INFLUENCE OF ANGLE PLY ORIENTATION ON INTERLAMINAR SHEAR STRENGTH OF BI-DIRECTIONAL KEVLAR FIBER REINFORCED COMPOSITES

Dr.K.Vasantha Kumar
Assistant professor, Mechanical Engineering Department, JNTUHCE jagitiyal

Abstract

The present investigation concerns experimental and finite element analysis of Kevlar epoxy composites with and without presence of filler materials to gauge interlaminar shear strength. Mechanical properties such as elastic modulus, Poisson’s ratios, thickness are kept constant, the corresponding deflections and interlaminar shear strengths are estimated by both experimental and ANSYS. From simple rule of mixtures, equivalent orthotropic material properties are estimated. For generating finite element model the estimated properties are used as input in ANSYS and the model short test beam specimen shell layered element is used. It is inferred that test outcomes are in top agreement with outcomes generated by ANSYS. The superiority of the presence of Kevlar epoxy in the composite is proved from experimental and finite element technique from the predicted fracture parameters. Many structures used in Automobile, Aerospace, Naval and other Transportation vehicle structural parts are subjected to diverse kinds of masses. These structures are further subjected to bending loads inflicting shear stress in the structures.

This paper investigates the effect of fiber orientation on the Interlaminar shear strength of Kevlar fiber reinforced polyester laminated composite material, with the variation in the orientation of the reinforced fibers there will be a substantial variation in the interlaminar shear strength of the laminated composites. In the present paper fabrication of Kevlar fiber reinforced laminated composites with varying orientation of reinforced fibers were prepared using the hand layup technique and these specimens are subjected to 3 point bending testing and the investigations are carried out as per the ASTM standards. The motive of this observe is to experimentally examine the progressive failure process of laminated composites subjected to shear loads, shear loading reason stresses in the composites.

Keywords: Kevlar fiber, filler material, 3-point bend test, ASTM,

1. Introduction

Composites materials are made by combining materials together to form an overall structure with properties that differ from the sum of individual components. These include metals alloys, plastic co-polymers, minerals, and wood. Composite materials differ from the other materials in that the constituent materials are different at the molecular level and are mechanically separable. the constituent materials work together but remain in their original forms. The final properties of composite materials are better than constituent material properties.

The use of composite materials has gained widespread acceptance as an excellent way of obtaining stiffness, strong and very light-weight structural elements. However, load introduction into composite structural elements through joints, inserts and mechanical fasteners is associated with considerable difficulties. The primary reason for this is the layered structure of composite laminates, which results in poor strength properties with respect to loading by inter laminar shear and transverse normal stresses.
2. Literature review:

The information on the issues to be considered in the present paper and to focus the significance of the current study. The objective is also to present a thorough understanding of effect of various parameters influencing on the mechanical properties of fiber reinforced polymer composites. In the recent years there is vast growth in fiber based polymer composites due to its various attractive features like biodegradability, no abrasiveness, flexibility, availability, low cost, light weight etc. Different researchers have performed various experiments to enhance the mechanical properties of fiber reinforced polymer composites. The literature review is based on the study by various investigators in the following aspects


3. Objectives:

After exhaustive literature survey and discussion, it is imperative that the use of polymer laminated composites is an emerging field in all sectors of the industry specifically in automotive industries because of its benefits of high strength to weight ratio to enhance the performance. Evaluation of flexural and shear properties of laminated composites are realized to be important as flexural test and short beam shear test are considered as real-time tests as most of the components are subjected to bending and shear load.

1. Flexural and short beam shear properties for plain bi-directional laminates were not much emphasized for different fiber orientation in the earlier literature.

2. Flexural properties for varying thickness of the specimens were not being evaluated especially for fiber reinforcement volume between 54-60% in the earlier literature.

3. Effect of de-lamination at the interface between the matrix and Fiber reinforcement under flexural loads is not being addressed.

