Fabrication and characterization of high-performance hybrid natural fiber-reinforced composites

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ABSTRACT

The utilization of natural composites in modern engineering applications offers numerous advantages due to their remarkable sustainability features and minimal environmental impacts. However, the widespread adoption of natural composites as alternative materials to conventional ones faces challenges related to environmental factors, particularly moisture content, which leads to varying shrinkage and swelling behaviors. Uncontrolled shrinkage can often result in the premature splitting of natural composites. In the present work, various composites such as Jute fiber composite, coir fiber composite, and hybrid composites are fabricated. This research focuses on the study measures of the tensile properties and flexural properties of prepared natural fiber composite materials. The experimental results showed that blending jute and coir fibers could be a promising approach to developing composite materials with tailored mechanical properties.

Keywords: - *Mechanical properties, Composite, Fibre, Epoxy.*

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1. Introduction

Our world is undergoing rapid growth and transformation, necessitating materials that can keep up with the pace of change. As a result, traditional materials that have been used for decades or centuries are being replaced by newer, more innovative alternatives [1], [2]. One of the main driving forces behind this transition is the quest for materials with a superior strength-to-weight ratio. This is particularly critical in industries like aviation and aerospace, where even the slightest reduction in weight can have a significant impact on performance and efficiency [3]–[9]. Additionally, the extraction and use of certain traditional materials have been linked to environmental pollution, causing global concern. Governments and businesses are facing mounting pressure to minimize their environmental impact and adopt sustainable practices. This includes sourcing materials that not only possess the desired properties but also contribute positively to the environment [10], [11]. The world is now actively seeking sustainable materials that can help mitigate the environmental consequences of manufacturing and production processes. Fortunately, advancements in technology and materials science have led to the development of novel and innovative materials that offer enhanced performance while also providing environmental benefits [12]–[16]. For instance, biodegradable plastics and plant-based materials have gained popularity due to their ability to naturally decompose and reduce plastic waste in the environment [17]–[20]. With ongoing research and development, we anticipate the emergence of even more groundbreaking and environmentally friendly materials in the future [21], [22]. By embracing these materials, we can contribute to building a sustainable and prosperous future for all.

Natural composites find a wide range of applications in various industries due to their unique properties and sustainability. Here are some examples of how natural composites are used in different industries such as the automotive industry, construction industry, aerospace industry, packaging industry, and furniture industry [23]–[26]. The use of natural composites in industries not only offers technical advantages but also contributes to sustainable practices by reducing reliance on non-renewable resources and minimizing environmental impacts. Composite materials are prepared by combining two or more distinct materials [27], [28]. For instance, Medium-Density Fiberboard (MDF) is made by blending wood fibers and glue, while fiberglass consists of glass fibers embedded in a sturdy polymer matrix. When composite materials are formed, the individual components retain their identities and do not dissolve or merge, making the disassembly of the composite easier. However, it is the collaborative interaction of multiple parts that gives the composite its unique properties. Without the use of composite materials, the construction of rocket ships would be impossible. Composites offer numerous advantages, including strength, resistance to corrosion, lightweight characteristics, design flexibility, and long-term durability. In terms of fracture toughness, composites generally fall between metals and most polymers, with higher values than polymers but lower than metals [29], [30].

2. Literature Survey

Sustainable materials, such as natural fibers like hemp, flax, jute, and sisal, provide an environmentally friendly alternative to synthetic fibers. Unlike synthetic fibers derived from non-renewable sources, natural fibers are renewable and biodegradable, decomposing in a much shorter time frame. One notable advantage of natural fiber composites is their lightweight nature compared to traditional materials like steel or aluminum. In addition, natural fiber composites boast a high strength-to-weight ratio, allowing for the production of robust and durable products without adding unnecessary weight. This attribute makes them an excellent choice for applications where strength and durability are paramount, such as in construction or aerospace [31]–[35]. Cost-effectiveness is another benefit of natural fiber composites. These materials are often more affordable than alternatives like carbon fiber or fiberglass. The ready availability of natural fibers and their lower production costs contribute to this advantage. Furthermore, natural fiber composites offer improved insulation properties compared to traditional materials. This makes them highly suitable for building insulation, helping to reduce energy consumption and lower heating and cooling costs [5], [36]–[40]. As the demand for sustainable and cost-effective materials continues to rise, natural fiber composites are becoming increasingly vital in various industries. Their numerous advantages make them a necessity for the future, as we strive for a more sustainable and resource-efficient world. In recent years, there has been significant research focused on enhancing the properties of epoxy composites through the incorporation of jute fibers. Saravanan et al. [41] (2017) conducted a study to examine the mechanical characteristics of jute fiber-reinforced epoxy composites. The results demonstrated that the inclusion of jute fibers resulted in improved tensile, flexural, and impact strength of the composites. Furthermore, the study revealed a positive correlation between fiber content and the mechanical properties of the composites.

