Mechanical Testing and Numerical Analysis of Flax/Glass Epoxy Hybrid Composite Material

S NARESH KUMAR¹, D VENKATESH², B. SUBBARATNAM³ M SHEKAR⁴

¹,³Department of Mechanical Engineering, Vardhaman College of Engineering, Hyderabad, India
²PG Scholar, Department of Mechanical Engineering, Vardhaman College of Engineering, Hyderabad, India
⁴Project Assistant, Instrumentation Group, CSIR-NGRI, Hyderabad, India

Corresponding author: venkateshd688@gmail.com

Abstract. The natural fibres, as reinforcing medium will tremendously use in polymer composite industries due to rapid development of research in this field to maintain the sustainable materials towards its application. In this paper, Bidirectional woven E-Glass and Flax Fabrics with Epoxy resin were used to fabricate the two different composites with (0⁰, 45⁰) orientation by hand layup method. Laminate-1 made of four flax/epoxy layers and four Glass/Epoxy layers consecutively arranged one after the other. Laminate-2 made of four Flax/Epoxy layers sandwiched between the two Glass/Epoxy layers top side and two Glass/Epoxy layers bottom side of the laminate. Tensile test and bending test results obtained as per ASTM standards. Finite element analysis was used in ABAQUS software for the simulation of important mechanical properties in tension and bending of the two laminates. Theoretical results obtained in FEA were compared with the experimental results of both laminates in terms of Force-displacement curve on the elastic domain. The error percentage of the maximum strength of two laminates were 4.8% and 8.04% respectively in the tensile test, similarly the maximum flexural strength of two laminates in order of 5.33% and 2.54% in bending test. Due to this experiment, it observed that the strength of the laminate is more in the hybrid composite than the composite made of purely natural fibres.

Keywords: Woven Flax, E-Glass, FEA model, Laminate, tensile test, bending test.

1. INTRODUCTION

The natural fibers (Jute, Hemp, Flax, Kenaf, and Sisal) have abundantly used in the process of fabrication of composites as reinforcement material for the last ten decades. The natural fibers were preferred than synthetic fibers (Example: E-Glass) because of increasing environmental concern and high need for eco-friendly material [1]. Sathish et al. [2] proved that laminate made of a combination of both natural fiber (jute) and synthetic fiber (E-Glass) with epoxy resin has more tensile strength & impact strength than laminate made only single type natural fiber. Ramesh et al. [3] showed that 0⁰ flax fiber orientations have more value on important Mechanical properties than 90⁰ orientations.
Camalia Cerbu et al. [4] paper reveals that the equivalent Young's modulus $E_x$ in bending for two different hybrid composites (Flax/Epoxy and Glass/Epoxy) in weft direction was more than wrap direction because flax yarn use in wrap direction is not same with the yarn used in the weft direction. The mechanical properties of hybrid composites depend on the orientation of fibers, the method of fabrication, the addition of fillers, and some geometrical parameters of fibers [5-8].

Flax fibers were excellent material that can be hybridized easily with carbon fiber, E-glass synthetic fibers. Moreover, it has a better tensile strength (343 – 1035MPa) and cost effective fiber, so that these are preferable to fabricate composite laminates for various applications than other natural fibers like Hemp, Jute fibers [9]. Here, the bleached brown color fiber yarns used whose 200µm fiber diameter and chemical composition of 88 % cellulose, 0.6-4 % lignin with 3 to 4 % pectin.

In this paper, two types of laminates fabricated by using a hand layup method with different stacking sequences and tested experimentally in the laboratory. Numerical analysis performed in ABAQUS (student edition 2018 Dassault system) software and validated by comparing the results of mechanical properties such as maximum Tensile strength, maximum force, Young's modulus, Flexural strength, and impact strength, etc.

The main objective of this work is to determine important mechanical properties from the experimental & numerical method for two laminates, compare themselves as well as those with previously published papers, and observe the strength variation across the lamina stacking sequence with different plies orientation in bending test.