4. The work has been done on correlation of experimental results with FEA results for different fiber fraction and fiber orientation. So, in the present paper, it is intended to focus the investigation on flexural and shear properties of the laminated composite materials which is very useful to the industry and helps design engineers to choose appropriate materials for specific applications.
4. Experimental work:

Kevlar fiber grade 360 GSM & diameter of glass fiber is 0.25 mm diameter is tailored with carbon fiber 0.25 mm diameter to prepare bi-woven clothes. The thickness of the cloth is 0.3 mm which are stacked layer by layer about 10 layers to attain required thickness. In the present paper fabrication of glass fiber polyester laminated composites with varying orientation of reinforced fibers were prepared using the hand layup technique. The specimens are stacked into sets form [±30°], [±45°], [±60°] and [±75°]. The four different angle ply orientations, laminates are prepared as per the balance symmetrical angle ply form [+45/-45/-45+45], and they are cut by the CNC milling machine as per the required ASTM D2344 standards. After, they appear to be like shown in figure 5.1. The dimensions are 80 mm length, span length 24 mm, 8 mm width and of 4 mm thickness, and short beam shear test is conducted to determine the Interlaminar shear strength across the cross-section of different laminated angles, and these specimens are subjected to 3 point bending test, the investigations are carried out as per the ASTM standards. Using the load-deflection graph the maximum load, maximum deflection and the interlaminar shear strength of the specimen for different laminated composites is evaluated and the appropriate conclusions are drawn and the results are compared and analyzed.

5. Mechanical Testing of Composites:

The performance of polymer composites is affected by many factors such as properties of the fibers, orientation of the fibers, content of the fibers, properties of the matrix, fiber-matrix interfaces etc. Increase in volume content of reinforcements can increase the strength and stiffness of a composite to a point. If the volume content of reinforcements is too high then there will not be enough matrix to keep them separate, and they can become tangled.

6. Short beam shear test:

The method which is based on the fact that in some cases, a beam loaded in three point flexure may be made to fail in interlaminar shear at the neutral plane before the outer fibers break in tension or compression. A number of investigations of the effect of specimen geometry on the measured strength have been made and for CFRP the recommended span to thickness ratio is six, but even at this ratio composites of low fiber strength or high interlaminar shear strength may fail prematurely in flexure.

The test is economical of material and simple to perform there is a number of drawbacks. The principal drawbacks are that the stresses are non-uniform, even in the plane of the laminate, the states of combined stress exist and that severe stress concentration arises at the points of load application. Classical beam theory gives the relationship for shear strength as

Shear strength = 0.75\(P_b/bt\)

Where \(P_b\) is the breaking load,
And \(b\) and \(t\) are the width and thickness respectively.

The test specimens were placed on the two 3.0 mm diameter supports, with care taken to align the center of the specimen in the center of the span. Loading supports were free to rotate, allowing free lateral motion of the specimen. Load was applied in the center of the specimen at the rate described above through the use of a 6.0 mm diameter steel dowel. The beam was loaded until fracture, and the fracture load was taken as a measure of the apparent shear strength of the material. Displacement was measured from the relative movement of the loading head through the use of the integrated MTS linear displacement gauge. The test set-up can be seen in Figure 4.3 below.
However, it has been shown that the assumptions on which this theory is based do not pertain to the short beam test. A finite element analysis by Berg has shown that due to stress concentration in the region of the loading points, the maximum shear stress does not occur at the centre of the beam and that the method may significantly under estimate the true maximum shear strength. However, even this theory is inadequate, since it assumes there are no end effects; also equation assumes a linearly elastic stress-strain relationship, which is in general not true. As previously noted, the measured shear properties are also depend on the state of loading. In this particular test the measured strength has been shown, to drop with very rapid loading and it is thought that these results from the fact that the stress concentration discussed above do not have time to dissipate plasticity.

