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Fabrication of Natural Fiber-Reinforced Polymer Composite by Hand Lay-Up Process

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Abstract

The recent development in technologies has increased the usage of non-renewable resources during production due to their remarkable properties. However, it has been a threat and is unable to be replenished once used. In addition to this, natural fibers strengthen in a more significant way and are widely applicable in polymer composite materials. Furthermore, the use of plant fibers in polymer composites is due to their low cost and significant properties. Additionally, using natural fibers results in a lighter composite compared to those made with synthetic fibers. As a result, the massive demand for natural fiber composites commercially in the industrial sector is for a safe environment. However, the development has many drawbacks and critical issues. The review focuses on various kinds of plant fiber polymer composites, along with their characteristics and applications. Therefore, in this paper, the authors prepared a natural fiber-reinforced polymer composite by the hand lay-up process. Further, the tensile tests have been performed on this composite using a universal testing machine. This paper has also summarized the chemical, mechanical, and physical properties of plant fibers and their reinforced polymer composites techniques. The shapes of specimens have been taken as length 34 mm, width 24 mm, and thickness 4 mm. After that, the average yield point of the workpiece was found that 18.28 MPa.

Keyword: Jute fibers, epoxy resin, mild steel plates, hand lay-up process, tensile test

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INTRODUCTION

The rising global energy demand has driven increased interest in both renewable (solar, wind, and water) and non-renewable (oil, coal, and natural gas) resources. Composite materials, particularly those using natural plant fibers such as flax, jute, and sisal, are becoming more prominent because of their eco-friendly benefits.

These fibers are cost-effective, biodegradable, and have lower manufacturing energy requirements than synthetic fibers. However, their use in composites is limited by performance constraints. Natural fiber-reinforced polymer composites (NFPCs) are gaining attention for use in automotive panels and other applications. These composites combine a polymer matrix with plant fibers to enhance their mechanical, thermal, and environmental properties. The polymers used can be

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thermoplastics, which are easier to process, or thermosets, which have higher temperature limits but are more complex to process [1, 2].

Composite materials are formed by blending two or more substances to improve their overall performance. The key types include:

- *Polymer matrix composites (PMCs):* Polymer resins (e.g., epoxy, polyester) reinforced with fibers (e.g., glass, carbon).
- *Metal matrix composites (MMCs):* Metal matrices (e.g., aluminum and titanium) with ceramic reinforcements.
- *Ceramic matrix composites (CMCs):* Ceramic matrices (e.g., silicon carbide and alumina) reinforced with ceramic fibers or particles.

APPLICATIONS

- *Aerospace:* Composites with high strength-to-weight ratios are commonly utilized in the aerospace industry to boost fuel efficiency by reducing weight.
- *Automotive:* In the automotive sector, they are used in body panels and chassis to enhance vehicle performance and improve fuel economy.
- *Construction:* In construction, composites are used for structures such as bridges, facades, and reinforcement bars because of their long-lasting nature and resistance to corrosion.
- *Sports equipment:* The sports industry also benefits, as the strength and lightweight properties of composites enhance the performance of equipment, such as tennis rackets and bicycles.
- *Renewable energy:* In addition, in the field of renewable energy, composites contribute to the efficiency and durability of wind turbine blades, solar panels, and other energy systems.
- *Marine:* Boats and ships use composites because of their resistance to water and chemicals.
- *Electronics:* Composites are used as heat sinks, circuit boards, and enclosures for efficient thermal management.
- *Medical:* Applied in prosthetics, implants, and dental materials owing to their biocompatibility and strength [3, 4].

The continuous evolution of composite technology has expanded its applications and improved material performance across various fields. Composite materials are created by merging two or more different substances to improve their overall properties. Natural fibers, which are biodegradable and compostable, help minimize waste and promote a circular economy. Their lightweight nature enhances their strength-to-weight ratio, which is particularly advantageous in the aerospace and automotive sectors. When integrated into composites, these fibers offer excellent mechanical properties, including high strength, rigidity, and resistance to impact. Additionally, natural fibers tend to be more economical than synthetic alternatives, making them a cost-effective choice for a wide range of applications.

Thermal and Acoustic Properties

Natural fibers offer good thermal insulation and sound absorption, useful in the construction and automotive sectors.

