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Experimental Investigation of the Mechanical Properties of Jute Fiber Reinforced Composites

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Abstract

This study presents an experimental investigation of the mechanical properties of jute fiber reinforced polymer (thermoset and thermoplastic) composites. Jute fiber, renowned for its ecofriendly and sustainable characteristics, has garnered attention as a potential reinforcement material in polymer composites. The study aims to assess the tensile strength and impact resistance of these composites through systematic experimentation. Tensile strength and impact resistance test were conducted following standardized procedures to evaluate the mechanical behavior of both unidirectional and cross-ply jute/epoxy and jute/polypropylene (PP) composites. This study demonstrates that jute fiber composites achieved tensile strength ranges varying from 141.47 to 99.79 MPa and elastic moduli 1.86 to 2.00 GPa across different configurations, indicating their potential as sustainable alternatives to synthetic reinforcements in moderate-strength applications. Ultimate tensile strength, and energy absorption capacity are among the key to characterize the mechanical behavior of the composites. The findings underscore the potential of jute fiber composites as sustainable and ecofriendly materials with competitive mechanical properties.

Keywords: Natural fiber, Scanning Electron Microscope, Polypropylene, Unidirectional, Cross-ply

Introduction

Natural fiber composites, especially those reinforced with jute fibers, have gained significant attention over traditional engineering materials such as plastic, metals, and metal alloys in recent years for their sustainable nature, economical, and excellent mechanical properties [1, 2]. Tensile strength and impact resistance, among other mechanical properties, are crucial in various engineering fields, particularly in the automotive and construction industries. The natural fiber such as jute has become popular as a sustainable alternative to synthetic fibers for composite reinforcement due to its comparable mechanical properties, despite its abundance and low cost [3]. More specifically, the automotive industry has shown special interest in jute-based composites due to their affordability, low density, and environmental benefits [4, 5]. Zhang et al. reviewed that natural fiber-reinforced composites have a promising future [6]. Fragassa et al. investigated the mechanical and impact characteristics of jute fiber composites under dynamic loading conditions [7]. However, jute fiver composites have some major drawbacks that limit their widespread adoption. One most challenging issue is the hydrophilic nature of natural fiber, which can lead to moisture absorption from the surrounding environment. This characteristic can make it difficult to bond hydrophilic fiber with hydrophobic matrix materials during the manufacturing process [8]. Ashik et al. investigated the effect of moisture absorption on the mechanical properties of natural fiber-reinforced polymer hybrid composites, highlighting the importance of understanding and mitigating these effects [9]. Studies showed that as the water absorption increases, the flexural and tensile properties of natural fiber composites tend to decline. The degradation is more visible at higher temperatures, which basically deteriorate the fiber matrix interface and lead to lower mechanical performance [11, 12]. Prasad et al. used finite element analysis to analyze the jute fiber composite materials, demonstrating the growing sophistication in jute fiber composite analysis [13]. Moreover, Gholampour and Ozbakkaloglu give a review of jute (natural fiber) composites, covering the modification techniques, processing methods, and applications [14]. Understanding and optimizing the tensile strength and impact resistance of jute fiber composites has become more important owing to the increasing demand for sustainable materials. The objective of this research is to compare

the mechanical properties of unidirectional and cross-ply jute composites of untreated jute fibers and to investigate the distinctions between thermoplastics and thermosetting jute composites in order to contribute to the growing trends of natural fiber composite research. These investigations provide us with valuable insights into the ways in which the mechanical characteristics of jute fiber composites are influenced by fiber orientation, matrix selection and fiber treatment. These insights have the potential to facilitate the development of more efficient and environmentally friendly materials for a variety of industries.