Despite these drawbacks it is a simple, reproducible test, useful for qualitative evaluation and likely to provide a satisfactory accurate measurement of „Interlaminar” shear strength. The method has been adequately described elsewhere, and the dimensions are given as ASTM D2344 of 80 mm long, span length 24mm, 8 mm width and 4 mm thickness. The specimen was tested to failure in the Instron universal machine at a head displacement rate of 2mm/min.

**Fig 1: Short Beam Shear Test Loading Configuration (ASTM D2344/D2344M)**

Short beam shear:

Load introduction can cause local failure under the loading noses. Use of proper radius of noses, soft loading pads, and four-point loading can reduce severe effects of such local damages but only to a limited extent. In addition to stress concentration under loading points, existence of bending stress complicates the stress state. Bending stresses can also be reduced by using the four point loaded specimen. Non-uniform shear stress distribution and small depths make measurement of strains impossible. Due to non-uniform shear stress distribution along the mid-plane, shear strength is often over estimated (by the assumption of parabolic variation) and perhaps for this reason the test sometimes yield strengths comparable to in-plane shear strengths. Effects of specimen imperfections are not known, but probably not significant. Failure often occurs in mixed mode and is also influenced by damage under the loading noses. Data reduction is simple, but the assumption of parabolic shear stress distribution may not be always valid for strength calculation.

7. Results and Discussions:

This paper presents the results of experimental and finite element analysis behavior of polymer composites and the effect of fiber parameter such as angle ply orientation on the performance of composites are analyzed.
A: Effect of Ply Orientation on Shear Strength of Composites

The influence of angle ply orientation on the shear properties of composites is shown in the Figure. It is evident that the shear strength gradually increases with increase in fiber orientation up to $[\pm 45^\circ]_6$ and decreases up to fiber orientation of $[\pm 75^\circ]_6$. It is observed that shear strength is maximum for angle ply oriented at $[\pm 45^\circ]_6$ in a composite specimen and is minimum for $[\pm 75^\circ]_6$ oriented fiber in a composite specimen in case of composite without addition of filler material. The experimental results are furnished in fig 15 to fig 18.

B: ILSS Testing of Kevlar Fiber Laminates with filler material:
Inter laminar shear strength was done at room temperature, three point bend testing on the universal testing machine as shown above in the figure 4.1 (a) cross head speed was 5mm/min. total eight samples were carried out to determine the inter laminar shear strength and the results are shown in table 1 and table 2 with and without filler material.

Case (1): ILSS OF $[\pm 0^\circ]_{14}$ Kevlar fiber Laminate with filler
Case (4): ILSS of $[75^\circ]_{14}$ Kevlar fiber laminate with filler

Fig 10: Graph of ILSS of $[75^\circ]_{14}$ by Short Beam Test

C: ILSS Testing of Kevlar Fiber Laminates without filler material

Case (1): ILSS of $[\pm 0^\circ]_{16}$ Kevlar fiber laminate without filler

Fig 11: Graph of ILSS of $[0^\circ]_{16}$ by Short test

Case (2): ILSS of $[30^\circ]_{16}$ Kevlar fiber laminate without filler

Fig 12: Graph of ILSS of $[30^\circ]_{16}$ by Short Beam Test

Fig 7: Graph of ILSS of $[0^\circ]_{14}$ by Beam test

Case (2): ILSS of $[30^\circ]_{14}$ Kevlar fiber laminate with filler

Fig 8: Graph of ILSS of $[30^\circ]_{14}$ by Short Beam Test

Case (3): ILSS of $[\pm 45^\circ]_{14}$ Kevlar fiber laminate with filler

Fig 9: Graph of ILSS of $[45^\circ]_{14}$ by Beam test

Fig 10: Graph of ILSS of $[75^\circ]_{14}$ by Short Beam Test

Fig 11: Graph of ILSS of $[0^\circ]_{16}$ by Short test

Case (2): ILSS of $[30^\circ]_{16}$ Kevlar fiber laminate without filler

Fig 12: Graph of ILSS of $[30^\circ]_{16}$ by Short Beam Test

Fig 8: Graph of ILSS of $[30^\circ]_{14}$ by Short Beam Test

Case (3): ILSS of $[\pm 45^\circ]_{14}$ Kevlar fiber laminate with filler

Fig 9: Graph of ILSS of $[45^\circ]_{14}$ by Beam test
D: Modal Analysis:

