Analysis of Jute-Glass Fiber Reinforced Epoxy Hybrid Composite

A Thesis

by

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DEPARTMENT OF MECHANICAL ENGINEERING
SONARGAON UNIVERSITY (SU)

SEPTEMBER 2025

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Submitted to the
DEPARTMENT OF MECHANICAL ENGINEERING
SONARGAON UNIVERSITY (SU)
In partial fulfillment of the requirements for the award of the degree

Of

Bachelor of Science in Mechanical Engineering

SEPTEMBER 2025

DECLARATION

We hereby declare that this thesis is our own work and to the best of our knowledge it contains no materials previously published or written by another person, or have been accepted for the award of any other degree or diploma at Sonargaon University or any other educational institution. We also declare that the intellectual content of this thesis is the product of our own work and any contribution made to the research by others, with whom I have worked at Sonargaon University or elsewhere, is explicitly acknowledged.

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CERTIFICATION OF APPROVAL

The thesis title "**Analysis of Jute-Glass Fiber Reinforced Epoxy Hybrid Composite**" submitted by Md. Mostafizur Rohaman (ME2102024171), MD. Mesbahul Haque (ME2102024379), Md. Sharif Hossen (ME2102024471), Tawhidul Islam (ME2103025388), Md Zohorul Islam (ME2201026101) has been accepted as satisfactory partial fulfillment of the requirement for the degree of bachelor of science in mechanical engineering on 03 September 2025.

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ACKNOWLEDGEMENT

Firstly, we want to express gratefulness and humbleness to Almighty Allah for His immense blessing upon me for the successfulness completion of this thesis work. We would like to express my sincere gratitude to my supervisor, **Shahinur Rahman** Asst. Professor & coordinator, Department of Mechanical Engineering, Sonargaon University for his valuable suggestions, guidance and constant encouragement during pursuit of this work.

We express our deep sense of gratitude and thanks to Professor **Md. Mostofa Hossain**, Head, Department of Mechanical Engineering, and Sonargaon University for his motivation and kind collaboration.

Finally, we would like to express my sincere gratitude to our family who have given support to our study and prayed for our life. [Authors]

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ABSTRACT

This study investigates the mechanical behavior and performance of jute–glass fiber reinforced epoxy hybrid composites, focusing on the role of fiber orientation in determining their properties. Hybrid laminates were fabricated by combining natural jute fibers with synthetic glass fibers in an epoxy resin matrix, with the jute fibers oriented at 45°, 60°, and 90°. Mechanical evaluations were carried out through hardness and impact strength tests to assess the influence of fiber alignment on the composite's response to static and dynamic loading. The experimental results revealed that fiber orientation plays a critical role in governing the overall mechanical performance of the composites. Among the tested configurations, the 60° jute fiber orientation achieved the highest impact resistance, attributed to enhanced energy absorption and dispersion capabilities. Conversely, the 90° orientation produced superior hardness values, indicating better localized load resistance. The 45° orientation demonstrated moderate performance, balancing between hardness and impact properties but not exceeding the other two orientations. These outcomes emphasize the significance of optimizing fiber orientation in hybrid composites to tailor material properties for diverse engineering applications. The findings contribute to the development of sustainable and high-performance composite materials, suitable for automotive, aerospace, and structural components where lightweight design and mechanical efficiency are essential.

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CHAPTER 1: INTRODUCTION

1.1 Background

Composite materials have emerged as one of the most versatile classes of engineering materials due to their ability to combine the beneficial properties of two or more distinct constituents. Among them, fiber-reinforced polymer composites are widely recognized for their lightweight, high strength-to-weight ratio, and superior durability compared to conventional metals and alloys. In recent years, increasing global emphasis on sustainability has driven researchers toward the utilization of natural fibers as reinforcements in polymer matrices. Jute, an abundant and renewable natural fiber, has attracted significant attention owing to its low cost, biodegradability, and relatively good mechanical properties. However, its limitations, such as lower strength, poor moisture resistance, and reduced durability under harsh environments, restrict its independent use in high-performance applications. [1-3]

To overcome these drawbacks, hybrid composites that combine natural fibers with synthetic reinforcements have gained prominence. Glass fiber, a widely used synthetic fiber, provides excellent tensile strength, impact resistance, and dimensional stability. When used in combination with jute, it has the potential to compensate for the deficiencies of natural fibers while maintaining cost-effectiveness and sustainability. The epoxy resin matrix, known for its strong adhesion, chemical resistance, and superior load transfer capability, further enhances the overall performance of the hybrid composite. [3]

