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Investigation of the Mechanical Properties of Hybrid Polymer Composites Reinforced with Luffa Cylindrica and Flax Fibers

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Abstract - In the present study, hybrid polymer composites reinforced with luffa and flax fibers using an epoxy matrix were fabricated, and their mechanical properties were investigated experimentally. The composites were prepared in a three-ply configuration, with luffa fiber placed between two outer layers of flax fiber mats. Laminates of dimensions 300 × 300 × 4 mm were fabricated using the hand layup technique. Epoxy resin (LY556) and hardener (HY951) were employed as the matrix system. Standard tests were conducted to evaluate the tensile, flexural, and impact properties of the fabricated composites. The experimental results indicated that the hybrid bio-composites exhibited enhanced mechanical performance, demonstrating the effectiveness of fiber hybridization in improving composite properties.

***Key Words*:** Tensile strength, Hybrid composite, flexural strength, impact strength.

Table 1. Chemical composition of Luffa fibre

Cellulose (%)	Lignin (%)	Hemi cellulose (%)	Ash (%)
63.0±2.5	11.69±1.2	20.88±1.4	0.4±0.10

Table 2. Physical properties of luffa fibre

Density (gm/cc	Diameter (µm)	Aspect	Micro fibrillar angle
0.92±0.10	270±20	340±5	12±2

1. Introduction

In recent years, industries such as automotive, aerospace, and construction have increasingly shifted toward the use of natural fiber-reinforced polymer composites due to their eco-friendliness, cost-effectiveness, wide availability, and lightweight nature [1]. Polymer matrix composites reinforced with natural fibers exhibit moderate mechanical properties; however, these fibers—often considered agricultural waste—can be effectively reused as reinforcement materials. While synthetic fibers generally offer superior mechanical performance compared to natural fibers, this gap can be narrowed by hybridizing different natural fibers such as flax, hemp, sisal, and coir. Tables 1 and 2 present the chemical and physical properties of luffa fiber, respectively [3].

Compared to synthetic fibers, natural fibers generally exhibit lower mechanical properties, making them less suitable for structural applications [2]. However, these limitations can be addressed through appropriate chemical and physical modifications of the natural fibers. Sudhir et al. reported that alkali treatment of luffa fiber led to an approximate 64% increase in tensile strength, while grafting treatments resulted in a 100% improvement [3].

Mechanical properties of luffa and glass fiber-reinforced epoxy composites and found that the optimal configuration consisted of two plies of luffa fiber sandwiched between layers of glass fiber. This hybrid structure showed significant improvement in both tensile and flexural strength [4].

Effect of incorporating basalt outer layers into flax fiber composites. Their findings revealed that the addition of basalt enhanced the composite's stability under both static and dynamic loading conditions [5]. The chemical composition of flax fiber is provided in Table 3.

Table 3. Chemical composition of flax fibre. [11]

Cellulose (%)	Hemicellulose	Pectin (%)	Lignin	Water (%)
64–74	11–17	≈1.8	2–3	8–10

Luffa and groundnut shell fiber-reinforced epoxy composites and observed that chemically treated laminates with 40% fiber content exhibited superior mechanical properties. However, a further increase in fiber content led to a decline in strength due to poor wetting between the fibers and the matrix [6].

Optimized the compression molding parameters for flax-reinforced biocomposites and determined that a molding pressure of 30 bar, time of 3 minutes, and a temperature of 200°C resulted in the highest impact energy of 48.902 kJ/m² [7].

Despite these promising studies, limited research exists on the development and characterization of luffa and flax fiber-based hybrid composites. Therefore, the present study aims to investigate the mechanical properties of epoxy composites reinforced with luffa and flax fibers, offering insight into their potential for lightweight and sustainable engineering applications.

2. Materials and Methods

2.1 Materials

Epoxy resin (LY556) and hardener (HY951) were used to prepare the polymer matrix for the composite fabrication. A wooden mold with dimensions of 300 × 300 × 4 mm was constructed for casting the composite laminates. Mansion wax was applied to the mold surface to facilitate easy release of the laminates after curing.

