Used

Material	Specification
Carbon Fiber	Formasa T6 6K
Glass Fiber	E-Glass 12000Tex
Epoxy	LY 556
Hardener	5200

The materials required for the fabrication are prepared according to the requirements. The primary constituents are the reinforcement and the matrix phase. For the hybrid composite, there are alternate layers of Formosa 6k carbon fiber reinforced lamina and E-glass fiber reinforced lamina. For the preparation of a lamina (of both carbon and glass fibers reinforcements), roving is the reinforcement with a outside pay off is mounted on to creel stand from which the fiber roving is passed out .The tension required for the fiber is provided at the creel stand so that the winding process can be carried out without any problem of lose fibers while winding [7,8].

The resin mixture with the basic constituents of resin and hardener is to be prepared for the fabrication process. The ratio at which the constituents are mixed at 1:27 parts by weight. To prepare the resin mixture all the things required are cleaned thoroughly with acetone to remove the dirt from the instruments. The resin, hardener, diluents are measured separately in a beaker according to the required quantity and mixed thoroughly with a stirrer as shown in Figure 1.

Figure 1: Resin mixing and Creel Stand

The resin is the primary constituent in the laminate, which is the matrix phase of the composite. The hardener acts as initiator or catalyst for the curing to take place for the formation of the laminate .The diluents decreases the viscosity of the resin so that the resin can be impregnated on to the fiber with ease.

The resin mixture is then poured into the resin bath of one-liter capacity in which the fiber is impregnated with the resin mixture. The resin bath consists of a comb, a doctor blade, a drum, and scraper blade. The fiber roving that is mounted on the creel stand is passed through the provisions provided with a tension applied through the resin bath on to the filament machine shown in Figure 2, where the mandrel: drum used for the winding process. The doctor blade maintains a uniform thickness of resin over the drum and the fiber is passed over the drum that is partially immersed in the resin mixture. The drum rotates as the fiber is passed over the drum that partially takes resin on to its surface and impresses the fiber with resin. The scraper blade, which is placed after the drum, removes the extra resin from the fiber so that there is a uniform resin distribution over on to the fiber.

Figure 2: Filament Winding Machine

These fibers are wound on the filament-winding lathe on a cylindrical drum and are cut to form a sheet. This sheet is cut into several pieces depending upon the required orientations and the number of pies.

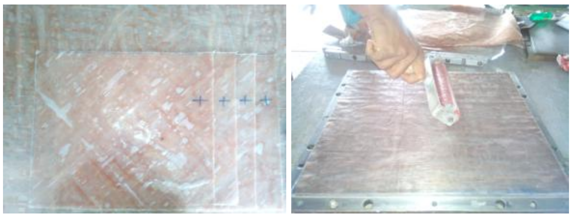

Figure 3: Nesting and Layup of Glass Fiber reinforced lamina

Thickness of glass fiber reinforced lamina was 0.36 mm and carbon fiber reinforced lamina was 0.25 mm, these lamina are cut in to pieces of 380X340 mm which is the tool size, to prepare a laminate of thickness 3.5 mm, depending on laminate number of piles are stacked to attain required thickness (Figure 3). The tool is then placed in a hydraulic press under a pressure of 15 bar for the extraction of undesirable resin along with exposure to a second environment with a two-step increase in temperature with 80°C for one hour and 120°C for next six hours. The time of polymerization for all the samples was 360 min, at120°C. Similar procedure and curing cycle was followed to prepare other two materials. Same ply-sequence was followed for all three materials. After samples were formed, test specimens were cutout, which were tested.

Flexural test specimens are shown in Figure 4 and dimensions are shown in the Table 2 and the length of specimen includes a span of sixteen times the thickness.

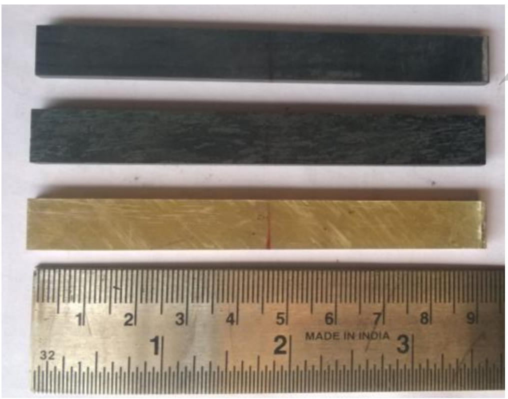

Figure 4: Flexural test specimens

Table 2: Specimen dimension according to ASTM D790

Specimen	Dimensions (W x T x L) in mm
Glass fiber composite	10x4.06x90
Carbon Fiber composite	10x3.94x90
Hybrid Composite	10x3.76x90

B. Testing

Most commonly the specimen lies on a support span and the load is applied to the center by the loading nose producing three point bending at a specified rate. The parameters for this test are the support span, the speed of the loading, and the maximum deflection for the test. These parameters are based on the test specimen thickness and are defined differently by ASTM and ISO. For ASTM D790, the test is stopped when the specimen reaches 5% deflection or the specimen breaks before 5%. The test is stopped when the specimen breaks. If the specimen does not break, the test is continued as far as possible and the stress at 3.5% (conventional deflection) is reported.