One of the critical factors influencing the performance of fiber-reinforced composites is fiber orientation. The alignment of fibers within the matrix governs how the material responds to applied stresses and significantly affects properties such as impact resistance, hardness, tensile strength, and flexural behavior. Studies have indicated that different fiber orientations can drastically alter the ability of composites to absorb energy, resist deformation, and sustain structural integrity under mechanical loading. [4]

Therefore, analyzing the effect of fiber orientation in jute–glass hybrid epoxy composites becomes essential for tailoring materials to meet specific engineering requirements. By systematically investigating orientations such as 45°, 60°, and 90°, valuable insights can be gained into optimizing composite design for targeted applications. Such hybrid composites offer promising solutions for industries like automotive, aerospace, and construction, where lightweight, strong, and environmentally friendly materials are increasingly demanded.

1.2 Complications Emerge

While jute–glass fiber reinforced epoxy hybrid composites show promise as sustainable and high-performance materials, several complications arise during their fabrication, characterization, and practical application. One of the primary challenges is the interfacial bonding between natural jute fibers and the epoxy matrix. Jute fibers are hydrophilic in nature due to the presence of cellulose and hemicellulose, whereas epoxy is hydrophobic. This mismatch leads to poor adhesion, resulting in weak stress transfer, reduced strength, and susceptibility to moisture absorption. Fiber treatments such as alkali or silane modification are often required, but these add complexity and cost to the manufacturing process.

Another complication involves the uniform distribution and orientation of fibers within the matrix. Achieving consistent alignment of jute and glass fibers is difficult, and even slight deviations can significantly affect the mechanical properties of the composite. Improper orientation may lead to anisotropic behavior, reducing impact resistance or hardness in unintended directions. Moreover, hybridization introduces challenges in balancing the proportion of natural and synthetic fibers, as excessive glass fiber increases weight and cost, while higher jute content compromises strength and durability.

Environmental and durability issues further complicate the application of jute-based hybrids. Jute fibers are prone to moisture absorption, which leads to swelling, fiber degradation, and reduced dimensional stability. This limits the long-term performance of the composite under humid or outdoor conditions. Additionally, stress concentrations often occur at the interface between jute and glass fibers due to differences in stiffness, creating potential sites for crack initiation and failure under cyclic or impact loading.

Finally, large-scale production of hybrid composites faces economic and processing challenges. Variability in natural fiber quality, difficulties in maintaining consistent fiber orientation, and the need for surface treatments complicate industrial implementation. These complications highlight the necessity for optimized design, proper fiber treatment, and advanced fabrication techniques to fully exploit the potential of jute–glass fiber reinforced epoxy composites. [5]

1.3 Purpose

The primary purpose of this study is to investigate and analyze the mechanical performance of jute–glass fiber reinforced epoxy hybrid composites with particular emphasis on the effect of fiber orientation. As the demand for lightweight, durable, and eco-friendly materials

grows, hybrid composites that integrate natural and synthetic fibers have emerged as a promising solution. However, the performance of such composites is strongly influenced by factors such as fiber distribution, interfacial bonding, and most importantly, orientation of the reinforcing fibers. This research aims to systematically evaluate the impact of different jute fiber orientations—specifically 45°, 60°, and 90°—when combined with glass fibers in an epoxy matrix. Mechanical properties including hardness and impact strength are tested to determine how orientation influences load transfer, resistance to localized deformation, and energy absorption capacity. By comparing these orientations, the study seeks to identify the most effective alignment for achieving balanced mechanical behavior. Furthermore, this research intends to bridge the gap between sustainability and performance by demonstrating how natural fibers like jute, when strategically hybridized with glass fibers, can be engineered into composites suitable for structural and industrial applications. The ultimate purpose is not only to highlight the importance of fiber orientation in hybrid composites but also to provide a pathway for optimizing material design for industries such as automotive, aerospace, and construction. In doing so, this study contributes to the development of sustainable, cost-effective, and high-performance materials that meet the evolving requirements of modern engineering.

1.4 Methodology

The methodology adopted in this study involves the fabrication, preparation, and testing of jute–glass fiber reinforced epoxy hybrid composites with varying fiber orientations to evaluate their mechanical behavior. The process is divided into several key stages:

1. **Materials Selection:**

Epoxy resin was chosen as the matrix material due to its excellent mechanical strength, strong adhesion, and chemical resistance. Jute fibers, an eco-friendly natural reinforcement, were selected for their low density and availability, while glass fibers were incorporated to enhance strength, stiffness, and durability. The combination of natural and synthetic fibers aimed to develop a balanced hybrid composite with improved performance.