Similarly, Thiruchitrambalam et al. [42] (2019) conducted research to investigate the impact of jute fiber content on the mechanical properties of epoxy composites. The study revealed that increasing the fiber content from 10% to 40% led to a significant enhancement in the tensile, flexural, and impact strength of the composites. Moreover, it was observed that composites with higher fiber content exhibited increased stiffness and fracture toughness. These studies highlight the promising potential of jute fiber-reinforced epoxy composites in enhancing the mechanical properties of the materials. The findings suggest that increasing the fiber content can lead to improved strength and performance characteristics, making them a viable option for various applications in industries ranging from automotive to construction. Numerous research studies have explored the reinforcement of epoxy composites using different types of natural fibers. For instance, Prasad et al. [43] (2016) investigated the impact of coir fiber content on the mechanical properties of epoxy composites. Their findings revealed that increasing the fiber content from 10% to 30% resulted in improved tensile, flexural, and impact strength. Moreover, composites with higher fiber content exhibited enhanced stiffness and fracture toughness

Wang et al. [44] (2020) investigated the use of flax fibers as a reinforcement material in polymer composites. Their study demonstrated that the mechanical properties of the composites improved with the addition of flax fibers, leading to enhanced toughness and ductility.

3. Experimental Procedure

A. The preparation procedure for jute and coir fibers involves several fundamental steps:

1. Harvesting and Cleaning: Raw jute and coir fibers are obtained from plants and require initial cleaning before use. This step involves removing any dirt or oil present in the fibers.
2. Soaking in Casting Soda Solution: The fibers are immersed in a solution of casting soda and water for a designated period, typically a few hours. This soaking process aids in the elimination of impurities.
3. Thorough Rinsing: The fibers are thoroughly rinsed with clean water to ensure the complete removal of any remaining impurities from the soaking process.
4. Air Drying: After rinsing, the fibers are left to air dry completely for a minimum of 24 hours. This critical drying phase eliminates moisture and residual impurities, which can impact the strength and durability of the final composite material.
5. Fiber Readiness: Once the fibers have undergone thorough drying, they are ready for use as a reinforcing material in composite manufacturing.

6. Cutting or Impregnation: Depending on the specific requirements of the composite material application, the jute and coir fibers can be cut to the desired size or impregnated with a resin for enhanced bonding.
7. Utilization in Composite Material: The prepared jute and coir fibers are then incorporated into the composite material, providing reinforcement and contributing to the overall strength and performance.
8. Quality Assurance: The process of washing and drying the raw fibers ensures that the final composite material attains optimal strength, durability, and freedom from impurities, meeting the desired quality standards.

B. The procedure of fabrication of coir fiber composite:

1. Calculate the required volume of epoxy mixture based on an 80 wt.% volume ratio, ensuring that 80% of the mold's total volume is filled with the epoxy mixture.
2. For a mold with a 20 wt.% volume ratio, use the calculated amount of 28 gm of coir fiber.
3. Using a weighing machine, accurately measure the required amounts of epoxy resin and hardener according to the calculated amounts needed for the mold volume. In this case, the resin and hardener should be 66 gm. and 48 gm. respectively.
4. Thoroughly mix the epoxy resin and hardener following the instructions provided by the manufacturer.
5. Add the coir fibers to the epoxy mixture and gently stir to ensure that the fibers are evenly coated.
6. Pour the prepared mixture into the mold, ensuring that the coir fibers are distributed.
7. Use a roller or suitable tool to compress the mixture, eliminating any trapped air bubbles.
8. Allow the composite material to cure for the recommended duration as specified in the epoxy manufacturer's instructions.

C. The procedure of fabrication of jute fiber composite:

1. Ensure that the jute fiber is properly cleaned and dried.
2. Determine the required amount of epoxy mixture based on the volume of the mold and a volume ratio of 80%. According to the calculation, the resin and hardener should be 64 gm. and 44 gm. respectively, while the amount of jute fiber is determined as 27 gm.
3. Use a weighing machine to measure the precise amount of epoxy resin and hardener as calculated for the mold volume.
4. Thoroughly mix the epoxy resin and hardener according to the instructions provided by the manufacturer.
5. Cut the jute fiber into 20 cm lengths and create layers of jute fiber in the mold. Pour the epoxy mixture onto each layer of jute fiber, followed by the addition of another layer of jute fiber and epoxy.
6. Pour the prepared mixture into the mold, ensuring that the fibers are evenly distributed throughout.
7. Utilize a roller or a suitable tool to compress the mixture and eliminate any trapped air bubbles.
8. Allow the composite material to cure for the recommended duration as specified in the epoxy manufacturer's instructions.

