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Effect of Fibre Orientation on the Tensile and Flexural Properties of Glass Fibre Reinforced Epoxy Angle-Ply Laminated Composites

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Abstract*: *The present work is aimed at studying glass fibre reinforced epoxy angle-ply laminated composites under in-plane and out-of-plane loads. Three symmetric laminates were fabricated at different combination of fibre ply orientations through a simple hand layup technique. The prepared laminates were characterized for tensile and flexural strength measurements according to the ASTM standards D3039 and D7264, respectively. Symmetric laminates consisting of fibre plies orienting in the direction of applied load have demonstrated greater resistance against tensile loads, whereas laminate system consisting of adjacent plies oriented in different angles promoted binding strength of the matrix which in turn resulted in enhanced flexural strength values.

Keywords*: *Angle-ply composites, Fibre orientation, Tensile properties, Flexural properties, GFRP composites.

I. INTRODUCTION

Fibre reinforced plastics (FRPs) are being utilized as viable alternatives to metallic materials in structures where weight is a critical consideration, e.g., aerospace structures, high-speed boats, and trains. In the domain of FRPs, glass fibre reinforced composites (GFRPs) offer excellent specific strength and stiffness in addition to their light weight and lower costs [1]-[3]. Hence, GFRP composites are found used in many automobile vehicles to improve the fuel economy. However, when compared to metals which exhibit greater plastic deformation, GFRP composites often noticed with brittle behaviour due to which their usage is limited in producing critical structural components [4]-[6]. Further, the orientation of the fibre plies in the laminate decides the properties to the composites [7]. Therefore, a thorough understanding on the fibre orientation and its effect is very much essential to generate the composite structures with enhanced mechanical properties and energy absorption capabilities [8]. In the literature, reports based on angle-ply, cross-ply and symmetric cross-ply (0°/90°) glass fibre/epoxy composite properties are available in great number, however, studies related to the stacking pattern consisting of ±30°, ±45°, 60° and 90° angle plies are limited [5]-[10]. Hence, in the present investigation, authors have made an attempt to evaluate the effect of fibre orientation (combination of 0°, 30°, 45°, 60° and 90°) on the properties of E-glass fibre reinforced epoxy composites under in-plane and out-of-plane loading conditions.

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II. EXPERIMENTAL

A. Materials

Low viscosity unfilled epoxy casting resin (Araldite CY230-1) with low viscosity aliphatic amine (Aradur HY951) (procured from Huntsman, USA) was used as matrix system. Unidirectional E-glass fabric of thickness 0.2 mm and surface density 350 gsm was purchased from Owens Corning Pvt. Ltd., Taloja, India used as reinforcement system for this work. Acetone was bought from Merck Specialities, India.

B. Preparation of composites

Laminated composites were fabricated through simple hand layup technique. At first, mould plate was cleaned thoroughly and applied with release spray to confirm release of the laminate. According to the desired thickness, the number of required fabric plies were cut into desired dimensions. The weight of total number of plies was measured using a weighing balance and the required quantity of resin-hardener mixture was calculated by considering a desired fibre to resin ratio as 60:40. Then, stack of reinforcement fabric plies were placed one by one onto the mould plate and each ply was applied with epoxy resin mixture. After completion of layup, a caul plate covered with plastic sheet was placed on top of the plies and a weight of approximately 5 kg has been applied to realise laminate with uniform dimensions. Finally, the laminate is cured at room temperature for about 24 hours. The angle-ply composite laminates were prepared using 12 fabric plies placing at different angles. Three different fibre orientations were considered in the present work for producing symmetric laminates, which were as followed: (i). $[0/30/45/60/-45/90]_S$ – named as $GFRP_1$, (ii). $[0/\pm45/\pm30/90]_S$ – $GFRP_2$, and (iii). $[0/\pm45_2/90]_S$ – $GFRP_3$. A subscript 'S' outside the bracket denotes symmetrical laminate definition code. The test specimens of desired dimensions were obtained with the help of a jig saw machine.

