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Mechanical Characterization of Jute-Epoxy Symmetric Cross-ply Composite Laminate

Babul Chowhan, Shayan Kumar Roy, Zannatul Ferdous Ruba, Md. Tanvir Hosain Tuhin, Al-Muntasir*

Department of Industrial and Production Engineering, Bangladesh University of Textiles, Dhaka, Bangladesh.
*Corresponding Author: Al-Muntasir, muntasir9513@gmail.com.

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ABSTRACT

This experimental investigation describes the development and characterization of a new set of natural fiber-based polymer composites consisting of unidirectional jute fiber cross-ply as reinforcement and epoxy resin as matrix material. The composites were fabricated using a hand lay-up technique and are characterized with respect to their physical and mechanical properties. Experiments were carried out to study the effect of fiber orientation and layer arrangement on the physical and mechanical behavior of these composites. Four layers of jute fibers were arranged, maintaining the order of angle (0°/90°/90°/0°) that forms a symmetric cross-ply jute-reinforced epoxy composite. Two types of samples were made according to fiber orientation in the composite. The results showed a significant increase in tensile strength for alkali-treated unidirectional composites, likely due to improved fiber-matrix adhesion and more effective stress transfer. Both the longitudinally and transversely oriented samples have shown improved performances compared with other jute-epoxy composites.

Keywords: Jute fiber composites, Cross-ply composites, Tensile properties, Epoxy resin.

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1. INTRODUCTION

Environmentally friendly, natural, recycled, or biodegradable materials are attracting a lot of interest. Natural fiber composites are preferred as compared to conventional synthetic fiber-based composites. Natural fibers have been in considerable demand in recent years and play a key role in the emerging “green” economy. The different kinds of natural fiber-reinforced polymer composites have received great importance in different automotive applications.

The mechanical properties of composite materials depend on many factors, such as fiber length, shape, size, composition, orientation, and distribution, as well as volume fraction. Mechanical properties of the matrix, manufacturing techniques, and bonding between fibers and matrix also play an important role. Fiberglass has been used in reinforcing polymer matrix composites since the 1930s. Kenaf, sisal, banana, cane, bamboo, jute flax, pulp, cane, wood flour, oil palm, pineapple leaf, and coir are the main natural fibers used as composite reinforcement. The typical properties of jute fibers are density: 1.5 g/cm^3; tensile strength: 393-773 MPa; and elastic modulus: 10-30 GPa.

Jute is cheap and has reasonable strength and resistance to rot. Jute is mainly used for packaging (sacks and bales). The epoxy resins belong to the group of thermosetting resins and have a wide range of applications in the aerospace, automotive, and marine industries, among others. In the preparation of composite materials reinforced with natural fibers, the hydrophilic nature of the epoxy resins becomes advantageous due to their high affinity with this type of fiber (hydrophilic nature). The versatile characteristic of epoxy and its diversity made it useful for different industrial applications. There are considerable suggestions for the natural fibers that can be implemented in order to enhance their mechanical properties. Once the base structures are made strong, the polymers can be easily strengthened and improved. There are a number of aspects that affect the performance of composites, which are the following: (a) orientation of fiber, (b) strength of fibers, (c) physical properties of fibers, (d) interfacial adhesion property of fibers, and many more.

Mechanical properties of PLA, epoxy, PP, and polyester matrices can be affected by reinforcing different types of natural fibers. The mechanical properties of jute-epoxy composites can be significantly enhanced through various fiber treatments. The effects of alkali treatment on jute fibers, which resulted in improved tensile strength and fiber-matrix adhesion [1]. This treatment not only cleans the fibers but also increases surface roughness, thereby enhancing interfacial bonding. Further contributed to this understanding by examining how the incorporation of particles into jute-epoxy composites can improve tensile and bending properties. The findings indicate that tailored composite formulations can achieve superior mechanical performance, underscoring the importance of both fiber treatment and composite design [2].

Investigation on bi-directional jute fiber epoxy composites, revealing that the orientation of fibers plays a crucial role in enhancing load-bearing capabilities [3]. The study demonstrated that bidirectional arrangements outperform unidirectional configurations, which is aligned with a comparative analysis of jute composites against glass and neat epoxy composites. It was found that jute composites not only matched but sometimes exceeded the mechanical strengths of traditional composites, illustrating the potential for jute in structural applications [4]. Fiber treatments significantly influence the physical and mechanical properties of jute composites. One study examined the interface strength between jute fibers and epoxy, emphasizing the importance of surface treatments in enhancing bonding [5-6].