Experimental Procedures

Jute composites have been manufactured by using untreated and hackled fibers with density of 1.5 gm/cm³ and with epoxy resin and polypropylene (PP) both. The extraction process of fibers is shown in Fig. 1. Untreated jute fiber was collected from local Market, Bangladesh. The LS800 epoxy was obtained and properly mixed with hardener [3:1] before using. The compression molding method was used to manufacture preforms of jute fibers initially. These preforms were produced by hackling of the jute fibers so that no entangled fibers would be present. A mold (18 cm × 18 cm) with the thickness of 3.2 mm was used in this process. Two Teflon sheets were used with aligned fibers from sticking them during compression molding. These jute fibers with Teflon sheets were placed in the compression molding machine which maintained the temperature of 180°C and the pressure was 13440 Psi. To ensure an accurate measurement, preforms were cut to fit at the mold size. In the interim, a 3:1 ratio of epoxy resin to hardener was mixed and the mixture was thoroughly stirred for a considerable amount of time. A preform made of jute fiber was placed on top of some epoxy resin that had been applied to a plastic sheet. A roller was used to apply layer of resin to the preform. Four layers of preform were used to manufacture unidirectional (UD) jute composite plates [19 cm × 18 cm × 3.2 mm] in hand lay-up method. Similarly, five layers of preform were used to manufacture cross ply jute composite plates [19 cm × 18 cm × 3.2 mm] in hand lay-up method. Additionally, jute fiber reinforced polypropylene composites were also manufactured by using the same compression molding method. In this case, PP was placed on the preforms during the compression molding method. The pressure was 6 tons and temperature were 180°C to fabricate the jute fiber reinforced PP composites. It took almost 35-40 minutes to manufacture the thermoplastic composite material.



Fig. 1: (a) Raw jute fiber (b) Hackling jute fiber (c) Preform of jute fiber (d) Compression molding machine (e) Composite plate

Tensile test

ASTM D 638 method was followed for the tensile test, conducting the test on a universal testing machine at a speed of 5 mm/min. The tensile test specimens are shown in Fig. 2. Sample size (165×13×3.2) mm. Five samples of thermosetting composite were tested for tensile testing along with five samples of thermoplastic jute composite enabling a comparative analysis of their tensile properties.



Fig. 2: Samples for tensile test

Impact Test

To conduct the test, an impact testing apparatus with a Charpy setup is used. The impact test specimens are shown in Fig. 4. The impact test sample size was (55×10×3.2) mm and ASTM D256 standard was used for this test. The sample tilts at 45 degrees.



Fig. 3: Sample for impact test

Results and Discussion
Tensile Test

The stress-strain curve is shown in Fig. 4. It is seen that, after an initial linear phase, the stress-strain curve's slope significantly reduced, and the relationship between stress and strain stayed fairly linear until a sudden collapse. This is because after a specific point material lose a certain amount of rigidity due to the complex micro-structure of the plant fibers. From comparative analysis (Fig. 4), it is seen that in tensile tests, the UD-oriented composite shows a higher value of strength than the cross-ply composites. This is because, in UD orientation, the fibers are fully aligned in the direction of tensile load, which allows them to carry grater load. In addition, in UD orientation, it has been seen that thermoplastic (PP) composites have a higher value of ultimate strength than thermosetting (epoxy) composites since the thermoplastic matrix will absorb more energy and deform plastically before complete failure. The ultimate tensile strength (UTS) and modulus of elasticity of UD/PP jute composites were 141.47 MPa and 1.86 GPa, respectively. The tensile testing data for cross-ply epoxy composites reveal a typical composite behavior characterized by a linear elastic region followed by yielding and eventual failure.

The stress-strain curve exhibits clear UTS, indicating that UD/PP composites had the highest strength and UD/epoxy composites had the lowest tensile strength. Cross-ply/epoxy composites demonstrate consistent mechanical behavior, making it suitable for applications requiring a balance of strength and ductility.

Similarly, Cross-ply/PP shows similar behavior with UTS of 99.79 MPa and modulus of elasticity 2.00 GPa, which refers that these composites offer moderate strength and stiffness, suitable for applications requiring intermediate mechanical properties.