C. Characterization

Tensile and flexural tests were carried out on a universal testing machine (UTM, Model: UNITEK 94100, Blue Star Engineering & Electronics, India) with help of 10 kN and 100 kN capacity load cells. Tensile test was conducted according to ASTM D3039 using flat wedges of tensile fixture, and, on the other hand, flexural test was performed on a three bending fixture as per the ASTM D7264 [11],[12]. The test specimen dimensions are as followed: tensile test – length 250 mm, width 25 mm and thickness 3 mm, and flexural test – length 115 mm, width 13 mm and thickness 3 mm. At least four specimens were tested for each material configuration, and an average value was calculated and tabulated. The tensile and flexural strengths were calculated from the obtained load versus displacement graphs as per the formulae given in the corresponding ASTM standards.

III. RESULTS AND DISCUSSION

Mechanical behaviour of the prepared glass fibre reinforced epoxy composite laminates was evaluated under in-plane and out-of-plane loads.

A. Tensile strength measurements

Tensile tests were carried out on the electronic universal testing machine in accordance with ASTM D3039 standard for at least 3 specimens in each configuration. All the tests were performed with a constant crosshead speed of 2 mm/min and the corresponding force values against the elongation were plotted into a graph. By recording the peak loads, the corresponding maximum tensile strength values were determined for each specimen. The average of strength values for each composite configuration is calculated and the corresponding values are summarized in Table 1.

Table- I: Tensile strength values of each composite system

Composite system	Peak load (kN)	Tensile strength (MPa)
$GFRP_1$	20.730 ± 0.3	242.1 ± 15
$GFRP_2$	21.090 ± 0.6	253.4 ± 21
$GFRP_3$	19.890 ± 0.25	223.3 ± 12

The force versus elongation plots of different composite configuration systems were provided in the figures 1-3, where peak loads and the sudden drop in load values can be observed for each case.

