Fabrication and Flexural Strength of Glass Fiber Reinforced Epoxy Matrix Composite

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Abstract— The present study investigated the influence of fiber orientation in the flexural properties of unidirectional glass fiber reinforced epoxy matrix composite. The filament winding technique was employed for the fabrication of composite. The flexural properties extensively studied by using three-point bend test and scanning electron microscopy. From the experimental results, it was found that flexural strength of the glass fiber reinforced epoxy matrix is significantly higher in longitudinal orientation as compared to transverse orientation of fibers; and more importantly show that such anisotropy is of an order of magnitude and higher.

Key words: Glass Fiber, Epoxy Matrix, Filament Winding Technique, Flexural Strength

I. Introduction

A composite is a structural material that consists judicious combination of two or more constituents that are combined at a macroscopic level and insoluble 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 particulates, fibers, flake or particles. The matrix phase materials are generally continuous [1, 2]. In recent years, the continuous fiber reinforced polymer matrix composites are now finding suitable materials for various application in building, electrical, automobile, and packaging sectors because of their several practical advantages like fast production cycling, ease of processing and low processing cost over traditional materials [3]. One of the major sciatic challenges for the composite researchers is the development of high strength to weight ratio structural materials supporting latest technologies and design concepts for the complex shaped structures like automotive structures, aircraft and large wind turbine blade structures [4].

Flexural strength is one of the most widely used properties in characterizing the mechanical behavior of composites. The flexural strength represents the highest stress experienced within the material at its moment of rupture. 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.

Glass fiber reinforced epoxy matrix composites results in an attractive combination of physical and mechanical properties which cannot be obtained by monolithic materials [5, 6]. These are widely used due to ease of availability of glass fibers and economic processing techniques adopted for production of components. Developments are still under way to tailor their properties for extreme loading conditions. The primary aim of this paper to study the flexural strength of unidirectional glass fiber reinforced composite in detail in order to evaluate the influence of directionality of glass fibers.

II. Experimental

A. Materials

In this present study LY 556 epoxy resin and Aradur 5200 hardener were used as matrix system. E-glass 1200 Tex glass fiber tows were used as reinforcing material. The synthesis was concluded by filament winding technique.

B. Material Processing

The materials required for the fabrication are prepared according to the requirements. The primary constituents are the reinforcement and the matrix phase. For the preparation of a lamina with glass fibers reinforcements, roving is the reinforcement with a outside payoff is mounted on to creel stand from which the fiber roving is passed out. The tension required for the fibers 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 epoxy resin and hardener is prepared for the fabrication process. The ratio at which the constituents are mixed at 100:27 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 epoxy resin, hardener and diluents are measured separately in a beaker according to the required quantity and mixed thoroughly with a stirrer as shown in Fig. 1.

The epoxy 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 diluent decreases the viscosity of the resin so that the resin can be impregnated on to the fiber with ease.

The epoxy resin mixture is then poured into the resin bath of one-liter capacity in which the glass fiber is impregnated with the resin mixture. The resin bath consists of a drum, a comb, a doctor blade and scraper blade. The glass 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 winding machine shown in Fig. 2, where the 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 glass 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.

Fig. 1: Resin mixing and Creel Stand

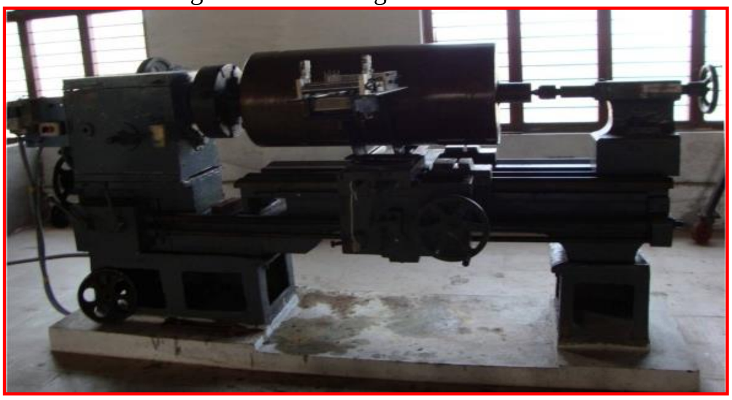

Fig. 2: Filament Winding Machine

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 plies.

