Effect of fibre alignment on mechanical properties of natural fibre reinforced polymer composites

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Abstract. The effect of alignment of natural fibres on the mechanical behavior of flax and jute fibre / epoxy composites was investigated in the present work. The epoxy composites were prepared using the compression moulding technique. To explore the variation in composite laminate properties, three composite laminates were prepared based on the fibre-orientation angle. The composite laminates produced having undergone mechanical characterization such as tensile, flexural and water absorption analysis. The test specimens were prepared to carry out the mechanical testing according to ASTM requirements. The findings of the density test showed that L2 composite laminate had maximum density and L3 composite laminate had minimum density. The results of the mechanical test indicated the highest tensile strength for L1 and L3 composite laminates and L2 composite laminate showed the maximum flexural strength. L1 composite laminate reported maximum water absorption percentage, and L2 composite laminate showed minimum water absorption percentage.

1. Introduction
As an outcome of increasing ecological alertness, manufacturers and experts are eager to research new materials that are environmentally friendly. Presently, the fibres produced from wood, plants, leaves, grasses are widely utilized as reinforcements in composites employed for various appliances, such as automotive (indoor and outdoor), construction, boats, packaging, etc., because of their unique performance relative to other synthetic fibres [1,2]. However, its hydrophilic nature and fireproof instability make it inappropriate for industry to utilize it as a structural part. Researchers have suggested hybrid composites use natural fibers in conjunction with synthetic fibers or ceramic particulates to enhance the mechanical properties, fire resistant and moisture protection of natural composites [3-5]. Hybrid composites consist of two or more fibers in one matrix or two polymer mixtures and one natural fibre-reinforcement. Through hybridizing one natural fiber / synthetic fiber into one matrix, the resulting composite is a unique product with superior mechanical and thermal behaviour compared to single fiber-strengthened polymer composites [6,7].

Hua et al [8] experimentally investigated the consequence of strain rate on the compressive performance of flax fabric strengthened epoxy laminates. They found that composites compressive behavior depends heavily on strain intensity, and its behaviour in the out-of-plane has a greater stress dependence than the in-plane. Kureemun et al [9] examined the consequence of hybridization and dispersion of hybrid fibers on the mechanical performance of woven carbon / flax epoxy composites. They stated that the increase in volume fraction of carbon fiber in flax / epoxy composite increased the tensile strength and modulus. Audibert et al. [10] examined the mechanical behavior of flax-Kevlar hybrid / epoxy composite produced through the process of vacuum infusion. They conclude that there is an average mechanical performance for hybrid composite relative to single reinforced composite.
The effect of carbon fibers on the mechanical behaviour of flax strengthened epoxy composites was explored by Flynn et al [11]. They suggested that the hybridization of synthetic fibers with natural fibers would be an effective way to improve mechanical properties and regulate vibration damping.

In two separate stacking sequences, Nisini et al [12] analyzed the mechanical and impact behavior of hybrid composite laminates with carbon, basalt and flax fibers. They found that basalt intercalation with flax layers was advantageous for flexural and interlaminar strength but the differences between the two laminates were quite limited against the impact performance. Venkateshwarana et al [13] researched banana / sisal reinforced hybrid composites mechanical and water absorption behavior. They found that adding up to 50 % sisal fiber by weight in banana / epoxy composites improves mechanical performance and decreases moisture uptake behavior. Navjot et al [14] studied the mechanical behavior of high-density polyethylene composite enhanced by hybrid sisal/hemp fiber and confirmed that hybrid composites are superior to single fiber composite. From the literature survey it was noted that no work on epoxy composite reinforced with flax and jute fibre is recorded. This research thus investigated the consequence of fibre alignment on the mechanical performance of epoxy composites strengthened by flax and jute fibre.