Luffa fiber and flax fiber mat were procured from Sakthi Fibres, Chennai. The fibers were thoroughly cleaned to remove dust, dirt, and other impurities. Luffa fibers were manually cut, and the seeds were removed before processing them into mat form. To enhance interfacial bonding, the fibers were treated with an alkali solution of 0.1 N sodium hydroxide (NaOH) for 1 hour. After treatment, the fibers were rinsed with distilled water to remove excess alkali and then dried under sunlight.

Composite laminates were fabricated using the hand layup technique, a widely adopted method for producing fiber-reinforced polymer composites. The fiber and resin volume fractions were calculated based on the rule of mixtures, ensuring an appropriate balance between the two constituents for each laminate layer.

Epoxy resin and hardener were mixed in a standard ratio of 10:1 by weight, as recommended by the manufacturer. Both treated and untreated fibers were used to study the effect of chemical treatment on composite performance. Laminates were fabricated with a 30% fiber content by weight. The prepared mats were laid into the mold layer by layer, with resin applied evenly to ensure thorough wetting of the fibers.

2.2 Preparation of Samples for Mechanical Testing

Tensile test specimens were prepared according to ASTM D638 standards with dimensions of 250 mm × 25 mm × 4 mm. The tests were conducted using a universal testing machine (Instron) at a constant crosshead speed of 0.01 mm/min.

Flexural test specimens were prepared in accordance with ASTM D790-10, with dimensions of 64 mm × 16 mm × 4 mm. The flexural tests were also performed using the universal testing machine.

Impact strength was determined using the Charpy impact test method, following the ASTM D6110-10 standard. Specimens were prepared with dimensions of 75 mm × 15 mm × 4 mm.

2.3 Water Absorption Test

The water absorption behavior of the composite samples was evaluated in accordance with ASTM D570 standards. Specimens were cut to dimensions of 25 mm × 25 mm and dried to remove any residual

moisture prior to testing. The initial mass of each sample was recorded using a digital precision balance.

The specimens were then immersed in distilled water at room temperature for time intervals ranging from 2 to 24 hours. After immersion, the samples were removed, surface moisture was gently wiped off with a dry cloth, and the final mass was measured.

The water absorption capacity was calculated using the following equation:

$$\text{Water Absorption Capacity } (\%) = \frac{M_f - M_i}{M_i} \times 100$$

Where,
Mf = Final mass of the composite (after immersion)
Mi = Initial mass of the composite (before immersion)

3. Results and Discussions

3.1 Tensile and Flexural Strength

The fiber content and the interfacial bonding between the fibers and the polymer matrix are key factors influencing the tensile and flexural strength of natural fiber-reinforced polymer composites.

As shown in Figure 1, the alkali-treated composite exhibited a higher tensile strength, reaching up to 24 MPa. The average tensile strength across samples ranged from 19 to 24 MPa. This improvement is attributed to the enhanced bonding between the fiber and matrix due to the alkali treatment.

Regarding flexural strength, the highest value of 59 MPa was recorded when the flexural load was applied along the flax fiber direction, as illustrated in Figure 2. This aligns with the findings of M. Gouda et al., who observed similar improvements in jute fabric-reinforced polyester composites [8].

The enhanced mechanical performance in alkali-treated fibers is primarily due to the removal of hemicellulose, pectin, waxes, and other surface impurities. The alkali treatment leads to a retting effect, which roughens the fiber surface and improves mechanical interlocking with the matrix. This ultimately results in stronger fiber–matrix adhesion, contributing to higher tensile and flexural strengths [9].