## 2. MATERIALS & METHOD

In this paper, Bidirectional plain-woven Flax and E-glass fabrics were taken whose size of yarn in the weft direction and wrap direction approximately same. The density of the E-Glass fabric is $\rho = 410$ g/m$^2$ while the density of the Flax fabric is $\rho = 250$ g/m$^2$. The Epoxy resin Araldite LY556 and Hardener Aradur HY951 were used as matrix material and both are applied in the ratio of 10:1, some of its mechanical characteristics without reinforcement are Tensile strength $\sigma_t$ =75MPa, Flexural strength = 112MPa, Modulus of Elasticity E = 4.5GPa.

Two laminated composite sheets of size 330 x 300 mm$^2$ were fabricated by using Hand layup method in two different stacking sequences as shown in table 1.

| Composite material | Stacking sequence | Resin used | No of specimens | Thickness of specimens |
|--------------------|-------------------|------------|-----------------|-----------------------|
| Laminate-1         | $[0^0G/0^0F/45^0G/45^0F]^2$ | Epoxy      | 5               | 5.1mm                 |
| Laminate-2         | $[(0/45)G/(0/45)F_4/(0/45)G]$ | Epoxy      | 5               | 5.08mm                |

Four Glass/Epoxy and four Flax/Epoxy were consecutively arranged one after the other called Laminate-1 and a sandwich-type sheet consisting of two Glass/Epoxy layers as a base layer, four Flax/Epoxy layers as a center, and again two Glass/Epoxy layers as top layers called laminate-2. The fiber content was equal to 40 % wt. The fabricated sheets kept under the hydraulic press about 24 hours to remove excess resin while preparing laminates and give two weeks for curing at room temperature of $33\pm2^0$, after that cut the laminates into specimens for tensile and bending as per ASTM standards.

![Figure 1. Specimens corresponding to tensile, bending and impact test as per ASTM standards.](image-url)
2.1. **Experimental Work**

The Hybrid composites laminate-1 & laminate-2 after curing ready to tested for their mechanical properties. Here, the specimens cut as per ASTM standards in CNC machine with Router mill 4 x 18 x 50 x 2F tool and finished manually with fine Emery paper for accurate dimensions. The Universal Tensile Machine (UTM) was used for both the tensile test & bending test by changing specimen grips.

The tensile strength of a material is the maximum amount of tensile stress in the direction of force applied longitudinally that can happen before the fracture of a composite. Tensile specimens were testing on UTM as per ASTM D638 standards [10]. The size of each specimen was 165 x 19 mm$^2$ and the test speed for the crosshead displacement was 5mm/min and a gauge length of 55 mm as shown in figure 2.

A three-point bending test was a straightforward and easy testing method to evaluate material properties while the load was subjected to the transverse direction of the specific cross-section of the beam. It was conducted on UTM by fixing support anvil and specimen grips as shown in figure 3. This testing furnished the values for Flexural stress $\sigma_f$, flexural strain $\varepsilon_f$, maximum bending load and the modulus of elasticity in bending $E_f$. Specimens of both laminates were cut as per ASTM D790 [11] whose size of each specimen equal to 127 x 19 mm$^2$ and specimens were placed onto two supports with a span to depth ratio of 16:1 and test speed equal to 5 mm/min.

![Figure 2. Specimen was clamped on UTM](image1)

![Figure 3. Specimen was simply supported on UTM](image2)

### 3. THEORETICAL APPROACH

Finite Element analysis (FEA) was done for both Tensile test & bending test in Abaqus software to obtain mechanical properties of two laminates. Specimen model was created in part module and simulation carried out by given input data [12] as shown in table 2.

| Constants | $E_1$ (GPa) | $E_2$ (GPa) | $E_3$ (GPa) | $G_{12}$ (GPa) | $G_{13}$ (GPa) | $G_{23}$ (GPa) | $\nu_{12}$ | $\nu_{13}$ | $\nu_{23}$ |
|-----------|-------------|-------------|-------------|----------------|----------------|----------------|-----------|-----------|-----------|
| Flax fiber| 52.04       | 10.61       | 11.49       | 3.17           | 2.92           | 2.75           | 0.473     | 0.161     | 0.279     |
| Glass/Epoxy* | 45          | 10          | 10          | 5              | 5              | 3.8462         | 0.3       | 0.3       | 0.4       |

*taken from ANSYS 16.0 material library.

