MECHANICAL CHARACTERIZATION OF GFRP LAMINATE REINFORCED WITH SHORT CARBON FIBRE FILLERS UNDER ILSS TEST AND 3-POINT BEND TEST

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ABSTRACT
This research work investigates the ILSS and 3-point bending performance of plain woven GFRP/epoxy laminate of six layers doped with carbon fibre fillers. The carbon fibre fillers are chopped into the size ranging from 5mm to 10mm. These carbon fibre fillers are mixed with resin in three proportions 0wt%, 1wt%, 2wt% and 5wt% in order to investigate enhanced properties of the prepared laminate. GFRP laminate was prepared by hand layup technique assisted by vacuum bagging. The size of the specimen for the experiment was taken as per the ASTM standards for ILSS and 3-point bend test. The experiment was performed on Hounsfield machine having maximum load capacity of 50 KN and loading rate ranging from 1 mm/min to 50 mm/min. The experimental results concluded that by adding carbon fibre fillers there is 5% to 10% enhancement in ILSS and 3-point bending strength properties.

Keywords: gfrp, chopped carbon fillers, ilss test, 3-point bend test.

INTRODUCTION
Composite materials are being used by human beings since ancient times e.g. to enhance the strength and structural properties of mud bricks straws were used as the reinforcement. Rapid technological advances in engineering have brought the scientists and engineers to a point, where they require something beyond the capabilities of traditional materials. Researchers in materials technology fields are constantly looking for solutions to provide stronger, durable, lighter and much more improved properties of a certain material which can replace the traditional materials being used. Composite materials are one of the most favored solutions to such requirements. Composite materials are being used in an ever-increasing variety of products and applications, as more and more industries realize the benefits that these materials offer. The low density, high strength and stiffness to weight ratio, excellent durability under various working environment and design flexibility of fibre reinforced polymers are the main reasons for their use in various fields such as in the manufacturing of aircrafts, automobiles and marine, and in much more industrial applications. As the demands for light-weight composite structures for aerospace, ground transportation, and environmentally sustainable and friendly energy systems develop, so do the mechanical testing requirements for composite materials, components and structures.

In case of GFRP laminate though it has been used successfully in many applications on the other hand after a certain point their capabilities become limited may be in terms of inter laminar shear strength, tensile strength, bending strength, impact strength etc. In general, when a composite material is loaded, load is ultimately transferred from the matrix to fibre through the interface, which directly affects the strength and toughness of the material and in this condition the fibre/matrix interfacial strength becomes critical and it must be determined. In the present study, inter laminar shear strength and bending strength have been experimentally determined and compared by taking a GFRP laminate with 0 wt.% of chopped carbon fibre and other ones with wt% of 1 wt%, 2 wt% and 5 wt% of chopped carbon fibres. GFRP being in the traditional laminated form undergo crack initiation and propagation along the interlaminar faces more frequently, causing delamination thereby reducing the strength and stiffness which further reduce the load carrying capacity and so on. To reduce these shortcomings transverse stitching, fibre hybridization at nano, micro and macro levels with relatively stronger materials, toughening the matrix resin etc methods can be employed [1-4]. Much more work has been done in this field by different researchers. To enhance the inter laminar shear strength of GFRP injection of carbon nano-tubes (CNT) has been done which shows an increment in ILSS by 33% [5]. CNT have good mechanical properties compared to GFRP. Zhou et al. by adding 2 wt% carbon nanofibres (CNF) into GFRP found increment in ILSS by 22.3%. Interlaminar shear properties of carbon fibre composite have been improved doped with Buckley paper interleaves made from carbon nanofibres [6]. Crosslink density through the incorporation of nanoparticles (NH₂-MWCNTs) with epoxy is the important factor that governs the physical properties of GFRP composites [7]. Also by incorporating PTW/Graphite hybrid fillers enhancements in mechanical as well as wear performances of GFRP composite were noticed [8]. Mechanical properties have significantly improved on adding Al₂O₃, SiO₂ and TiO₂ micro particles in GFRP composite [9]. Hybridization also has improved bending stiffness, load carrying capacity in bending keeping different considerations into account [10]. The specimen dimensions also play a significant role in determining flexural behaviour of GFRP laminate [11].