2. Materials and methods

2.1. Materials

The thermosetting epoxy resin (LY 556) was used as matrix material and aliphatic amine (HY 951) used as hardener. The properties of these materials are presented in Table 1. The resin and hardener were purchased from M/s New one Fiber, Chennai. The natural fibres such as flax and jute was used as reinforcement in the form woven fabric. The properties of these reinforcements were listed in table 2. The jute and flax woven fabric were purchased from M/s ST Advanced composite, Chennai.

| Materials | Viscosity at 25°C (mPa s) | Density at 25°C (g/cm³) |
|-----------|--------------------------|-------------------------|
| Epoxy (LY556) | 10000 - 12000 | 1.15 – 1.20 |
| Hardener (HY951) | 10 – 20 | 0.95 – 1.05 |

| Fabric (Woven) | Thickness (mm) | Density (g/cm³) | Modulus of elasticity (GPa) | Tensile strength (MPa) | Elongation at Break (%) |
|----------------|----------------|-----------------|---------------------------|---------------------|------------------------|
| Jute           | 0.5            | 1.3 – 1.5       | 20 – 55                   | 200 – 500           | 0.8 – 1.8%             |
| Flax           | 0.5            | 1.4 – 1.5       | 50 – 70                   | 500 – 900           | 1.8 – 2.2%             |

2.2. Fabrication of Composite Laminate

The flax/jute woven fabric strengthened epoxy composite was produced by compression moulding process. The image of the compression moulding machine is shown in figure 1 (a). The flax and jute fabric were cut into 300 mm x 300 mm of the required dimensions. The epoxy resin and the hardener were blended in a 10:1 ratio and stirred to obtain the homogeneous mixture for a certain time. Now the releasing medium is poured over the mould surface, and then the jute fabric was put over the surface of the mould. The resin / hardener mixture was poured over the surface of the jute fabric and spread with the assistance of roller over the entire surface. The flax fabric was then put over the jute fabric and the matrix mixture were poured over and spread over the entire surface of the flax fabric again. This method was continued for preparing the composite, which consists of the fabric in alternative arrangement. The composite laminate was then positioned on the compression moulding machine's mould surface. The composite laminate was compressed for 3 minutes at 60 bar pressure and 90 °C.
temperature, and then allowed for curing. Finally, the composite laminate was withdrawn from the mould as shown in Figure 1 (b). The composite laminates details are presented in Table 3.

![Composite laminate](image)

**Figure 1.** (a) Compression molding machine and (b) Composite laminate.

| Laminates | Fibre arrangement | Fibre orientation angle (°) |
|-----------|-------------------|-----------------------------|
| L1        | Jute/Flax/Jute/ Flax | 0/90                        |
| L2        | Jute/Flax/Jute/ Flax | +45/-45                    |
| L3        | Jute/Flax/Jute/ Flax | 90/0                        |

### 2.3. Testing of composite Laminate

Various testing such as density, tensile, flexural and water absorption was carried out to explore the characteristics of the composite laminates. The specimen for performing the mechanical testing was prepared as per ASTM standard from the produced composite laminates. The switch board cutting machine was used to cut the specimen as per required dimensions.

#### 2.3.1. Density testing.

The experimental density test was carried out by water immersion method. In this process, the weight of sample in the dry air and sample immersed in water was measured. The experimental density was calculated by equation (1).

\[
\rho_{\text{Composite}} = \frac{W_{\text{dry}}}{W_{\text{wat}}} \times \rho_{\text{water}}
\]  

(1)

Using the fiber weights noted before fabrication and the composite weight noted after fabrication of composites, the weight of the infused resin was determined. From the calculated composite density and weight of constituent materials, the volume fractions of resin and fiber was calculated. The theoretical density of composite was determined by equation (2)

\[
\rho_{\text{Theory}} = V_{\text{Fiber 1}} \times \rho_{\text{Fiber 1}} + V_{\text{Fiber 2}} \times \rho_{\text{Fiber 2}}
\]  

(2)

#### 2.3.2. Tensile testing.

The tensile properties of the composite laminate such as yield strength, ultimate tensile strength and elongation were determined by performing tensile testing. The dimensions of the specimen being 250 mm x 25 mm x 2 mm. Figure 2 shows the image of the specimen before and after being subjected to testing.
Figure 2. Image of the tensile specimen (a) before testing and (b) after testing.