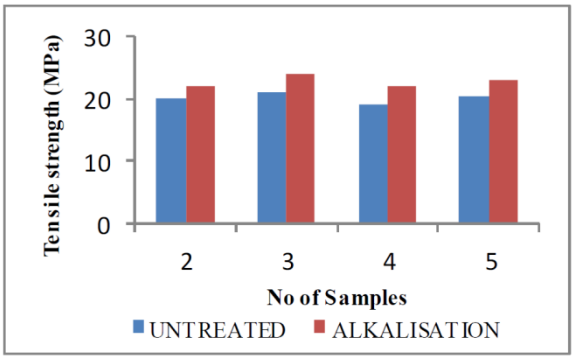

Figure 1. Tensile strength of the composite

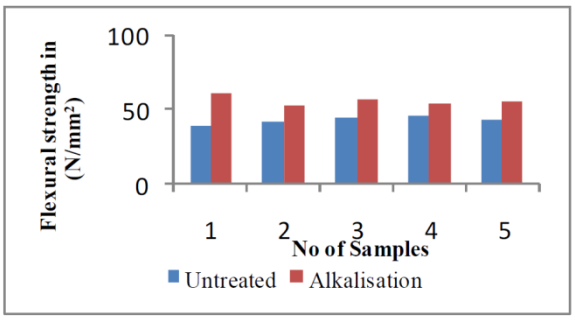

Figure 2. Flexural strength of the composite

3.2 Impact Strength

The impact strength of a composite indicates the maximum energy the material can absorb before failure under sudden loading conditions. As shown in Figure 3, the chemically treated fiber composites demonstrated improved impact strength compared to the untreated counterparts.

The impact strength of the treated specimens ranged from 1.2 to 1.9 joules. This enhancement is primarily attributed to the removal of hemicellulose and other surface impurities during the alkali treatment process, which enhances the fiber–matrix adhesion and energy absorption capability during fracture [10].

The improved bonding facilitates more efficient stress transfer under dynamic loads, thereby increasing the resistance of the composite to sudden impacts.

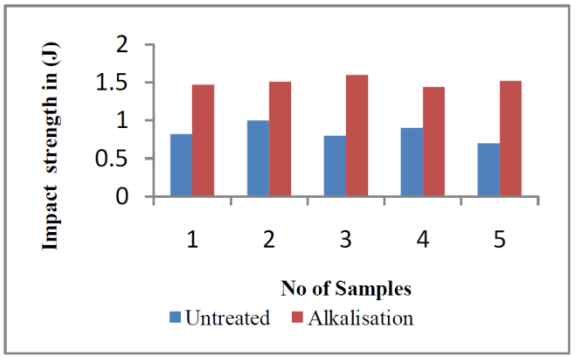

Figure 3. Impact strength of the composite

3.3 Water absorption

The water absorption capacity of the composite increased with the fiber content in the laminate. Natural fibers are hydrophilic in nature, primarily due to the presence of pectin, hemicellulose, and other polar constituents, which promote moisture uptake.

However, chemical treatment, such as alkali treatment, can significantly reduce the water absorption tendency by removing these components. As illustrated in Figure 4, the alkali-treated composites exhibited lower water absorption compared to untreated ones. This reduction is attributed to the removal of surface impurities and hydrophilic constituents, resulting in reduced moisture affinity and enhanced dimensional stability of the composite [12].

The improved resistance to moisture uptake in treated fibers contributes to better long-term performance, especially in humid or aqueous environments.

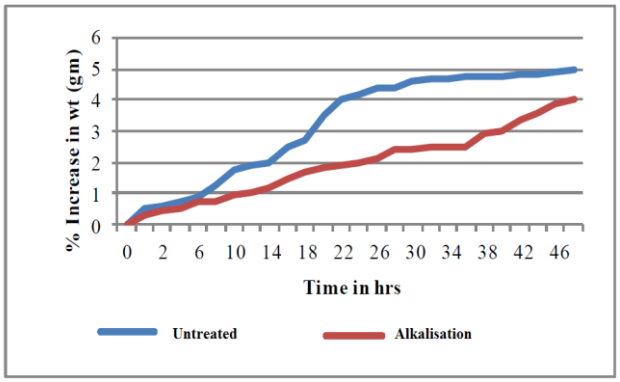

Figure 4. water absorption of the composite

4. Conclusion

In this study, hybrid epoxy composites reinforced with luffa cylindrica and flax fibers were successfully fabricated using the hand layup technique. The experimental investigation demonstrated that alkali-treated fibers significantly enhanced the mechanical properties of the composites compared to untreated fibers.

Notably, improvements were observed in tensile, flexural, and impact strength, which can be attributed to the removal of hemicellulose, pectin, and other surface impurities during the chemical treatment process. The retting action associated with alkali treatment created a rougher fiber surface, promoting better adhesion between the fiber and matrix.

Overall, the findings confirm that chemical treatment of natural fibers plays a crucial role in improving the mechanical performance of flax and luffa-based hybrid epoxy composites, making them more suitable for potential applications in lightweight and sustainable engineering materials.

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