EXPERIMENTAL EVALUATION OF FLEXURAL PROPERTIES OF POLYMER MATRIX COMPOSITES

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ABSTRACT

Prediction of the flexural strength of a laminated composite is important for engineering application yet difficult in nature. The purpose of this work is to experimentally analyze the progressive failure process of laminated composites subjected to a bending load, with application to different reinforced fibers. The analysis is based on the classical lamination theory and a bridging micromechanics model. Only the mechanical properties of constituent fiber and matrix materials under the bending load condition and the laminate geometric parameters are required. All these data can be measured independently before composite fabrication. As the internal stresses in the fiber and matrix have been explicitly determined using the bridging model, a lamina in the laminate is considered to have failed whenever any of its constituents fails, according to a stress failure criterion. Then, a stiffness discount is applied to the failed lamina, and a predicted progressive failure process results. Unlike in an in-plane load situation where the ultimate tensile strength occurs when the laminate's last ply fails, the ultimate bending strength of the laminate is attained generally before its last-ply failure. As one does not know a priori which ply failure corresponds to the ultimate failure, the use of only the stress failure criterion is no longer sufficient for the determination of the laminate ultimate strength. An additional critical deflection or curvature condition must be adopted either. The critical deflection or curvature is the laminate deflection or curvature corresponding to which the ultimate bending strength is measured. Experiments have been...
carried out to obtain the bending stiffness and strength of laminated beams reinforced with six layers of bi-woven plain glass cloth and carbon fibers under three-point bending. The laminate lay-ups used are: [0], where 0 denotes that the fabric along the beam axial direction. For these laminates and based on the stress failure criterion, the measured load-deflection curves till the -ply failure agree reasonably with the available literature data. By incorporating with the critical deflection condition, the laminate ultimate bending strengths thus obtained correlate favorably with the measured results.

Keywords: Carbon Fiber, Glass Fiber, Flexural Test, Laminated Composites, Vacuum Lay-Up.

I. INTRODUCTION

Fiber composites with brittle materials, including glass, ceramic, and carbon have potential that may make them attractive structural materials for different types of applications. Recent progress in materials and processing research and development has advanced several systems to a stage appropriate for detailed structural evaluation. Composites used in this configuration will be fabricated in a typical process with unidirectional tapes stacked in the desired ply configuration and compression molded at a temperature where the glass matrix would flow sufficiently to form fully densified material. Most fibers can be degraded to some extent at very high processing temperature, and an effective technique for developing high-temperature resistance is to use glass-ceramic matrices have been successfully fabricated with several carbon and ceramic fibers [1-3]. The mechanical properties of these materials have been evaluated in most studies by three and four point flexural specimens, which are convenient to run on small samples of material and at elevated temperatures. While a number of programs are underway to develop high temperature tests, a few studies have reported high temperature properties other than flexure [4-7]. Flexural tests of sufficient span to depth ratio usually produce a tension dominated failure mode with qualitative strength and damage trends that agree with tensile data. However, as with other fiber composites, flexural tests do not give adequate material property data for quantitative structural characterization [8-11].

The physical properties of carbon fiber reinforced polymer (CFRP) composite material depends considerably on the nature of matrix, the fiber alignment, the volume fraction of the fiber and matrix, and on the molding conditions. Therefore, by choosing suitable parameters, it is possible to make composite suited to a particular need. Several types of matrix material such as polymers, glass and ceramics and metals have been used as matrices for reinforcement by carbon fibers. However, from the point of view of mechanical properties, density and fiber matrix cohesion, epoxy resins are frequently the best choice. Carbon fibers are considered excellent reinforcement for polymers because

1. They are strong, stiff, and lightweight
2. Their high modulus makes the reinforced structure stiff and
3. Many polymers have good adhesion characteristics towards carbon fibers and can make sound structures. Based on theoretical and experimental work on fiber-resin system, a
The number of following requirements must be fulfilled in order to realize the maximum benefits from fiber reinforcement (Chung et. al., 1994):

1. The fiber content should be as high as possible since the fibers are the source of strength. In practice, up to 70% by volume of fiber can be achieved with care.

2. The alignment and directions of the fibers is of paramount importance. The property of fibers in any direction determines the properties of composite in that direction. Twist in the reinforcement, even though it may involve only a small percentage of fibers, is detrimental as twisted fibers do not contribute fully, but do give uneven resin distribution.