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 80ºC for one hour and 120ºC for next six hours. The time of polymerization for all the samples was 360 min, at 120ºC. After samples were formed, test specimens were cutout as per ASTM standard, which were tested. In the present composite the volume fraction of fibers found to be 58.63 %.

C. Flexural Testing

Specimens of rectangular cross section with an approximate thickness of 3 mm, width 10 mm and length of 70 mm (with an included span length equivalent to 16 times the thickness) were used to evaluate flexural strength. In this three point bend test 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 cross head speed rate of 2mm/min as per ASTM D790 and performed at ambient temperature. These parameters are based on the test specimen thickness and are defined by ASTM D790. 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. The three point bending test provides values to calculate the flexural behavior 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 Fig. 3.

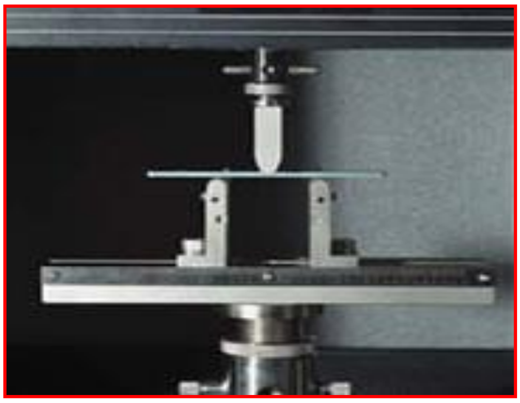

Fig. 3: Three Point Bending Test Setup

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:

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

Where, σ_f is flexural strength, F is load at a given point on the load deflection curve, L is span length, b is width of test specimen, d is thickness of tested beam.

III. RESULTS AND DISCUSSION

For the sake of accuracy in determination of flexural strength, five specimens were tested experimentally in both i.e. longitudinal and transverse orientation of fibers, conforming to the ASTM standard D790. For each specimen, the initial dimensions were carefully measured, and then maximum load (F), i.e. the force causing the flexural stress in the specimen, was determined by means of the universal 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.

A. Flexural Strength in Longitudinal and Transverse orientation

The tensile stress is mainly responsible for the failure of the specimen and not the compression. It can be clearly seen from Table 1 that the material possesses excellent flexural strength in the longitudinal direction with an average value of 360 MPa, where as in the case of transverse is 4.4 MPa. This can be attributed to the presence of light weighted E-glass fibers. The typical loads vs displacement curve is shown in Fig. 4 which explains the exceptional behavior of the composite material. The graphs pertaining to the longitudinal specimen's exhibit a gradual increase in load along with increase in displacement.

The Table 1 and Table 2 gives the data corresponding flexural strength for glass fiber reinforced composite in longitudinal and transverse specimens respectively. For the sake of clarity only one load vs displacement curve is shown in Fig. 4.

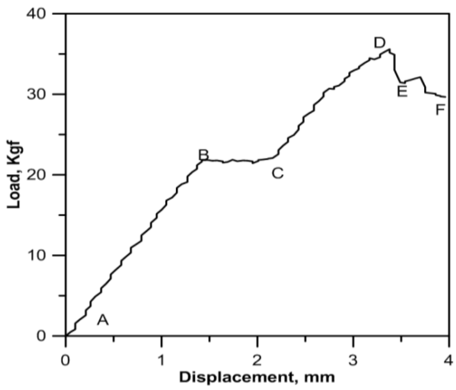

Fig. 4: Load vs Displacement data for flexural strength test in longitudinal orientation

As shown in the Fig. 4, the load increases with displacement (AB). Then, the displacement increases at constant load (BC). Major fiber bundle fracture takes place at point D. Then, the load decreases at constant displacement (DE) and then the load increases slightly due to stress induced in the surrounding fibers (EF). Whereas for transverse specimens, the composite fails suddenly after attaining the peak load. This may be due to the fact that load bearing capacity is lower and there is minimal contribution of fibers.

The fractograph (Fig. 5) clearly shows fracture of matrix and fiber surface. The fractured morphology indicate that the inter laminar failure mainly resulted from the delamination of layers. The fracture of the matrix and debonding of fibre/matrix interface are the main fracture mechanisms in these glass fibre reinforced epoxy matrix composites.