A deformable 3D model created in dog bone shape as per ASTM D638 in tensile test. Composite Layup option makes facilitate to create required two laminates simply stacking sequence and assign each ply orientation as per design in software i.e. $0^\circ$ and $45^\circ$ as shown in figure (4a) & (4b) and stacking arrangement of two type laminates plies shown in figure 5.
Figure (4a). Axis 2 represents a longitudinal direction (say $0^\circ$) of the fiber in woven fabric.

Figure (4b). Axis 2 represents a diagonal direction (say $45^\circ$) of the fiber in woven fabric.

Figure 5. Defining the layout layers (Stacking sequence) in case of two composite materials theoretically analyzed: (a) Laminate-1, (b) Laminate-2.

A parameterized model with the finite element of the two laminates were constructed in Abaqus software to perform the simulation of mechanical behavior such as Stresses, strain, and displacements in both tension test and bending test. Here, the results attained by FEA in the bending test would compare with experimental results for the elastic domain only. It is shown that the composite layup tool for shell-type parts has facilitated to create stacking sequence and ply orientation as per requirement. It was designed a shell whose dimensions are 127 x 20 mm in bending and 165 x 20 mm in the tensile test. The scheme of loading & mesh model in both bending and tensile test was as shown in figure 6 and figure 7.

In tensile test, Laminate-1 employed of maximum load of 4281 N with total elements about 672, Laminate-2 subjected to maximum load of 4030 N with 656 total elements and for bending test maximum force applied for elastic domain about 100N for both specimen composites. In this paper, the finite element model was defined with a 4-node doubly curved S4R element which was used for thin or thick shell element for both tests. Boundary conditions were applied according to loading for tensile and bending test separately.

Figure 6. Model of the laminated composite material in bending with an applicator at the middle of the span.
4. THEORETICAL RESULTS

4.1. For Bending Test

The distribution of the normal stress generated $\sigma_1 = S_{11}$ across the thickness in bending through integration points for both laminates as shown in figure 8. Shell tool has defined that each layer of the specimen has three integration points, one is represented lower layer surface, middle point represented the center of the layer, and third layer represented a top surface of the layer. Abaqus automatically assign these integration points across the given thickness of shell to found the variation of mechanical property in each layer.

Figure 7. Model of the laminated composite material in tensile test (a) scheme of loading (b) meshing with shell elements

Figure 8. Distribution of the normal stress $\sigma_1 = S_{11}$ across the thickness in bending in case of two composite structures analyzed: (a) Laminate-1 (b) Laminat-2
From above figure, it is noticed that the laminate-2 was subjected to maximum normal stress at bottom layer of the composite material and sudden decrease at the interaction of Flax/Epoxy and Glass/Epoxy layers. Laminate-1 has employed maximum normal stress at the top surface and minimum stress at lower layer as they were arranged alternately. The figure (9) & (10) shows the Distribution of vertical displacement $U_2$ and the distribution of stresses in the direction of loading in bending respectively after the simulation of specimens of both laminates.

![Figure 9](image1.png)

**Figure 9.** Distribution of the vertical displacement $U_2$ in the direction of the axis OY in the case of (a) composite laminate-1, (b) composite laminate-2.

![Figure 10](image2.png)

**Figure 10.** Flexural stress distribution $\sigma_f$ in the direction of the axis OY in the case of (a) laminate-1 and, (b) laminate-2.

### 4.2 For Tensile test

It is shown that the distribution of stresses in tension test in the direction of the axis OY of both laminate specimens as shown in figure 11.
4.3. Experimental Results

The average values of the mechanical properties of five specimens for each laminate were experimentally determined in Table 3. In that, it is marked that the Laminate-2 shows greater values than Laminate-1 in the bending test because the Flax/Epoxy layers accumulated as reinforcement fully with Glass/Epoxy layers like a sandwich model whereas in tension testing the laminate-1 obtained somewhat better values than other laminate. It may also observe that the Flexural Modulus of Elasticity $E_f$ in bending is 80% higher in the case of laminate-2 than in the case of the laminate-1 whereas the modulus of Elasticity $E_x$ in tensile testing is with 1.434% more in case of laminate-1 than in case of laminate-2. Moreover, the maximum flexural strength in bending in the case of laminate-2 shows 92.2% more than in the case of laminate-1 due to the advantage of reinforcing the Glass/Epoxy layers in both top and bottom shell layers.