D. The procedure of fabrication of Hybrid (coir+jute fiber) composite:

1. The procedure for creating a hybrid composite sheet is similar to that of the jute and coir sheets, with slight differences in the amount of fiber used. However, the amount of epoxy remains constant for each composite sheet.
2. Begin by cleaning both the jute and coir fibers, and then allow them to dry in sunlight for a few hours.
3. Segregate the fibers and cut them into lengths of 20 cm. For the epoxy, use the calculated amounts of 64 gm. for the resin and 48 gm. for the hardener.
4. To enhance the mechanical properties of the hybrid composite sheet, compare the strength and durability of the jute and coir composite sheets.
5. For the hybrid composite sheet, use a different amount of jute and coir fibers to create a sustainable material. In this case, the volume fraction consists of 25 gm. of coir fiber and 30 gm. of jute fiber.
6. Apply the layers of jute, coir, and epoxy sequentially, ensuring proper bonding between each layer.
7. After pouring the epoxy mixture, securely fasten the fixture with a manual tightening fixture. For additional protection and improved grip, a C clamp can be used.
8. Allow the composite material to cure for the recommended time according to the epoxy manufacturer's instructions.

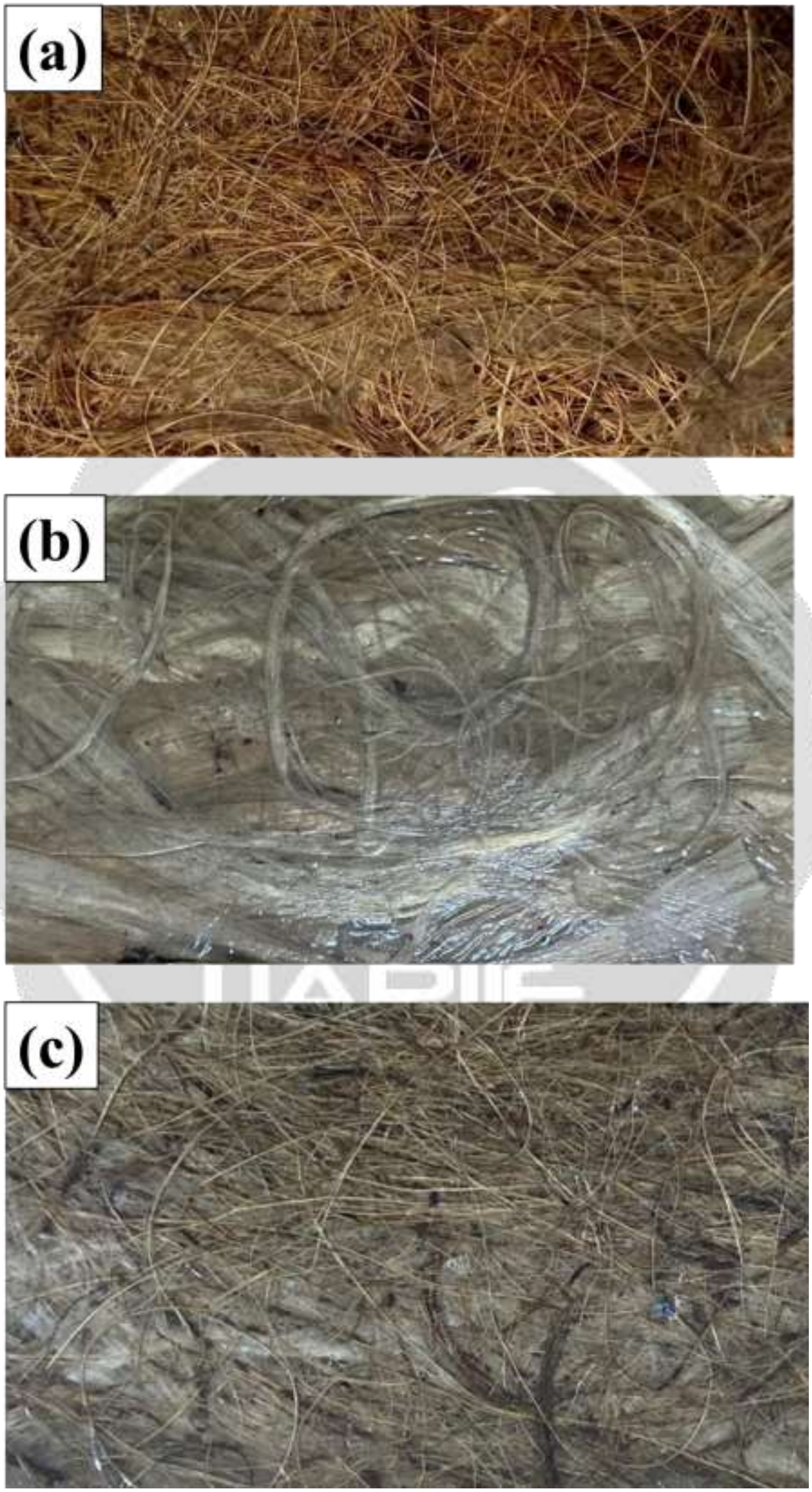

Fig 1: Photographs of (a) Coir fiber composite, (b) Jute fiber composite, and (c) Hybrid composite.

4. Result and Discussions

The experiments involved conducting tensile and flexure tests on separate composite sheets fabricated from jute fiber, coir fiber, as well as a hybrid composite sheet that integrated both jute and coir fibers (Fig. 1). The test outcomes showcased intriguing distinctions among each sample, emphasizing the distinct properties of each fiber and their potential applications. These findings offer valuable insights for future research and advancements in the realm of natural fiber composites.

The tensile test conducted on the ASTM D638 specimen is a significant procedure for obtaining essential information regarding the mechanical properties of composite sheets. This test entails subjecting the material to a uniaxial force until it reaches its fracture point. Throughout the test, the values of load versus displacement are measured and recorded, and the resulting graph allows us to gain insights into the material's behavior under tension. By analyzing the load versus displacement graph, we can ascertain crucial parameters such as tensile strength, elastic modulus, and ultimate elongation of the material. Understanding the properties of composite materials is crucial for optimizing their performance in different applications. The tensile test provides valuable information about the material's behavior, enabling us to assess its suitability and make informed decisions regarding material selection and processing methods. By analyzing the results of the tensile test, we can gain insights into important properties such as tensile strength, elastic modulus, and ultimate elongation. This knowledge allows us to optimize the design and production of composite sheets with specific properties tailored to meet the requirements of various applications. Ultimately, the tensile test plays a critical role in characterizing and developing composite materials, ensuring their suitability and enhancing their performance in real-world scenarios.