3. Fibers should be wetted out fully by the resin to ensure good contact and bonding at the interface so that the load may be transferred from one fiber to another throughout the composite.

4. Good bond strength at the resin-fiber interface is essential for load transfer in the composite. The matrix should be compatible with the fiber and should not debond or crack when the fiber undergoes maximum strain at full load.

Polymer-matrix composites are much easier to fabricate than metal-matrix, carbon matrix and ceramic-matrix composites, whether the polymer is a thermoset or thermoplastics. Thermosets (especially epoxy) have long been used as polymer matrices for carbon fiber composites. The properties of several thermoplastic resin with carbon fiber are listed in Table 2.1 in comparison with epoxy. In contrast, epoxies have tensile strengths of 30-100 MPa, moduli of elasticity of 2.8-3.4 GPa, ductilities of 0-6% and a density of 1.25g/cm3. Thus, epoxies are much more brittle than most of the thermoplastics.

Composite construction is well known for providing high stiffness with light weight, and is widely used to provide efficient structures. The design of an efficient composite structure entails the specification of a number of parameters, including the materials, density, and thickness of the layers, materials used as fibers. Because of the number of design variables, the optimization of the composite structure is not trivial, and has been considered by a number of authors [12–16].

II. FABRICATION OF TEST SPECIMENS

Bi-woven glass cloth & carbon laminate which is commercially available is used as fibers for making the specimens with epoxy resin as matrix. The cloth ply was trimmed to the correct size and stacked in 0°/90° orientation and was built to a thickness of around 2.0 mm & 3.0 mm. The surfaces were thoroughly cleaned in order to ensure that they are free from oil, dirt, etc., before bonding at room temperature. An adhesive made from a mixture of LY556 resin & HY 951 hardener mixed in the ratio of 100:10 by weight was then applied. Vacuum hand lay – up technique (Figure 1) was used to make the specimens. Vacuum level (500 mm of Mercury for 2 hours) was monitored so as to avoid surface undulations and also avoid air pockets at the interface. The specimens were allowed to cure for about 4 hours at room temperature.

Vacuum hand lay – up process offers many benefits when compared to conventional hand lay-up techniques. As it is a closed molding process, it virtually eliminates potentially harmful volatile organic compound (VOC) emissions. It also allows unlimited set-up time because the resin system is not introduced until all the reinforcements and core materials are in place. This method is of a particular benefit when producing large Facings due to the
weight savings that can be gained, greater structural strength and efficiency gains against the Hand Lay process. The vacuum system also facilitates good resin distribution and consolidation of the laminate. As a result, the resulting mechanical properties of the laminates are likely to be markedly higher than would be the case with hand laminating.

Fig. 1: Laminates Curing Under Pressure

III. EXPERIMENTATION

The experimental process involves flexural testing of 12.5mm wide x 125 mm length of specimens. Two thicknesses of 2 mm & 3mm for both glass fiber and carbon fiber specimens were mounted on test equipment as shown in fig below. Three point bend test were conducted as per ASTM D 790 were carried out to determine laminate bending stiffness and bending strength on both the types of composite panels. Three-point bend tests were conducted and the method of loading is indicated in Fig. 2. Flexural testing with central loading has been carried out in accordance with ASTM D 790 using Flexural Testing Machine. The movable carriage of the machine is brought on the loading bar and load is applied gradually at the cross head displacement rate of 2 mm/min. Plot of load versus deflection is recorded. Few of the specimens are tested up to the elastic limit and few up to failure load. The above tests were carried out for both the types of specimens and the results were recorded.

<table>
<thead>
<tr>
<th>Specimen Designation</th>
<th>Panel Size (mm)</th>
<th>Panel Thickness (mm)</th>
<th>Specimens Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel A – Glass fiber</td>
<td>125 x 12.5</td>
<td>2 mm thick</td>
<td>3 Nos.</td>
</tr>
<tr>
<td>Panel B – Glass fiber</td>
<td>125 x 12.5</td>
<td>3 mm thick</td>
<td>3 Nos.</td>
</tr>
<tr>
<td>Panel C – Carbon fiber</td>
<td>125 x 12.5</td>
<td>2 mm thick</td>
<td>3 Nos.</td>
</tr>
<tr>
<td>Panel D – Carbon fiber</td>
<td>125 x 12.5</td>
<td>3 mm thick</td>
<td>3 Nos.</td>
</tr>
</tbody>
</table>