However, comparative study on various mechanical properties with different macro modifiers like chopped carbon fibres with different wt% have not been studied much for GFRP composite. In the present study, to
characterize the mechanical properties of GFRP composite specimen i.e. GFRP doped with chopped carbon fibre fillers with different proportions dispersed in epoxy prepared by hand lay-up technique assisted by vacuum bagging has been prepared. The specimen is tested over Hounsfield machine which is a fully computerized machine up to the first appearance of failure or breakage point of the lamina and then experimentally determining the inter laminar shear strength and bending strength of the number of specimens of the GFRP composite whose dimensions are considered as per the ASTM standards

EXPERIMENTAL DETAILS

MATERIALS

In the present study, six layers unidirectional composite material specimens were prepared using glass fibres reinforcement and epoxy as a resin material (epoxy resin L-12 and hardener K-6 supplied be Atul Limited, Valsad, Gujarat, India) doped with chopped short carbon fibres of size ranging from 5-10 mm. The glass fibres chosen were having orientation of [0/90] as shown in Figure-1. woven roving E-glass made of 600 GSM supplied by Hindustan Fibre Glass Industries, India. Regular weave method was used to prepare the glass fabric. GFRP being a good engineering material available at relatively lower cost and has high impact strength, high strength to weight ratio, easily moldable and can even be used at lower temperature and competing well being in service in comparison to many other advanced polymer composites.

PREPARATION OF SPECIMEN

The technique that has been used to prepare this GFRP composite laminate with the given orientation is called as Hand layup technique assisted with vacuum bagging at 1 atm pressure. The fibres chosen for this research work were glass fibres and chopped carbon fibre as fillers. The GFRP laminate were cut to the required size as shown in Figure-2, and bonded to the glass fibre cloth by using an adhesive that is a thermosetting resin (L-12 based on Bisphenol-A) and hardener (K6) (manufactured by Atul Ltd. Gujarat, India) mixed in mass ratio of 10:1 has been used for impregnating different layers. In order to add randomly the equal wt% of chopped carbon fibres in between the five different layers, chopped carbon fibres where divided into five equal weights and then were added manually in between the layers. Prior to these things the surfaces used for the specimen preparation will be thoroughly cleaned in order to ensure that they were free from oil, dirt, etc. before bonding at room temperature and pressure.

In this manufacturing technique glass fibre sheet of measured dimension was taken, kept on a flat surface and then wetting the upper surface of glass fibre sheet with the adhesive by using a brush and then pressed with weighted roller to squeeze out extra epoxy resin, then the adding of chopped carbon fibre was done, then we put the second layer of fibre on it taking care of the orientation required as in our case it is [0°/90°]. The above steps were repeated and in between the stacking was pressed using a weighted roller so that the extra epoxy present in between the layers of glass sheets and fibres get squeezed out. This is done in order to remove the excess epoxy present which may create handling problem while vacuum bagging as shown in Figure. 3 of that laminate and it was also necessary to keep the high fibre volume fraction. Further preparing the complete stacking it is kept inside a vacuum bagging at the pressure of 760 mm of Hg for one hour and then a heavy load is placed over it for the next 24 hours. After the specified time period the laminate is taken out and the specimen is cut as per the ASTM standards i.e. ASTM D-2344 for ILSS tests and ASTM D-790M for 3-point bend test.

The seven different specimens were prepared by using different wt% of chopped carbon fibre fillers which are 0 wt%, 1 wt%, 2 wt% and 5 wt%. The specimen prepared was of six layers, chopped carbon fibre fillers were divided in five equal wt% in order to add them in between the six layers of the specimen. The size of the laminates prepared with different wt% increasing from left to right as 0 wt%, 1 wt%, 2 wt% and 5 wt% respectively have been shown below in Figure-3. The size of the specimens considered as per the ASTM standards for ILSS and 3-point bend test have been represented below in Figure-4 and Figure-5.
TESTING PROCEDURE

Experiment was conducted on a Hounsfield machine which has maximum load carrying capacity of 50 KN and loading rate can be varied from 1mm/min to 500 mm/min and is a fully computerized machine as shown in Figure-6 made up by DUCOM, Bangalore (India). Before performing the experiment the specimens for testing were cut as per the ASTM standards, for 3-point bend test the specimen size taken was 40mm×20mm×3mm NOMINAL as per the ASTM D-790M and for ILSS test specimen size taken was 20mm×8mm×3mm NOMINAL as per the ASTM 2344. Seven specimens for each wt% of chopped fibre were taken for experiment. After setting the proper machine fixture, experiments were performed on the machine. Different graphs as shown in Figure-7(a-d) and Figure-8(a-d) i.e. load vs. extension were plotted on the computer screen and through these graphs different values of flexural strength and inter laminar shear strength were noted down and the value for each strength were calculated.
RESULTS AND DISCUSSIONS

In order to determine the bending strength and inter laminar shear strength seven different specimens each with 0 wt%, 1 wt%, 2 wt% and 5 wt% of chopped carbon fibre were tested on the Hounsfield machine to calculate the behaviour and strength of the doped GFRP laminate prepared under 3-point bend test and ILSS test.