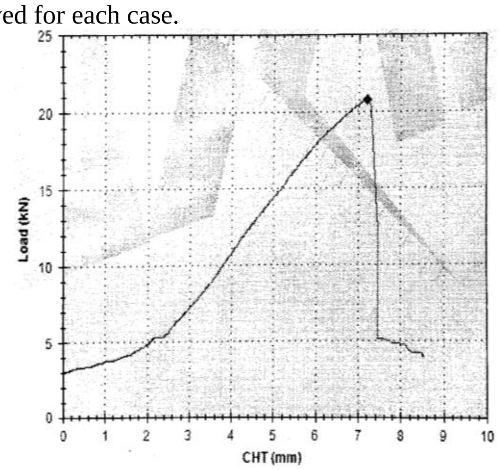

Fig. 1. Load versus crosshead travel (CHT) curve of $GFRP_1$ composite system

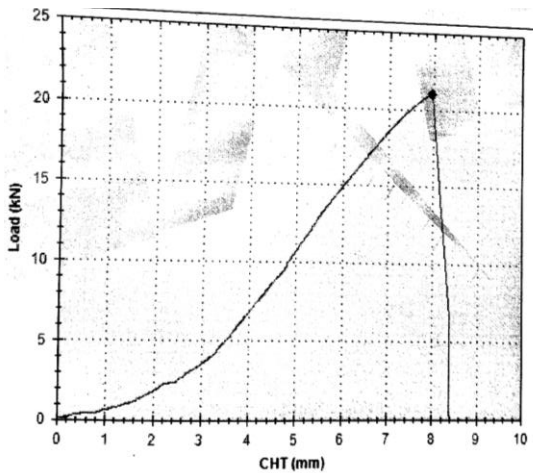

Fig. 2. Load versus crosshead travel (CHT) curve of $GFRP_2$ composite system

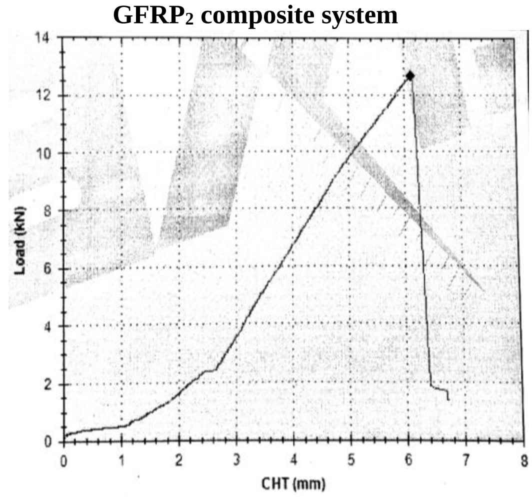

Fig. 3.Load versus crosshead travel (CHT) curve of $GFRP_3$ composite system

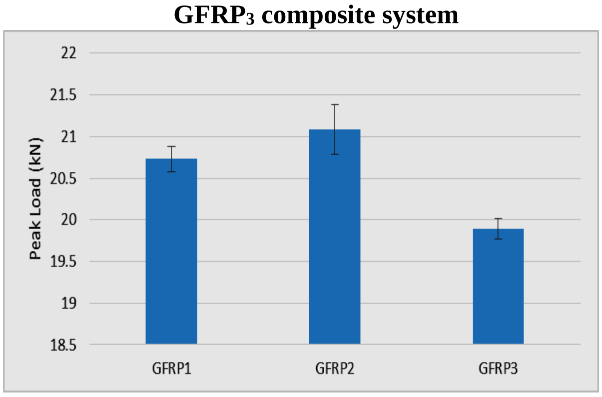

Fig. 4.Peak loads observed for each composite system under tensile loading

The bar graphs representing the peak loads and tensile strength values of each composite system were provided in the figures 4 and 5, respectively. The maximum peak load of 21.090 kN has been noticed with $GFRP_2$ configuration system, which resulted in highest tensile strength of 253.4 MPa. When compared to $GFRP_2$ system, $GFRP_1$ and $GFRP_3$ cases have noticed with lower peak loads and respective strength values as 20.73 kN and 19.89 kN, and 242.1 MPa and 223.3 MPa, respectively.

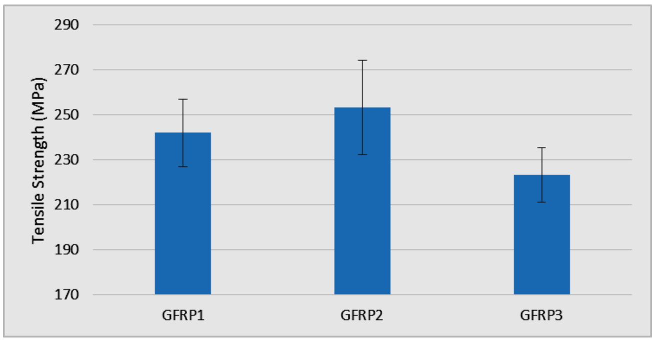

Fig. 5. Tensile strength values of each composite system

It can be understandable that the ply orientation in the each composite configuration system has played a crucial role in resisting the applied in-plane loads. The total number of 30° plies considered for the $GFRP_2$ composite system are 4, whereas $GFRP_1$ and $GFRP_3$ systems are considered with 2 and 0, respectively. It is observed that these 30° plies have significantly contributed in taking up the applied in-plane loads. It is known that when more number of UD fibre plies are oriented in the direction of applied loads, the more amount of load can be taken up by the corresponding system. In this context, when compared to $GFRP_1$ and $GFRP_3$ systems, $GFRP_2$ system is consisted of more fibre plies oriented in the direction of applied loads, hence, the highest improvement is noticed with $GFRP_2$ system.