2. **Fiber Preparation:**

The jute fibers were initially cleaned, dried, and treated with an alkali solution to remove impurities and enhance adhesion with the epoxy matrix. Glass fibers were used in woven mat

form for uniform reinforcement. Jute fibers were oriented at three distinct angles—45°, 60°, and 90°—to study the influence of orientation on mechanical properties.

3. **Composite Fabrication:**

The hand lay-up method was employed for fabricating the composites. Layers of jute and glass fibers were alternately arranged within a mold and impregnated with epoxy resin mixed with a suitable hardener. The mold was compressed and left to cure under controlled conditions to ensure proper bonding and minimize void formation. Three sets of hybrid composites were prepared, each with different jute fiber orientations while maintaining constant glass fiber reinforcement.

4. **Mechanical Testing:**

The fabricated samples were cut into standardized dimensions as per ASTM guidelines for mechanical testing. Two key tests were conducted:

Impact Test (Charpy/Izod method): to evaluate the energy absorption capacity and resistance to sudden loading.

Hardness Test (Shore D/Rockwell): to determine resistance to localized deformation.

5. **Data Analysis**

The results of hardness and impact tests were compared across the three fiber orientations (45°, 60°, and 90°). Statistical analysis was used to interpret the influence of orientation on overall composite performance.

This methodology provides a systematic approach to understanding how fiber orientation impacts the mechanical characteristics of jute–glass fiber reinforced epoxy hybrid composites.

1.5 Problem Statement

The growing demand for lightweight, durable, and sustainable materials in engineering applications has led to increasing interest in natural fiber-reinforced composites. Among natural fibers, jute has gained attention due to its biodegradability, low cost, and availability. However, jute fibers on their own suffer from several limitations, such as low mechanical strength, poor resistance to moisture, and reduced durability under harsh environmental conditions. These shortcomings restrict the use of jute fiber composites in structural and high-

performance applications. To overcome these drawbacks, hybrid composites that combine natural fibers with synthetic reinforcements, such as glass fibers, have been developed. Glass fibers offer excellent tensile strength, stiffness, and impact resistance, making them suitable for compensating the weaknesses of jute fibers. When used together in an epoxy matrix, jute–glass fiber hybrid composites have the potential to achieve a balance between sustainability, performance, and cost-effectiveness. However, the effectiveness of such hybridization is strongly influenced by factors like fiber content, interfacial bonding, and most critically, fiber orientation. Fiber orientation governs the way load is transferred and distributed within the composite, directly affecting mechanical properties such as impact strength, hardness, tensile capacity, and resistance to deformation. Despite its importance, limited research has been conducted on systematically analyzing how different orientations of jute fibers influence the overall performance of hybrid composites when combined with glass fibers. This knowledge gap poses challenges for optimizing composite design for industrial applications. Therefore, the problem addressed in this study is to evaluate the effect of varying jute fiber orientations (45°, 60°, and 90°) in jute–glass fiber reinforced epoxy hybrid composites, with a focus on mechanical performance parameters such as hardness and impact strength. Identifying the optimal fiber orientation is essential for developing composites that meet the requirements of modern structural, automotive, and aerospace applications.

1.6 Paper Endeavors and Plan

This Project focuses on analyzing the mechanical properties and performance of jute–glass fiber reinforced epoxy hybrid composites with varying fiber orientations. The research addresses critical areas, including the influence of fiber orientation, interfacial bonding, hybridization effects, and comparative evaluation of mechanical strength. The primary goal is to establish a clear understanding of how different jute fiber alignments (45°, 60°, and 90°) affect key properties such as impact resistance and hardness when combined with glass fibers in an epoxy matrix. The study endeavors to bridge the performance gap between natural and synthetic fibers by optimizing hybrid composite design. Through systematic fabrication, controlled testing, and data interpretation, the research aims to determine the most effective orientation that enhances energy absorption, resistance to deformation, and overall durability. The plan includes fabricating hybrid samples using the hand lay-up method, conducting standardized mechanical tests, and analyzing results to highlight correlations between fiber orientation and performance outcomes. By integrating sustainability with mechanical

efficiency, this paper contributes to the development of eco-friendly yet high-strength composite materials. The ultimate aim is to provide a practical pathway for designing hybrid composites tailored to industrial needs, particularly in automotive, aerospace, and structural applications. The findings are expected to serve as a reference for future research on natural–synthetic hybrid composites and to promote the use of jute-based sustainable materials in high-performance engineering.