Moreover, analysis of the thermomechanical properties of jute-epoxy laminates indicates that treatment processes such as heat curing can improve thermal resistance, making these materials suitable for high-temperature applications [7]. Research into jute fiber-reinforced epoxy composites continues to evolve, with increasing attention on optimizing fiber treatments, composite formulations, and hybrid configurations. The potential for jute composites to replace traditional materials in various applications is promising, provided that ongoing research addresses the mechanical limitations and performance variability associated with natural fibers [8].

All studies have been done concerning the mechanical behaviors of jute-epoxy composite. But no study has been conducted on the influence of fiber orientation and cross-ply arrangement on the mechanical performances of jute-epoxy composite to investigate the influence of fiber orientation on modulus of elasticity.

In this study, a tensile test has been conducted on a jute fiber-epoxy resin composite with 30% fiber mass fraction in a symmetric cross-ply arrangement (0°/90°/90°/0°) in order to investigate the tensile properties in the longitudinal and transverse directions.

2. MATERIALS AND METHODS

2.1 Raw materials

Jute fiber was used as the reinforcing material in this study. The initial length of jute fiber was 95-100 cm. White grade jute fiber was selected, which is shown in Fig. 1.

Fig.1. Raw jute fiber (type Corchorus capsularis).

Commercial-branded Epoxy LAPOX® B-11 was purchased from a local source. It is an unmodified liquid epoxy resin of medium viscosity. Appearance was a clear pale-yellow liquid; epoxy value was mentioned as 5.2 - 5.5 eq/kg; hydrolyzable chlorine was max. 400 ppm; viscosity at 250°C was 9000 - 12000 mPas; and epichlorohydrin content was max. 10 ppm. Commercial hardener K-6 was used as Triethylene Tetramine, which is a low-viscosity room-temperature curing aliphatic amine curing agent. Its properties are visual appearance: Pale yellow liquid Refractive index at 250C: 1.4940-1.5000 Water content: 1% max. Shear strength on A1 alloy lap joint (in combination with Lapox C 51): 1.4

kgmm²/min. The epoxy and hardener container are shown in Fig. 2.

Fig.2. Commercial epoxy resin and hardener.

2.2 Resin preparation

The resin and fiber ratio was 70:30, where the hardener K-6 was mixed with resin, maintaining the ratio of resin and hardener as 10:1. For each layer, 35 gm of epoxy along with 3.5 gm of hardener was poured into a one-time mug and stirred with a glass rod at room temperature.

2.3 Jute fiber treatment

Jute strands were washed with distilled water and finally dried. Jute strands were poured into a reaction flask, and a solution of sodium hydroxide solution (5%) was added onto the fibers. The suspension was held at room temperature for 24 h. Afterwards, the reaction medium was filtered, and jute strands were thoroughly washed with distilled water until neutralization. At last, the alkali-treated jute strands were dried in an oven in sunlight for 12 h and kept to be used as reinforcement for the composite preparation.

2.4 Composite preparation

15 gm epoxy layer was placed on the milot paper placed on the MS plate, and a fiber layer of 15 gm jute was placed on it unidirectionally at 0°, and 35 gm epoxy resin along with a 3.5 gm hardener mixture was applied on the fiber layer, and rolling was done using a hand roller to distribute the resin mixture. Then the mid-1, mid-2, and top layer were placed on the frame, maintaining the same amount of fiber & resin mixture and defined angle to form a cross-ply (0°/90°/90°/0°) composite sheet. Finally, a 25kg load was applied on the composite sheet to eliminate void formation and to ensure uniform distribution of resin liquid. The process was done at room temperature. The final composite sheet was placed for curing at room temperature, applying 25 kg of force for 24 hours. The composite preparation sequence is shown in Fig. 3.