B. Flexural strength measurements

Flexural tests were carried out on electronic universal testing machine in accordance with ASTM D7264 standard for at least three specimens in each configuration. All the tests were performed with a constant crosshead speed of 1 mm/min and the corresponding force values against the deflection were plotted into a graph. By recording the peak load, the corresponding ultimate flexural strength values were determined for each specimen. The average of strength values for each composite configuration is calculated and the corresponding values are summarized in Table 2.

Table-II: Flexural strength values for each composite system

Composite system	Peak load (N)	Flexural strength (MPa)
$GFRP_1$	38 ± 1.1	50.5 ± 14
$GFRP_2$	36.3 ± 0.85	49.3 ± 10
$GFRP_3$	33.6 ± 0.98	48.0 ± 11

The force versus displacement plots of different composite configuration systems were provided in the figures 6-8, where peak loads and the sudden drop in load values can be observed for each case. The bar graphs representing the maximum force and flexural strength values of each composite system were provided in the figures 9 and 10, respectively. The maximum force of 0.038 kN has been noticed with $GFRP_1$ configuration system, which resulted in highest flexural strength of 50.5 MPa. When compared to $GFRP_1$ system, $GFRP_2$ and $GFRP_3$ cases have noticed with lower maximum force and respective strength values as 0.0363 kN and 0.0336 kN, and 49.3 MPa and 48.0 MPa, respectively.