Importance of Natural Fibers

- *Renewable:* Sourced from plants, natural fibers are more sustainable than non-renewable synthetic fibers.
- *Environmental impact:* A reduced environmental impact is one of the key benefits, as these materials typically consume less energy during production, generate fewer greenhouse gas emissions, and result in minimal waste.
- *Versatility:* They are also highly versatile, allowing customization to meet specific performance requirements while maintaining a balance between strength, weight, and sustainability.
- *Jute fiber—a prime example:* Jute fibers offer several advantages. It is an eco-friendly option, being renewable, biodegradable, and requiring little water and few chemicals for cultivation [5,

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6]. In addition, jute is durable and strong, making it ideal for demanding uses such as packaging and heavy-duty sacks. Breathable and comfortable in hot climates because of its ventilation properties.
- *Insulation:* Effective thermal insulation of building materials.
- *Affordable:* Cost-effective compared to synthetic fibers and reduces carbon footprint by absorbing CO_2 during growth.

Natural fiber composites, including those with jute, offer a sustainable and efficient alternative with diverse applications across industries. This study explored the use of jute composites in structural concrete, revealing that simulated acid rain had a more corrosive impact on basalt fiber-reinforced polymer (BFRP) compared to the alkaline environment of concrete pore water. The performance of BFRP in this alkaline setting was aligned with prior research, suggesting that bamboo effectively retains its mechanical strength within the high-pH matrix of concrete. While Sikadur-31 was found to increase the bond strength between BFRP rebars and concrete, it also heightened the vulnerability of the composite to alkaline degradation and failed to protect against acidic exposure. In contrast, epoxy coatings based on bisphenol-A (BPA) not only enhance the durability of BFRP under acidic conditions but also improve the bonding behavior, particularly when sand particles are added. To extend the structural applications of bamboo in areas such as large-span components, reinforced bamboo scriber composite (RBSC) beams have been developed by integrating bamboo with reinforcement materials. Testing across six beam types led to key findings: both the load-bearing capacity and flexural stiffness of RBSC beams saw significant increases of up to 58% and 82%, respectively, compared with unreinforced bamboo beams. The mechanical model proposed in this study showed good agreement between the theoretical predictions and experimental outcomes, indicating its reliability in evaluating flexural behavior. Additionally, the reinforcement contributed between 23% and 45% of the bending stiffness and 15% to 31% of the load-bearing capacity, depending on the reinforcement diameters ranging from 12 mm to 20 mm. Three primary failure modes were observed: longitudinal cracking, vertical cracking within the bamboo element, and shear failure [7, 8].

MATERIAL AND METHOD

Selection and Preparation of Jute Fibers

Jute Fiber Mats

Jute fibers were chosen because of their strength and eco-friendly properties. Preparation involves several key steps:
- *Fiber selection:* Choose high-quality, long, and fine jute fibers, free from impurities. Fiber Cleaning: Remove contaminants by washing or mechanical methods such as beating or carding.
- *Fiber retting:* Soak jute stems in water to separate fibers through natural enzymatic and bacterial actions. After retting, the fibers were washed and dried.
- *Fiber spinning:* Spin-cleaned fibers are spun into yarn or roving to enhance alignment and compatibility.
- *Mat formation:* Layer spun fibers in a desired pattern (unidirectional, random, or cross-ply). Press or bond layers to form mats.
- *Mat pretreatment:* Apply surface modifications or chemical treatments to improve adhesion and reduce moisture absorption [9, 10].

Materials for Composite Sheet Preparation

Jute fiber mat (30 mm × 20 mm), epoxy resin (LY 556), hardener (HY 951), spacers (3 mm thick), mild steel plates (400 mm × 400 mm × 5 mm), Universal Testing Machine (UTM), PVC sheets, release agent, and filler material (titanium dioxide micro particles).

Matrix Material Selection

- *Epoxy resin and hardener:* LY 556 Epoxy: Offers excellent mechanical properties, adhesion strength, and chemical resistance. It provides good wetting and high mechanical strength and durability.

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- *HY 951 hardener:* A low-viscosity, fast-curing agent that ensures good adhesion and easy mixing with the epoxy resin.
- *Suitability:* The LY 556 epoxy and HY 951 hardener are suitable for natural fiber composites because of their excellent impregnation properties and mechanical strength. The mixing ratios and curing conditions were adjusted as per the manufacturer's guidelines for optimal results.

Fabrication Techniques for Jute Fiber Composite Hand Lay-Up

Manual layering of jute fibers in a mold, with resin applied to impregnate the fibers. Subsequently, the composite was cured under pressure.