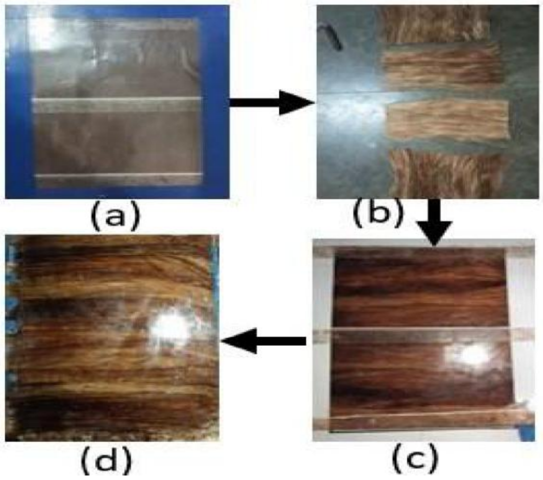

Fig.3. Composite preparation, frame preparation (a), jute fibre layers (b), resin application (c), final composite (d).

2.5 Mechanical Characterization

In accordance with the methods and requirements of ASTM D638 and at a crosshead velocity of 5 mm/min, the tensile properties were assessed using the Shimadzu AGS-X (AGS-X-5kN, Japan), a universal testing machine (UTM). The gauge length was 115 mm, and the overall length of the specimen was 165 mm. Fig. 4 shows the gauge and the samples for mechanical testing.

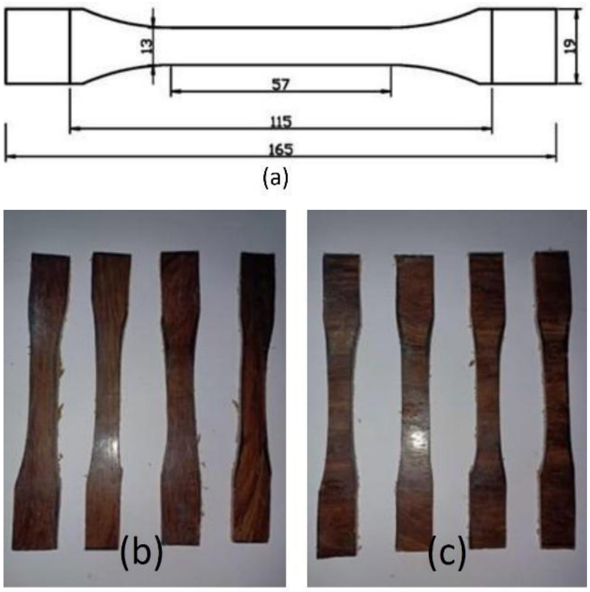

Fig. 4. Gauge (a) longitudinal (b) and transverse fiber (c) oriented composite samples.

3. RESULTS AND DISCUSSION

3.1 Tensile properties of symmetric cross-ply composite laminate

The mechanical performance of both longitudinal and transverse-oriented jute-reinforced epoxy composite laminates was evaluated using tensile testing. The key parameters measured were tensile stress and modulus of elasticity, which provide insight into the strength and stiffness of the materials, respectively. Two different types of composite samples were prepared and tested in this study to analyze the effects of fiber orientation on the mechanical properties of the jute fiber-reinforced epoxy composite.

The first five samples were longitudinally oriented unidirectional jute fiber-reinforced epoxy composites; the result was taken from their mean. The second five samples were a transverse-oriented unidirectional jute fiber-reinforced epoxy composite; the result was also taken from their mean.

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Fig. 5 shows the tensile strength of two types of composites. The results demonstrate that the orientation of jute fibers significantly affects the mechanical properties of the epoxy composites. The unidirectional, longitudinal-oriented treated jute fiber-reinforced epoxy composite exhibited the highest strength of 66.42 MPa.

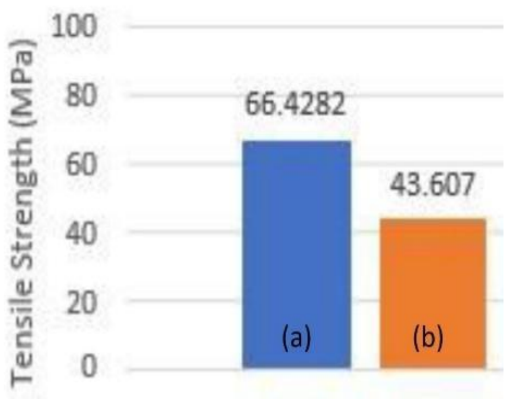

Fig.5. Tensile strength of composites, laminate with fiber oriented longitudinally (a), laminate with fiber oriented transversely (b).