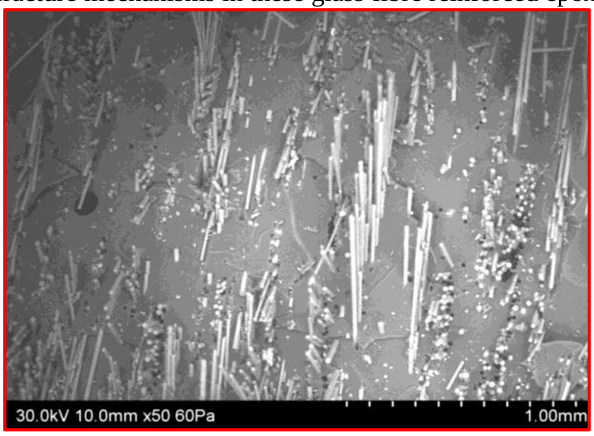

Fig. 5: SEM Fractograph of glass fiber reinforced epoxy matrix composite

B. Directionality in Strength Properties

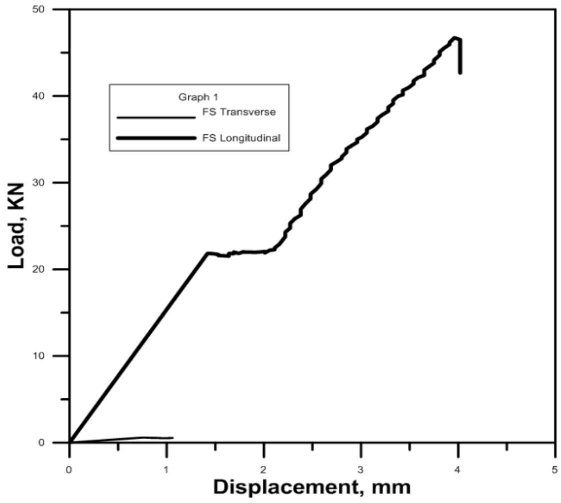

Fig. 6: Effect of directionality on Flexural Strength

Fig. 6 shows load vs displacement for both directions, some of the points are derived such as (i) the composite material in longitudinal direction possesses significant flexural strength when compared to transverse direction. This is attributed to the presence of fibers and their participation in strength enhancement as crack path obstacles; (ii) the material in transverse direction yields poor results due to the direct matrix cracking; (iii) the failure of the material in longitudinal orientation has taken over a wider displacement range(0-4 mm). But in the case of transverse specimen the failure takes place in narrow displacement range (0-1 mm); (iv) the load bearing capacity of longitudinal specimens (478 N) are significantly higher as compared with transverse specimen (5.78 N) and a clear distinction can be observed in the flexural strength values in both the alignments, where longitudinal directions of fibers dominate.

Specimen	Width (mm)	Thickness (mm)	Length(mm)	Maximum load (N)	Flexural strength (MPa)
FS-L1	10.10	3.03	72.33	397.26	317.80
FS-L2	10.17	3.01	71.11	506.92	405.38
FS-L3	10.13	3.06	70.02	422.92	338.36
FS-L4	9.91	3.07	71.19	472.53	377.65
FS-L5	10.05	3.02	70.97	447.35	358.33

Table 1: Flexural strength of glass fiber reinforced composite in longitudinal orientation

Specimen	Width (mm)	Thickness (mm)	Length (mm)	Maximum load (N)	Flexural Strength (MPa)
FS-T1	10.33	3.07	70.33	5.65	4.52
FS-T2	10.11	3.05	71.12	4.95	3.96
FS-T3	10.25	3.06	70.79	5.78	4.62
FS-T4	10.09	3.04	70.15	5.66	4.52

Table 2: Flexural strength of glass fiber reinforced composite in transverse direction

IV. CONCLUSIONS

The glass fibre reinforced epoxy matrix composite was successfully fabricated by using filament winding technique. The flexural strength of the composite is nearly 90 magnitudes higher in longitudinal orientation in comparison to transverse orientation of fibres. Thus the composite showed an appreciable influence of fiber orientation. These properties obtained from the glass fiber reinforced epoxy matrix show that it is clearly suitable for applications, where the exceptionally high values of longitudinal flexural strength can be exploited.

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