The flexural test is a critical method for evaluating the bending strength and stiffness of composite sheets, providing valuable insights into their behavior. In this test, an ASTM D790 specimen is subjected to a load while supported on two points, resulting in bending until fracture or failure occurs. Load vs. displacement values are recorded and used to analyze the material's response under bending.

By examining the load vs. displacement graph, we can determine important properties such as flexural strength, modulus of elasticity, and flexural strain. These properties play a vital role in understanding how the material performs in different applications and allow for the optimization of composite sheet performance. They guide material selection and processing methods to achieve specific properties. The results from the flexural test are crucial in characterizing and developing composite materials. They ensure the suitability of these materials for various applications. In addition, these results inform the design and production processes, aiding in the creation of composite sheets with desired properties.

Table 1 presents the outcomes of both the tensile and flexural tests conducted on specimens composed of coir fiber, jute fiber, and hybrid fiber. The tensile test evaluates the maximum stress a material can withstand under tension before breaking, while the flexural test measures the bending strength. These test values are essential for determining the mechanical properties of the composite materials and provide valuable insights into the performance of each fiber type. They help identify the strengths and weaknesses of each fiber, aiding in further research and development.

Table 1. Results of tensile and flexure tests.

Sample	Fiber Weight (gm)	Resins (gm)	Hardener (gm)	Ultimate Tensile Strength (MPa)	Flexural Strength (MPa)
Coir fiber composite	28	64	48	30 ± 5	160 ± 6
Jute fiber composite	27	64	48	27 ± 4	120 ± 8
Hybrid composite	28	64	48	47 ± 5	195 ± 11

5. Conclusion

In the present research work, various natural fiber composites such as coir fiber composite, jute fiber composite, and hybrid composite were successfully fabricated. Prepared composites were tested to measure their tensile and flexure properties. Experimental results showed that the composite sheets made from jute fiber had higher tensile strength and modulus of elasticity compared to those made from coir fiber. This may be due to the superior mechanical properties of jute fiber and its ability to form strong interfacial bonds with the matrix material. The high tensile strength of jute fiber composite sheets suggests that they could be used in applications that require materials with high strength-to-weight ratios, such as automotive and aerospace industries.

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