C. Three Point Bend Flexure Test

The three point bending flexural test provides values for the modulus of elasticity in bending E_f, flexural stress σ_f, flexural strain ϵ_f and the flexural stress-strain response of the material. The main advantage of a three point flexural test is the ease of the specimen preparation and testing. The specimen is characterized as shown the Figure 5

Figure 5: Three point bending specimen

The test method for conducting the test usually involves a specified test fixture on a universal testing machine. Details of the test preparation, conditioning, and conduct affect the test results.

Calculation of the flexural strength (σ_f) for rectangular cross-section is as follows:

$$\sigma_f = \frac{1.5FL}{bd^2}$$

In the above formula the following parameters are used:

- σ_f = Flexural strength, (MPa)
- F = load at a given point on the load deflection curve, (N)
- L = Support span, (mm)
- b = Width of test beam, (mm)
- d = Depth of tested beam, (mm)

III. RESULTS AND DISCUSSION

For the sake of accuracy in determination of flexural strength, for each type of reinforcement, five specimens were tested experimentally, conforming to the appropriate ASTM standards. For each specimen, the initial dimensions were measured, and then maximum load (F), i.e. the force causing the flexural stress in the specimen, was determined by means of the testing machine. Based upon this value, the geometry of the tested specimen (width and thickness) and using the above equation, the flexural strength is found out.

The Table 3, Table 4 and Table 5 show the maximum load values and the corresponding flexural strength for glass fiber reinforced composite, carbon fiber reinforced composite and carbon/glass/epoxy hybrid composite respectively.

Table 3: Flexural strength values of various glass fiber reinforced composite specimens

Specimen #	Maximum Load (N)	σ_f (MPa)
1	750	443.35
2	838	495.37
3	780	461.08
4	840	496.55
5	812	480.00
Average	804	475.27
Standard Deviation	38.76	22.91

Table 4: Flexural strength values of various carbon fiber reinforced composite specimens

Specimen #	Maximum Load (N)	σ_f (MPa)
1	470	286.29
2	498	303.35
3	530	322.84
4	488	297.26
5	516	314.31
Average	500.4	304.81
Standard Deviation	23.47	14.30

Table 5: Flexural strength values of various glass/carbon fiber reinforced hybrid composite specimens

Specimen #	Maximum Load (N)	σ_f (MPa)
1	893	570.00
2	857	547.02
3	878	560.43
4	804	513.19
5	821	524.04
Average	850.6	542.94
Standard Deviation	37.54	23.96

The average σ_f value of hybrid composite is obtained as 542.94MPa. This is due to the combination of dual reinforcement i.e. carbon and glass fiber and all the tested ILSS values of different specimens are shown in Table 5.

The σ_f value of glass fiber reinforced epoxy matrix composite and carbon fiber reinforced epoxy matrix composite were also evaluated to know the influence of individual fibers. The flexural strength value in glass fiber composite was obtained as 475.27 MPa (Table 3) and value in case of carbon fiber reinforced epoxy matrix composite is 304.81 MPa (Table 4). This result indicates that the flexural strength predominantly depends on the properties of the fibers. Even though the carbon fibers have very high tensile strength, they are very brittle compared to that of glass fibers. As a result the flexural strength of the composite made with carbon fiber reinforcement consists of about 55% less flexural strength than that of glass fiber reinforced composite (Figure 6).

For the Hybrid material the σ_f value is significantly improved by about 15% as compared to glass fiber composite, this is due to the contribution of carbon and glass fibers along with matrix material. Minimum five specimens were tested in each material as per the ASTM standard.

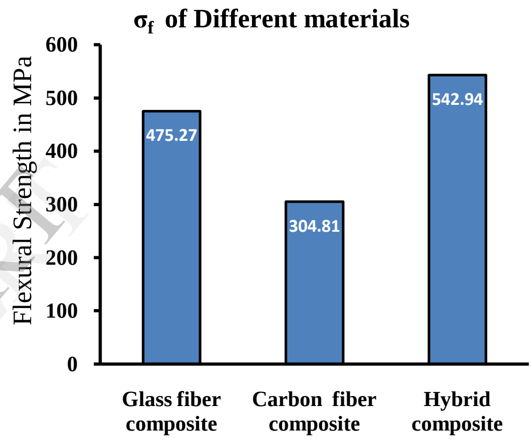

Figure 6: Flexural strength values of Glass fiber composite, hybrid composite and carbon fiber composite

IV CONCLUSIONS

The three different composite materials namely, glass and carbon fiber reinforced epoxy matrix hybrid composite, glass fiber reinforced epoxy matrix composite and carbon fiber reinforced epoxy matrix composite were successfully processed by filament winding technique. The flexural strength of hybrid composite is significantly higher as compared to other two materials. Thus, the composite showed an appreciable influence of glass and carbon fibers. With this property obtained from hybrid composite, it is clearly suitable for structural applications such as aerospace applications. The flexural strength of glass fiber reinforced composite is significantly higher than carbon fiber reinforced composite; this is due to the brittleness of carbon fibers in spite of their high values ultimate tensile strength.

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