- *Compression molding:* The jute fibers were impregnated with resin, placed in a mold, and subjected to high pressure and temperature to shape and cure the composite.
- *Resin transfer molding (RTM):* Dry fibers are placed in a closed mold; resin is injected under pressure and cured.
- *Vacuum infusion:* A vacuum is used to draw resin through dry fibers placed in a mold, ensuring complete impregnation.
- *Filament winding:* Wind jute fibers onto a mandrel, apply resin, and cure them to form cylindrical or spherical structures.

Curing Process and Condition Preparation

- *Cut and align jute fibers:* The epoxy resin and hardener were blended according to the manufacturer's instructions.
- *Impregnation:* Apply a resin mixture to fibers using a roller or brush to ensure full saturation and remove air bubbles.
- *Curing:* Follow a two-stage curing process: an initial low temperature for gelation and a higher temperature for final curing. The specific temperatures and times depend on the specifications of the resin and hardener.
- *Pressure (optional):* Pressure was applied using methods such as vacuum bagging or autoclaving to enhance consolidation and bonding.
- *Post-curing and cooling:* The composites were allowed to cool gradually. Post-curing at higher temperatures is often required to achieve the desired material properties in jute fiber composites.

Standardized Testing

Standardized testing methods were employed to assess performance.

- The tensile strength was measured using ASTM D3039 and ISO 527, whereas the flexural strength was evaluated using ASTM D790 and ISO 178.
- The impact resistance was determined using ASTM D256 and ISO 179.
- The moisture absorption was tested using ASTM D570.
- The thermal characteristics were assessed using ASTM E831 and ASTM D3418 standards.
- The fiber content was analyzed using ASTM D3171 and ISO 1172.
- The composite density was measured using ASTM D792 and ISO 1183.

These standardized tests provide a comprehensive evaluation of the mechanical, thermal, and physical properties of jute fiber composites, helping to ensure their effectiveness across a range of applications.

MECHANICAL TESTING

Tensile Strength Analysis of Jute Fiber Composites

The mechanical properties of the three specimens were determined via tensile testing (Figures 1–3). The specimens were subjected to an axial load until failure, and their elongation, yield strength, ultimate tensile strength, and fracture characteristics were analyzed. The results provided valuable information for material selection and structural design (Figure 4).

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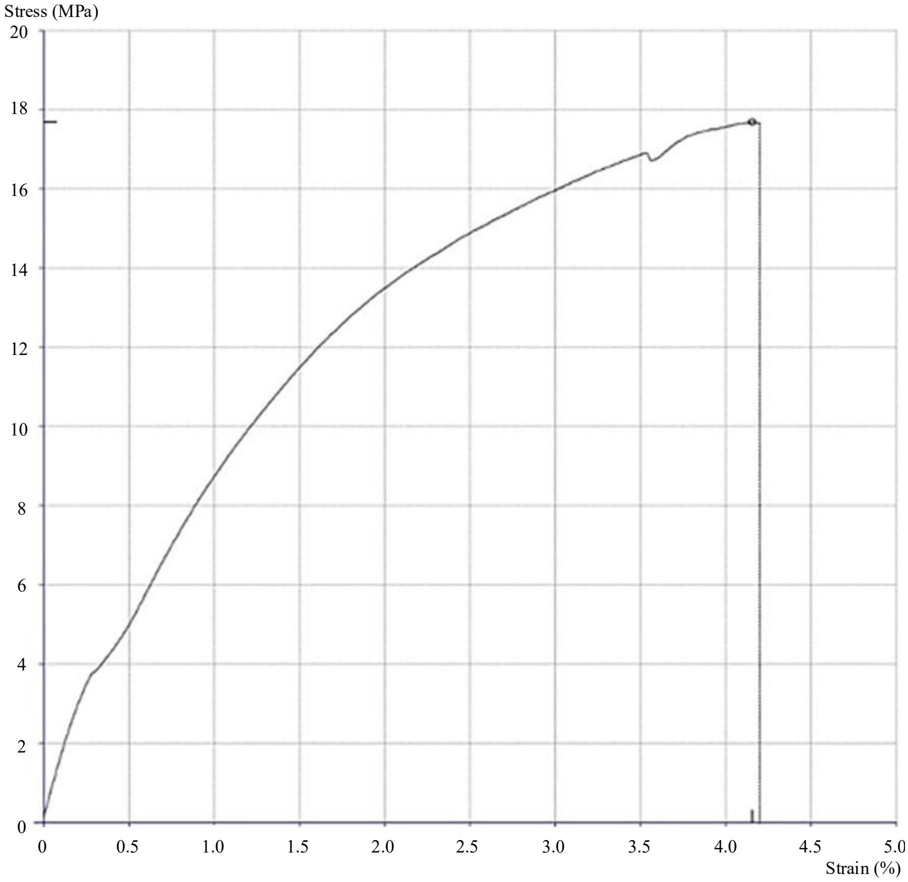

Figure 1. Result of specimen for yield point 17.69 MPa.