THREE-POINT BENDING TEST

The value of bending strength of GFRP laminate with different wt% of chopped carbon fibre has been represented in the Table-1. From the observed data we can clearly justify that the bending strength of the GFRP laminate have shown an increment when wt% of chopped carbon has increased from 0 wt% to 1 wt% and the value of bending strength has started decreasing at wt% of 2 wt% and 5 wt%. Since, secondary reinforcement has been made by adding chopped strands of carbon fibres and as the quantity of chopped carbon fibre are increasing amount of fibres lying in the perpendicular direction of applied load is also increasing. As it has been observed that the initial damage is always associated with the fibres lying perpendicular to the applied load, thus increasing amount of chopped fibres increases the amount of fibres lying in the perpendicular direction to the loading direction and crack initiation, fibre matrix debonding start from that point. Also with the increase of short fibre composite causes ‘end effects’ which cannot be neglected as mechanical properties of composite are the function of
fibre length. Thus end effects also significantly influence bending response at higher wt%.

Table-1. Dimensions of specimen used and the value of bending strength of the doped GFRP composite.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Specimen, wt%</th>
<th>Width, mm</th>
<th>Thickness, mm</th>
<th>Bending strength, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 wt%</td>
<td>18</td>
<td>3</td>
<td>454</td>
</tr>
<tr>
<td>2</td>
<td>1 wt%</td>
<td>18</td>
<td>3</td>
<td>468</td>
</tr>
<tr>
<td>3</td>
<td>2 wt%</td>
<td>18</td>
<td>3</td>
<td>364</td>
</tr>
<tr>
<td>4</td>
<td>5 wt%</td>
<td>18</td>
<td>3</td>
<td>304</td>
</tr>
</tbody>
</table>

ILSS TEST
The value of inter-laminar shear strength of GFRP laminate with different wt% of chopped carbon fibre has been represented in the Table-2. From the observed data we can clearly justify that the inter-laminar shear strength of the GFRP laminate have shown a gradual increment when wt% of chopped carbon has increased from 0 wt%, 1 wt%, 2 wt% to 5 wt%. This gradual increase in inter-laminar shear strength for ILSS samples is due to secondary reinforcement i.e. chopped carbon fibre. This chopped carbon fibre takes the load applied on the ILSS samples with different wt% as load bearing capacity of carbon fibre is significantly higher as compared to glass fibre. Therefore, for this type of sample inter-laminar shear strength increases with increase in wt% of chopped carbon fibre. To calculate the inter-laminar strength of the specimen, the general equation used was,

$$ILSS = \frac{0.75 P}{A}$$

Where, $P$ = Maximum load applied  
$A$ = Cross-sectional of the specimen.

Table-2. Dimensions of specimen used and the value of inter-laminar shear strength of the doped GFRP composite

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Specimen, wt%</th>
<th>Width, mm</th>
<th>Thickness, mm</th>
<th>Inter-laminar shear strength, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 wt%</td>
<td>8</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>1 wt%</td>
<td>8</td>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>2 wt%</td>
<td>8</td>
<td>3</td>
<td>19</td>
</tr>
<tr>
<td>4</td>
<td>5 wt%</td>
<td>8</td>
<td>3</td>
<td>25</td>
</tr>
</tbody>
</table>

CONCLUSIONS
After observing all the experimental results of three point bending test and Inter-laminar shear strength test of the GFRP composite doped with 0 wt%, 1 wt%, 2 wt% and 5 wt% of chopped carbon fibre taken in consideration, the following conclusions can be made:

1. The bending strength of the GFRP doped with chopped carbon fibre with varying wt% has increased when the wt% of chopped carbon fibre has increased from 0 wt% to 1 wt% but at the 2 wt% and 5 wt%, the value of bending strength has decreased significantly. This behaviour is observed as the chopped carbon fibre has provided the reinforcement up to 1 wt% but after that the amount of chopped carbon is increased, the amount of fibre lying in the perpendicular direction is also increasing which increase the chances of failure of the material because of crack initiation and fibre-matrix debonding and these short fibres also cause end effects as the mechanical properties of the composite material is also a function of fibre length.

2. The inter-laminar shear strength of the GFRP doped with chopped carbon fibre with varying wt% has gradually increased when the wt% of chopped carbon fibre has increased from 0 wt%, 1 wt%, 2 wt%, 3 wt% and 5 wt% significantly. The secondary provided in the form of chopped carbon fibre which is stronger than glass fibre increase the load bearing capacity of the ILSS sample of composite material and enhances its strength.

REFERENCES