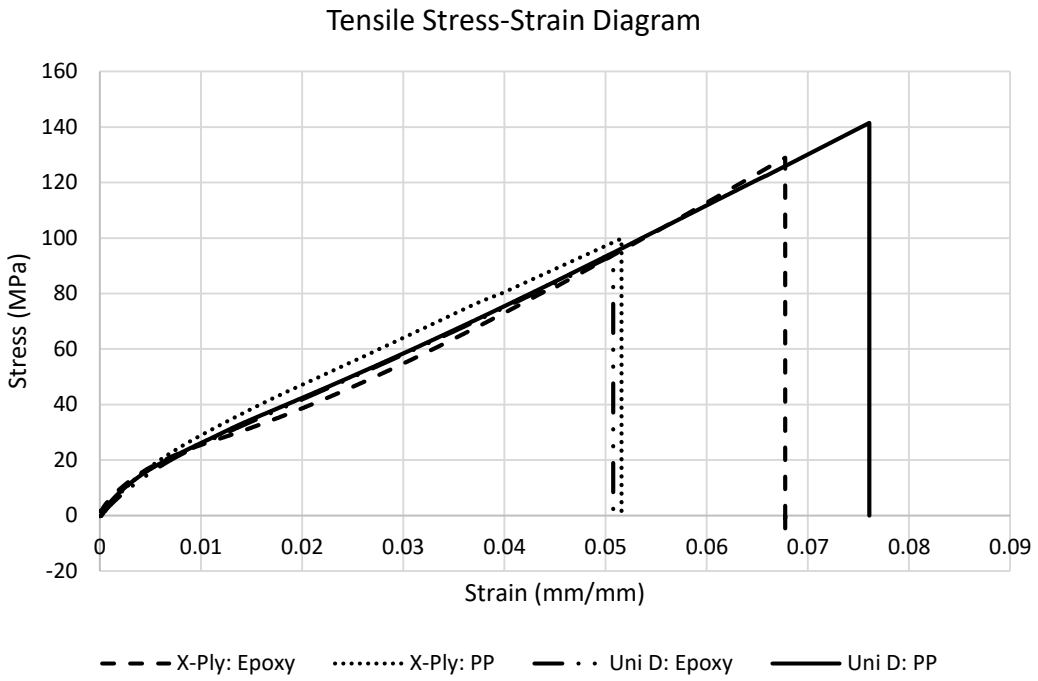


Fig. 4: Stress/strain curve of jute/epoxy and jute/PP composite in UD (Unidirectional) and cross-ply orientation

Impact test

In impact testing, five samples were tested for each composite sample. Then an average was made for the results and compared it in Fig. 5. It can be seen that; highest impact force (1.65 Nm) was found in case of cross-ply pp composites. Almost similar impact forces were found in case of UD epoxy and UD PP composites but lowest impact force was found in case of cross-ply epoxy jute composites.

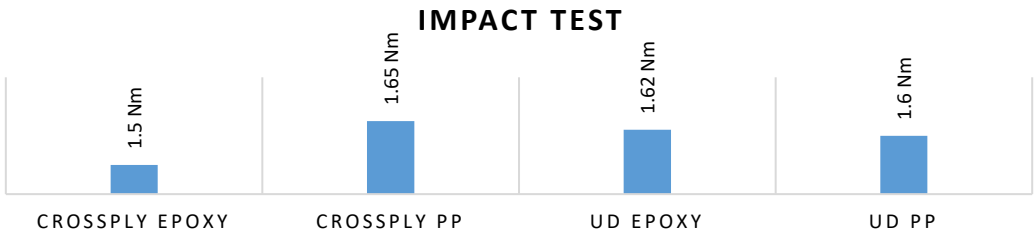


Fig. 5: Comparison of average results of epoxy and pp for both UD and cross-ply jute composites

Conclusion

This work presented a comparative study on jute/PP and jute/epoxy composites based on their mechanical properties in two different fiber orientations. The jute/PP composites in UD orientation showed better strength as shown by higher UTS values than jute/epoxy, even though modulus is same for both the materials. UD

fibers offer maximum strength in the fiber loading direction. In addition, jute/epoxy composites in cross-ply orientation have more ability to withstand applied stress than jute/PP composites in cross-ply direction. The cross-ply orientation provides balanced mechanical properties but lower ultimate strength. The highest impact resistance was found in case of cross-ply/PP jute composites. Therefore, jute/epoxy composite was stiffer and more durable than its counterpart. It's resistance to stress and its ability to provide robust mechanical support make it an ideal material for certain applications. In contrast, the jute/PP composites showed better ductility as they have higher maximum strain values although they possess lower stiffness and yield strength. Overall, the findings of this study provide information on the applicability and usefulness of jute/epoxy and jute/PP composites in various settings and offer suggestions for improving these materials by using the most of their unique properties.

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