From the analysis the materials used are Kevlar fibers and epoxy resin as matrix material. The test piece Analysis is conducted by the use of ANSYS 14.5 finite element analysis as shown in table 1 and table 2 with and without filler material. In case of pre-processing the material properties of the test specimen, stacking sequence and angle of orientation, modeling and meshing are made then solve the current problem option in the solution stage and the last general post processor is used to read and analyze the unlike parameters obtained by the solutions.

In case of pre-processing procedure 3D 4 nodes 181 shell element is used to replicate the laminates. Specification of the specimen is taken as per the ASTM D2344, 30 mm x 10mm laminates with 5mm thickness. From simple rule of mixtures material properties are calculated with Kevlar FRP composite is made of 60% fiber and 40% epoxy matrix by volume. The results are furnished in fig 19 to fig 26.

(a) Laminate with filler material
Table 1: Interlaminar shear strength in kevlar epoxy Reinforced Polymer Composite with Variation in angle ply orientation in experimental and ANSYS.

<table>
<thead>
<tr>
<th>S. No</th>
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<th>EXPERIMENTAL</th>
<th>ANSYS</th>
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<tbody>
<tr>
<td></td>
<td>Max Load [Kgf]</td>
<td>Shear Strength [MPa]</td>
<td>Max Load [Kgf]</td>
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<td>$[\pm 0^\circ]_{14}$</td>
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<td>4</td>
<td>$[\pm 75^\circ]_{14}$</td>
<td>46.8</td>
<td>6.88</td>
</tr>
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</table>

(b) Laminate without filler material:

Table 1: Interlaminar shear strength in kevlar epoxy Reinforced Polymer Composite with Variation in angle ply orientation in experimental and ansys
E: Comparison of Results Experimental and ANSYS:

<table>
<thead>
<tr>
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<th>ANSYS</th>
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Fig 15: ILSS of Short Beam Test of Experimental Results plotted in Shear Strength Vs angle ply orientation (without addition of filler).

Fig 16: ILSS of short beam test for experimental results plotted in shear strength Vs angle ply orientation (with and without addition of filler).

Fig 17: ILSS of short beam test for both experimental results and ANSYS results plotted in shear strength Vs angle ply orientation without filler material.
Fig 18: ILSS of short beam test for both experimental results and ANSYS results plotted in shear strength Vs angle ply Orientation (with filler material)

Fig 19: FEM Analysis of [±0°] orientation by ANSYS

Fig 20: FEM Analysis of [±30°] orientation by ANSYS

Fig 21: FEM Analysis of [±45°] orientation by ANSYS

Fig 22: FEM Analysis of [±75°] Orientation by ANSYS
CONCLUSIONS

From the experimental and analysis results the following conclusions are drawn.

1. Presence of the sample after breakdown demonstrates the expected behavior. As per standards the samples are breakdown at span length.

2. ILSS is greatly influenced by the angle ply orientation. Here ILSS increases at the orientation of fiber at \([±45°]_{16/14}\), and there is gradual decrease at angle of \([±75°]_{16/14}\).

3. Maximum value of ILSS is observed at the angle ply orientation of \([±45°]_{16/14}\). ILSS decreases with increase in angle ply orientation of laminates up to \([±45°]_{16/14}\) and later decreases up to \([±75°]_{16/14}\).

4. As expected by comparison between composite laminates made with and without filler material, the filler material composites showed more strength and can carry loads heavier.

5. Both the composites made with and without filler material showed similar behavior under similar loading conditions.

6. The outcomes of this study can’t be contrasted with other sorts of fiber reinforced laminate.

7. For better ILSS property, orientation of fibre should be less than \([±45°]_{16/14}\) of 5 mm thickness.
REFERENCES