The universal tensile testing machine was employed for conducting the test as per ASTM D3039 with a cross head speed of 2 mm/min.

2.3.3. Flexural testing. The flexural properties of the composite laminate such as maximum load, displacement and flexural strength were estimated by conducting three-point bending test. The dimensions of the specimen being 125 mm x 12.5 mm x 2 mm. Figure 3 shows the image of the specimen before and after being subjected to three-point bend testing. The test was carried out as per ASTM D790 standard using universal tensile testing machine with a cross head speed of 2 mm/min. The flexural strength and modulus were calculated by using equation (3) and equation (4).

Figure 3. Image of the flexural test specimen (a) before testing and (b) after testing.

\[
\sigma_f = \frac{3PL}{2BD^2}
\] (3)

\[
E_f = \frac{ML^3}{4BD^3}
\] (4)

where P is the load applied on the specimen, L is the length of specimen between support, B is the width of specimen, D is the thickness of specimen and M is the slope of force-displacement diagram.
2.3.4. Water absorption testing. The natural fibres are hydrophilic which degrade the mechanical behaviour of composite laminate. Therefore, it is significant to examine the water uptake behaviour of natural fibre strengthened composites. The specimens were developed to perform the water absorption test as per ASTM D570 standard. The specimens were submerged in distilled water for 5 days at room temperature. At regular intervals, the specimens were taken from the water, then it is cleaned by dry cloth for measuring the weight. Equation 3 provides the percentage of water uptake for composite laminates.

\[ W = \frac{W_w - W_d}{W_d} \times 100 \]  

where \( W \) is the percentage of water uptake, \( W_w \) is the weight of wet specimen and \( W_d \) is the weight of dry specimen.

3. Results and Discussion

3.1. Density testing
The theoretical density of flax/jute reinforced epoxy composite laminates is presented in Table 4. It is known that the theoretical density is always greater than experimental density. In this study, the theoretical density of all the laminates is more than that of experimental density.

| Laminates | Theoretical density (g/cm³) |
|-----------|----------------------------|
| L1        | 1.25324                    |
| L2        | 1.25475                    |
| L3        | 1.24839                    |

The experimental density of flax/jute reinforced epoxy composite laminates is exhibited in figure 4. It is noticed from the figure 4 that L2 composite laminate showed the maximum experimental density. L3 composite laminate revealed the minimum experimental density. Fibre orientation plays a major role in increasing composite laminate density. It is found from this study that the fibre-orientation at ±45° resulted in maximum density. Both the theoretical and experimental density values of composite laminates are very close to each other.

3.2. Tensile testing
The load vs displacement diagram of flax/jute woven fabric reinforced epoxy composite laminates is exhibited in figure 5. It is noticed from the figure that L1 composite laminate revealed the maximum force of 1.690 kN and L2 composite laminate revealed the minimum force of 1.340 kN. The L3 composite laminate showed the force of 1.530 kN which is slightly lower than L1 composite laminate. The test results of flax/jute woven fabric reinforced epoxy composite laminates are presented in table 5. It is observed from the results that the L1 and L3 composite laminate showed more or less close values of tensile strength. But L2 composite laminate revealed the lower value of tensile strength compared to other composite laminates. There is no much change in the elongation of composite laminates. In L1 and L3 composite laminates, most of the fibres are aligned along the loading direction which yielded maximum tensile strength. In this case, the load applied to the composite is transferred directly to the fibre, which increased the composite laminate’s load carrying capacity. But, in L2 composite laminate, the fibres are aligned at an angle ±45° to the loading direction which resulted in lower values of force and tensile strength. It is due to matrix failure before the load is properly
transferred to the fibre. It is understood that the composite’s tensile strength is decreased by increasing the fiber orientation from 0° to 90°.