Table 1: Composite Panel Specification

Fig. 2: Flexural Testing of Composites
IV. RESULTS AND DISCUSSIONS

The flexural properties of the composite specimens have been calculated using the measured data of the Load vs. Deflection Curve. Typical load versus deflection curves has been obtained for composite specimens of 2mm thick and 3mm thick with Glass and Carbon fibers respectively. The data obtained from the independent tests from three point tests on the same specimen were used in the calculations. The graphs of load versus deflection were linear until the specimen reached the yield / breaking point. The deflections undergone by the specimen have been found to be large in the case of three-point load test. The flexural stiffness of the specimen kept increasing steadily in case of carbon fiber specimens when compared to specimens with glass fiber inserts and also it is close to the theoretically estimated values.

It has been found that the flexural stiffness parameter obtained from flexural tests as per ASTM standard are in excellent agreement and suggestive of simpler tests to predict the static behavior of composite beams. The results also suggest that fibers with carbon can bring out an increase of 20% or 35% increase in flexural strength with a marginal increase in weight increase of the composite beam.

<table>
<thead>
<tr>
<th>No. of Trials</th>
<th>Specimen</th>
<th>Max. load, kN</th>
<th>Average Load, kN</th>
<th>Flexural Strength, MPa</th>
<th>Disp. mm</th>
<th>Average Disp. mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>Glass Fiber 2mm</td>
<td>0.4</td>
<td>0.4</td>
<td>390.4</td>
<td>1.0</td>
<td>1.04</td>
</tr>
<tr>
<td>Trial 2</td>
<td></td>
<td>0.38</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 3</td>
<td></td>
<td>0.42</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 1</td>
<td>Glass Fiber 3mm</td>
<td>0.58</td>
<td>0.57</td>
<td>542.6</td>
<td>3.25</td>
<td>3.28</td>
</tr>
<tr>
<td>Trial 2</td>
<td></td>
<td>0.56</td>
<td></td>
<td></td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td>Trial 3</td>
<td></td>
<td>0.58</td>
<td></td>
<td></td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td>Trial 1</td>
<td>Carbon Fiber 2mm</td>
<td>0.30</td>
<td>0.28</td>
<td>443.2</td>
<td>2.25</td>
<td>2.08</td>
</tr>
<tr>
<td>Trial 2</td>
<td></td>
<td>0.27</td>
<td></td>
<td></td>
<td>2.0</td>
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<tr>
<td>Trial 3</td>
<td></td>
<td>0.28</td>
<td></td>
<td></td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Trial 1</td>
<td>Carbon Fiber 3mm</td>
<td>0.42</td>
<td>0.48</td>
<td>592.34</td>
<td>2.9</td>
<td>3.20</td>
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<td>0.47</td>
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<td></td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>Trial 3</td>
<td></td>
<td>0.53</td>
<td></td>
<td></td>
<td>3.6</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Experimental Results of Three Point Bend tests

It is evident from the above table, carbon fibers manifest the flexural strength and load when compared to glass fibers, and this is due to the fact that glass fibers are brittle in nature. In addition, the results obtained from the above tests are in good agreement with the literature available and in concurrence with the theory, which states that the strength and stiffness of carbon fibers are higher than any fibers.
V. CONCLUSIONS

Experimental Flexural Testing of two composite specimens with bi-woven glass fiber and graphite with two different thicknesses such as 2mm and 3mm were investigated. The following observations were made from the two composite specimens when tested.

1. Composite specimen with glass fibers seems to improve the flexural parameters when compared to graphite fibers for the same loading and boundary condition.
2. There has been increment in the stiffness from the specimen with glass fibers. The table above provides the details of the flexural testing on both the specimens.
3. Graphs describe the 3-point bend test of both the types of specimen with boundary conditions as simply supported mounted on the fixtures as shown in the figure. The flexural strength corresponds to 45% increase in case of glass fibers with 2mm whereas the value further increases to 50 % with 3mm; this is very evident that graphite fibers have poor resistance to flexural load than glass fibers.
4. Similarly, figures above depict the different failure modes of composite specimens when subjected to flexural load. It can be observed that the carbon fibers take less bending load as compared to glass fibers.
5. It can be observed from the above table that there is significant improvement in the failure load in case of glass fibers with 2 & 3 mm along with carbon fibers. Therefore, it is very clear from the investigation that glass fiber manifests flexural strength and stiffness and is recommended in the use of structures where flexural load is expected.

REFERENCES

Journal Papers