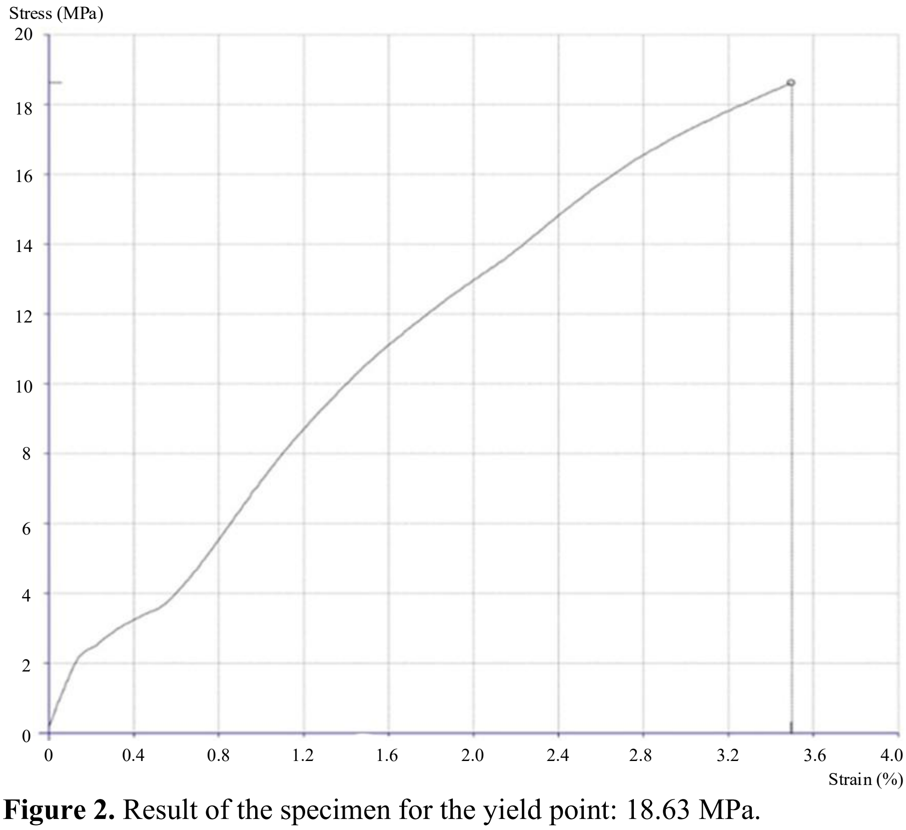

Figure 2. Result of the specimen for the yield point: 18.63 MPa.