This suggests that when the fibers are aligned along the load direction, the composite can bear a higher tensile load. Fig. 6 explains the modulus of elasticity for this sample was found to be 3.25 GPa, indicating good stiffness and resistance to deformation.

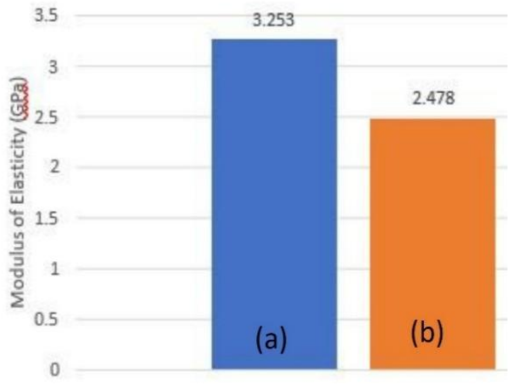

Fig.6. Maximum modulus of elasticity of longitudinal (a), and transverse fibre-oriented composite.

In contrast, the transverse-oriented treated jute-reinforced epoxy composite showed a significantly lower strength of 43.60 MPa, along with a reduced modulus of elasticity of 2.47 GPa. The strain of the longitudinal fibre-oriented composite is shown in Fig. 7. Fig. 8 shows the strain of the transverse fibre-oriented composite.

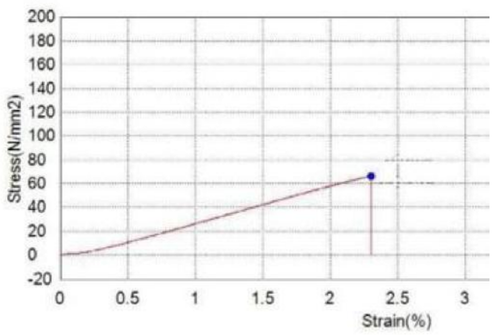

Fig. 7. Stress-strain diagram of longitudinal fiber-oriented composite.

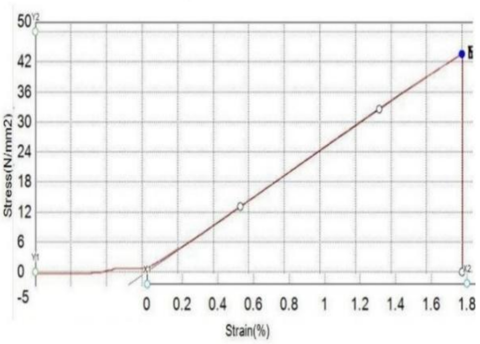

Fig. 8. Stress-strain diagram of transverse fiber-oriented composite.

The strain of the longitudinal fibre-oriented composite was 2.4% while the strain of the transverse fibre-oriented composite was 1.8%. The lower performance in both stress and stiffness is expected, as fibers aligned perpendicular to the direction of the applied load offer less resistance to tensile forces. This highlights the importance of fiber orientation in enhancing the mechanical strength of fiber-reinforced composites.

4. CONCLUSION

This work explored the effect of fiber orientation and ply arrangement on the mechanical properties of jute fiber-reinforced epoxy composites, with a focus on comparing longitudinal and transverse-oriented samples. The tensile testing results showed a clear dependence of composite performance on both fiber orientation and ply arrangement. The longitudinally oriented jute fiber-reinforced epoxy composite exhibited the highest tensile strength (66.4282 MPa) and a modulus of elasticity of 2.8872 GPa, indicating that proper fiber alignment is crucial for achieving high mechanical strength. Meanwhile, the transverse-oriented composite showed significantly lower performance, reinforcing the critical role of fiber orientation. The symmetric cross arrangement (0°/90°/90°/0°) of fiber layers in the composite also influences the mechanical behavior, resulting in higher tensile strength and modulus of elasticity. Both the longitudinal and transverse-oriented samples show improved mechanical performance due to symmetric and cross arrangement. In summary, fiber orientation and fiber arrangement highly affect the mechanical performance of the composite. The unidirectional fiber and symmetric cross-ply arrangement show the improved performance of jute fiber-reinforced epoxy composites.

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