Table 3. The average values of the mechanical properties measured in both tensile test and bending test in case of two composite materials tested

| S.No | Type of the composite material | Laminate-1 | Laminate-2 |
|------|--------------------------------|------------|------------|
| 1.   | Maximum Tensile strength $\sigma_{\text{max}}$, MPa | 67.08      | 64.89      |
| 2.   | Modulus of Elasticity $E_x$ in Tensile test, MPa | 753.99     | 743.33     |
| 3.   | Maximum Flexural stress $\sigma_f$, MPa | 98.698     | 189.742    |
| 4.   | Modulus of Elasticity $E_f$ in bending test, MPa | 4549.742   | 8186.55    |

4.4. Theoretical versus experimental results

Here, force-displacement curves (F-U) from the experimental test obtained graphically compared with the theoretical curve drawn by using the FEA model in the elastic domain with the help of Abaqus software in the case of both laminates. In figure 12, the data obtained in the bending test experimentally has shown with different color lines for three specimens of both laminates while the theoretical curves (F-U) drawn by using red lines. Similarly, in figure 13, the data obtained in the tensile test has indicated with various color lines but the theoretical curves (F-U) drawn by using blue lines. It may be noticed that analysis model gets with available data in a beautiful manner in the case of both material.
It can be noticed that the FEA model force-displacement curve fits linearly with experimental data in good manner in case of both laminates. It is marked that the error percentage for both test recorded in table (4) that calculated by comparing the important mechanical properties of both laminates experimentally with the values evaluated theoretically from the FEA model.

![Comparison between the results experimentally obtained in bending and ones obtained by FEA concerning the Force-Displacement curve (F-U) in the case of (a) Laminate-1, (b) Laminate-2.](image1.png)

![Comparison between the results experimentally obtained in tensile test and ones obtained by FEA concerning the Force-Displacement curve (F-U) in the case of (a) Laminate-1, (b) Laminate-2.](image2.png)

**Table 4. Comparison between the experimental and theoretical results obtained from FEA model.**

| Test method   | Type of the composite material | Maximum strength in MPa | Error in (%) | Exp. Versus FEA |
|---------------|--------------------------------|--------------------------|--------------|-----------------|
|               |                                | FEA model | experimentally |                  |
| Tensile Test  | Laminate-1                     | 64.0126   | 67.0811       | 4.793          |
|               | Laminate-2                     | 70.5735   | 64.8976       | -8.042         |
| Bending Test  | Laminate-1                     | 93.7      | 98.698        | 5.334          |
|               | Laminate-2                     | 194.7     | 189.742       | -2.546         |
5. CONCLUSION
The main conclusions taken from experimental and numerical investigation of tensile and bending test on two laminated composites are as follows:

- Laminate-2 appeared in better results in terms of maximum flexural strength $\sigma_f = 189.742$ MPa in bending than the value $\sigma_f = 98.698$ MPa recorded in case of laminate-1.
- In tensile test both laminates showed almost same property maximum tensile strength that means changing the stacking sequence of same fibers in tensile test not enough to improve the mechanical properties of composite materials.
- Numerical analysis carried out in the tensile and bending test of two laminated composite materials and these results experimentally validated and therefore calculated error percentage about 4.8 % and 8.04 % respectively in the tensile test. In the bending test, it has found that an error percentage of about 5.3 % and 2.5 % respectively.

It has also noticed from this work that the mechanical characteristics of the hybrid composite are higher than composite made up of only Flax/Epoxy composite [4] material. These hybrid composite materials can be useful in the innovation of automotive and aerospace applications in the aspect of lightweight and cost effective eco-friendly manufacturing technology.

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