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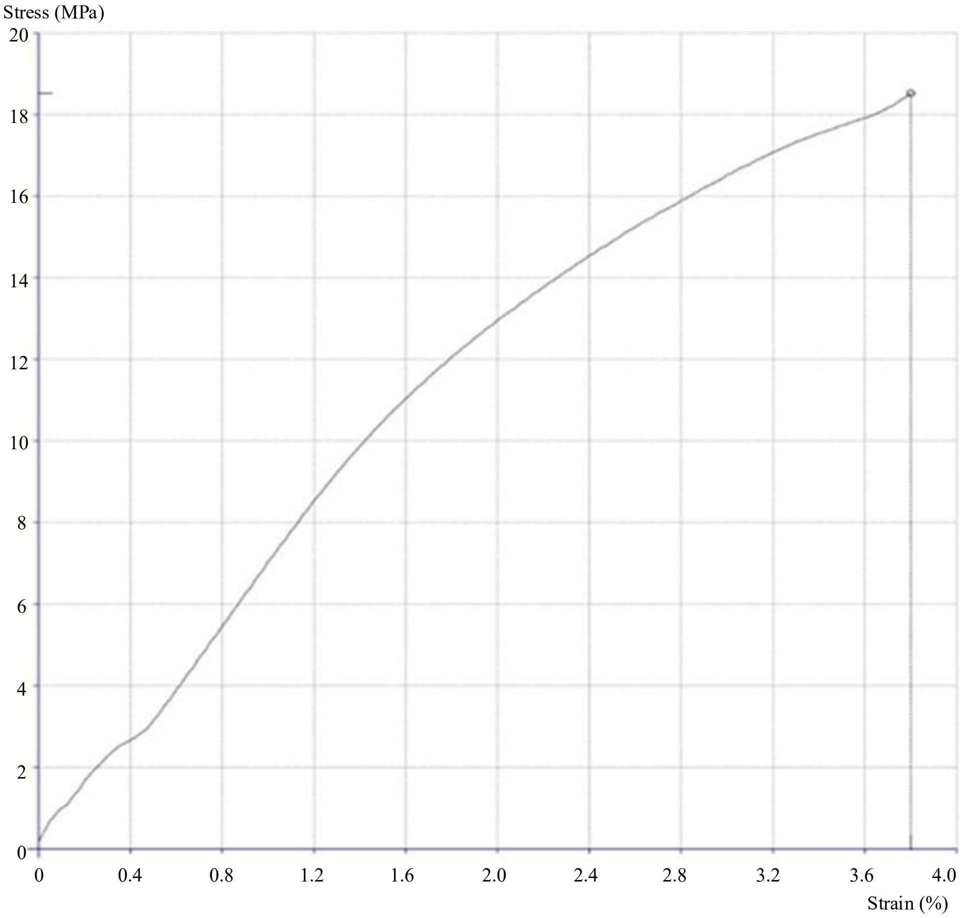

Figure 3. Result of the specimen for the yield point: 18.52 MPa.

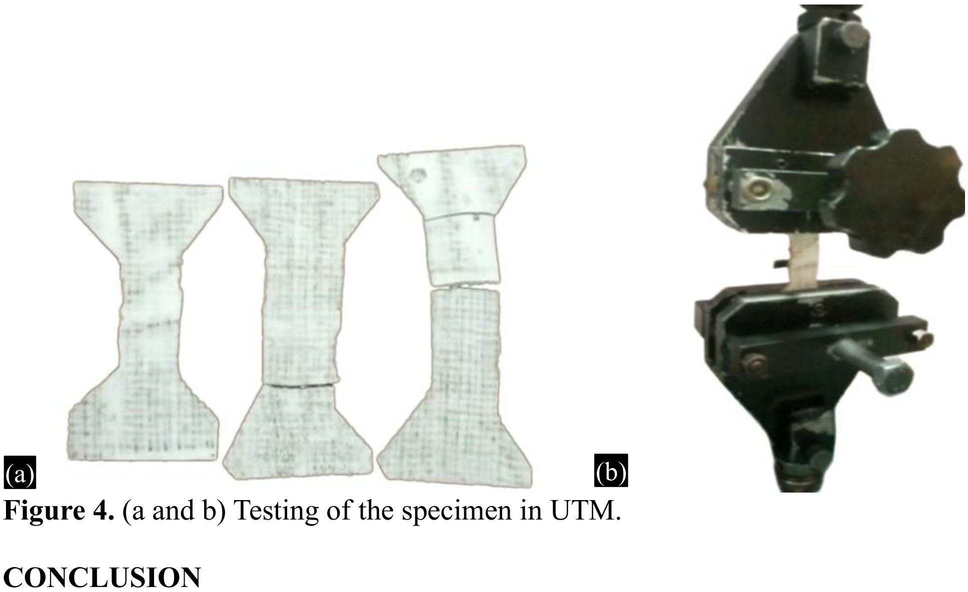

Figure 4. (a and b) Testing of the specimen in UTM.

CONCLUSION

This study explored the potential of jute fibers as reinforcing agents in composite materials. Key findings include:

- *Performance:* Jute fiber composites demonstrated strong mechanical properties, making them a viable alternative to traditional materials.
- *Environmental impact:* Jute is renewable and requires less water and chemicals, thus offering an eco-friendlier option.

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- *Cost effectiveness:* Jute fibers are cheaper than carbon or glass fibers, promoting their adoption, particularly in cost-sensitive industries.
- *Compatibility and processing:* Proper treatment and matrix selection enhance jute fiber adhesion and composite performance.

Jute composites have significant potential across various industries, including the automotive, construction, and packaging industries. Research efforts should focus on enhancing manufacturing methods, increasing material longevity, and discovering novel uses. Overall, jute fiber composites are environmentally friendly, affordable, and possess strong mechanical properties, indicating their suitability for wider industrial adoption and ongoing development.

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