![Graph showing experimental density of composite laminates.](image)

**Figure 4.** Experimental density of composite laminates.

![Load vs Displacement diagrams](image)

**(a)** (b) (c)

**Figure 5.** Load vs Displacement diagram for (a) L1, (b) L2 and (c) L3 composite laminate under tensile load.

| Laminates | Maximum Force (kN) | Tensile strength (MPa) | % Elongation |
|-----------|--------------------|------------------------|--------------|
| L1        | 1.690              | 46.051                 | 2.00         |
| L2        | 1.340              | 36.612                 | 2.00         |
| L3        | 1.530              | 46.163                 | 2.07         |

**Table 5.** Tensile test results.

3.3. **Flexural testing**

The load vs displacement diagram of flax/jute woven fabric reinforced epoxy composite laminates is exhibited in Figure 6. It is noticed from the figure that L2 composite laminate revealed the maximum force of 0.140 kN and L1 composite laminate revealed the minimum force of 0.070 kN. The L3 composite laminate showed the force of 0.120 kN which is greater than L1 composite laminate.
Figure 6. Load vs Displacement diagram for (a) L1, (b) L2 and (c) L3 composite laminate under flexural load.

The test results of flax/jute woven fabric reinforced epoxy composite laminates are presented in table 6. It is observed from the results that the L1 composite laminate showed lower flexural strength among the composite laminates. But L2 composite laminate revealed the maximum value of flexural strength compared to other composite laminates. The flexural strength of L3 composite laminate is 666.864 MPa which is lower than that of L2 composite laminate. The reverse trend is observed for composite laminates displacement.

Table 6. Flexural test results.

| Laminates | Flexural strength (MPa) | Maximum Force (kN) | Displacement (mm) |
|-----------|-------------------------|--------------------|-------------------|
| L1        | 494.380                 | 0.070              | 11.850            |
| L2        | 828.567                 | 0.140              | 10.360            |
| L3        | 666.864                 | 0.120              | 10.820            |

In L1 and L3 composite laminates, most of the fibres are aligned 0 or 90° direction which resulted in low amount of load carrying capacity. This is related to the more robust bending of the fibers due to their orientation in the composite laminate. But when the fibres are aligned at an angle ±45° in L2 composite laminate, the load carrying capacity of material is increased and the displacement is decreased. It is due to somewhat difficulty in bending fibers in the composite laminate due to its orientation.

3.4 Water absorption testing

Table 7 shows the percentage of water absorption for different composite laminates. From the Table, it is observed that all the composite laminates revealed the closest percentage of water uptake. L2 composite laminate revealed the maximum percentage of water absorption and L1 composite laminate revealed the minimum percentage of water uptake.

Table 7. Water absorption results of Composites.

| Laminates | Weight of dry sample (g) | Weight of wet sample (g) | Percentage of water uptake (%) |
|-----------|--------------------------|--------------------------|--------------------------------|
| L1        | 1.1117                   | 1.2428                   | 11.79                          |
| L2        | 1.1137                   | 1.2458                   | 11.86                          |
| L3        | 1.1168                   | 1.2492                   | 11.85                          |
Figure 7. Water absorption characteristics of composite laminate.

Water absorption behaviour of composite laminate is shown in figure 7. Initially, the amount of water uptake characteristics increased to maximum value to attain the saturation level. Further, there is a slight decrement in water absorption characteristics for the remaining days. The composite laminate absorbs the water molecules through the micro pore or void present thereon. The percentage of water absorption based on the composite void content. Low water absorption rate is observed in this work due to low void content produced by compression moulded composite.

4. Conclusions
The flax and jute fibre strengthened epoxy composites were produced by using compression moulding process. The effect of natural fabric alignment on mechanical behaviour of flax and jute fibre/epoxy composites was investigated. The following conclusions have been drawn from the study. The density test results showed that L2 composite laminate had maximum density and L3 composite laminate had minimum density. The mechanical test results revealed that the L1 and L3 composite laminates showed the maximum tensile strength and L2 composite laminate showed the maximum flexural strength. L2 composite laminate revealed the maximum amount of water uptake and L1 composite laminate showed the minimum amount of water uptake.

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