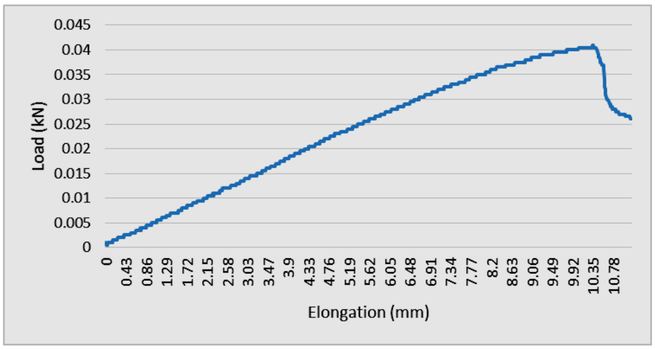

Fig. 6.Load versus elongation curve of $GFRP_1$ composite system

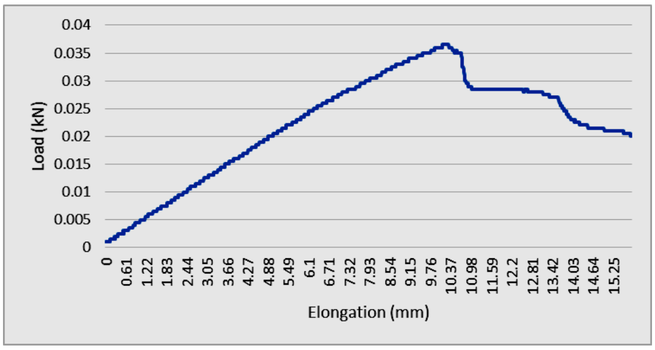

Fig. 7.Load versus elongation curve of $GFRP_2$ composite system

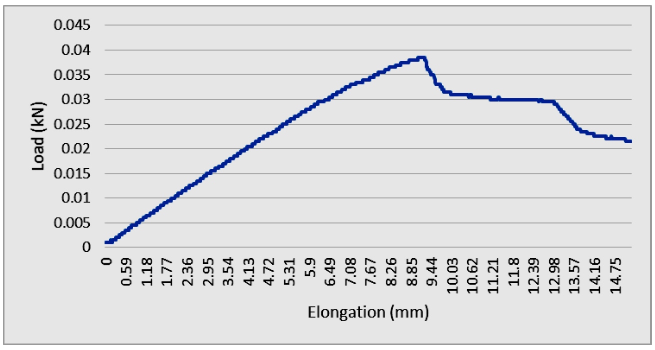

Fig. 8.Load versus elongation curve of $GFRP_3$ composite system

It can be understandable that the ply orientation in the each composite configuration system has played a crucial role in binding the fabrics in turn resisting the applied out-of-plane loads. The $GFRP_1$ composite system comprises of plies with different orientations with respect to ply to ply i.e., (0/30/45/60/-45/90), which enhanced binding nature of matrix between individual plies. On the other hand, $GFRP_2$ and $GFRP_3$ systems are considered with adjacent plies of similar orientations, i.e., (0/±45/±30/90) and (0/±45$_2$/90), respectively, have understood to be forming the possible fibre bridging, which can hinder the binding ability in turn reduces the load bearing capabilities. Hence, it is clear that the plies of different orientations have significantly contributed in taking up the applied out-of-plane loads by promoting the binding process.

In this context, when compared to $GFRP_2$ and $GFRP_3$ systems, $GFRP_1$ system consisting of adjacent fibre plies oriented in different angles has noticed the highest improvement.

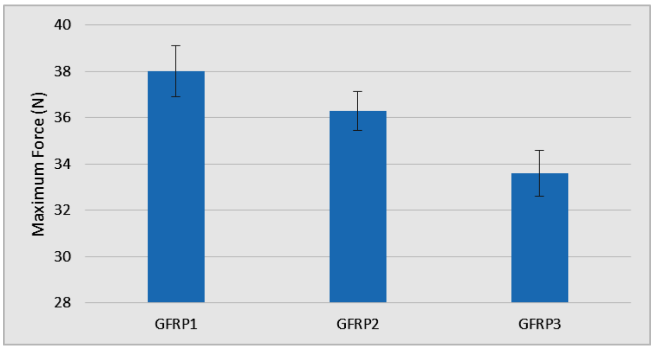

Fig. 9.Peak load values of each composite system under bending load conditions

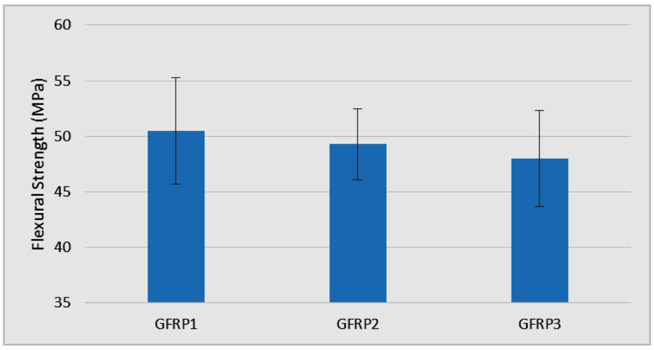

Fig. 10. Flexural strength values of each composite system

IV. CONCLUSIONS

The present work investigates the effect of ply orientation in the glass fibre reinforced epoxy composite laminates under tensile and bending load conditions.

1. Unidirectional (UD) E-glass fibre reinforced epoxy composite laminates are successfully fabricated through simple hand layup technique.
2. The prepared composite laminates are cut into desired dimensions according to the test standard requirements.
3. The test specimens are characterized under tensile and bending loads as per the corresponding ASTM standards D3039 and D7264 respectively for evaluating their strength values.
4. It has been observed that the $GFRP_2$ composite system demonstrated the maximum tensile strength value i.e., 253.4 MPa whereas a slightly lower values are noticed with $GFRP_2$ and $GFRP_3$ systems. It has been understood that the ply orientation in the each composite configuration system has played a crucial role in resisting the applied in-plane loads, where more number of fibres aligned in applied load direction has contributed great in withstanding the applied loads.
5. The flexural strength is found to be high in $GFRP_1$ composite system i.e., 50.5 MPa, due to enhanced binding strength of matrix against the plies where $GFRP_1$ comprises adjacent plies of different orientations.

Further, the current work can be extended to study the effect of ply orientation on the interlaminar shear and fracture properties.

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