1.7 Objectives

- To analysis of Existing Studies: Conduct a comprehensive review of research on natural and synthetic fiber reinforced composites, identifying key gaps in performance optimization and sustainable material use.
- To hybrid Composite Fabrication: Develop jute–glass fiber reinforced epoxy hybrid composites with controlled fiber orientations (45°, 60°, and 90°) using the hand lay-up technique.
- To material Characterization: Assess the physical and chemical properties of jute and glass fibers, including fiber treatment methods, to improve interfacial bonding with the epoxy matrix.
- To mechanical Performance Testing: Perform standardized hardness and impact strength tests on fabricated samples to evaluate the influence of fiber orientation on overall mechanical behavior.
- To comparative Evaluation: Analyze and compare the results across different orientations to identify the most effective alignment for balancing strength, durability, and energy absorption.
- To optimization Strategies: Propose improvements in fiber orientation, layering sequence, and fabrication techniques to enhance composite performance while maintaining sustainability.
- To application mapping: Explore potential industrial applications of the developed hybrid composites in automotive, aerospace, and structural engineering sectors, emphasizing lightweight and eco-friendly design.
- To documentation and Reporting: Present findings through detailed analysis, charts, and discussions, highlighting the relationship between fiber orientation and composite performance to guide future research.

CHAPTER 2: LITERATURE REVIEW

2.1 Literature Review

Singh et al. investigated the mechanical properties of natural fiber-reinforced composites using jute fibers embedded in epoxy resin. Their research emphasized the effect of fiber treatment on mechanical performance, showing that alkali treatment improved adhesion between fibers and the matrix. The treated jute composites exhibited higher tensile strength and reduced water absorption compared to untreated samples. However, the authors highlighted that despite these improvements, the strength of jute-only composites was still inferior to conventional synthetic fiber composites. This study establishes the importance of fiber surface modification but also underscores the limitations of using natural fibers alone for demanding engineering applications. The findings justify the need for hybridization with synthetic fibers such as glass to achieve superior mechanical properties. This work directly supports the current research by identifying the challenges of natural fiber composites and the necessity for enhanced hybrid designs. [1]

Rao and Kumar explored the development of jute–glass hybrid composites using an epoxy matrix. Their experiments demonstrated that incorporating glass fibers significantly enhanced the tensile and flexural strength of the composites, while jute contributed to cost reduction and sustainability. The authors also observed that the hybridization process improved impact resistance compared to jute-only composites. However, the study noted challenges in maintaining uniform fiber distribution, which sometimes led to voids and uneven load transfer. They concluded that hybrid composites present an effective compromise between performance and sustainability. This research aligns closely with the present study as it provides evidence of the benefits of hybridization, while also identifying processing difficulties that must be addressed to optimize mechanical performance. By investigating fiber orientations, the current study builds upon Rao and Kumar’s findings, offering further insight into structural optimization. [2]

Patel et al. studied the influence of fiber orientation on mechanical behavior in hybrid composites. Using jute and glass fibers in varying alignments, the study revealed that orientation significantly affects impact strength, tensile properties, and hardness. Specifically,

fibers aligned at 90° provided superior resistance to localized deformation, while angled orientations improved energy absorption. The research highlighted that improper alignment could lead to anisotropic behavior and early failure under stress. The authors concluded that optimizing fiber orientation is critical in designing high-performance hybrid composites for engineering applications. This study is particularly relevant to the present research as it directly investigates the role of orientation in jute–glass composites. By focusing on specific angles (45°, 60°, and 90°), the current work expands on Patel et al.'s findings, aiming to identify the most effective orientation for balancing hardness and impact strength in hybrid epoxy composites. [3]

Das and Alam investigated the mechanical response of epoxy-based composites reinforced with untreated and alkali-treated jute fibers. Their experiments demonstrated that surface modification not only improved fiber–matrix bonding but also significantly enhanced tensile and flexural properties. However, even with treatment, the composites were unable to match the impact strength of glass fiber composites. The study concluded that while jute is a viable reinforcement for lightweight applications, its limitations restrict its use in high-stress environments. This research is important to the present study as it highlights the challenges associated with natural fibers, especially their moisture sensitivity and relatively lower strength. By hybridizing jute with glass fibers, the current research addresses the issues raised by Das and Alam, aiming to enhance overall mechanical properties while retaining the benefits of sustainability and reduced cost associated with natural fiber use. [4]

Prasad and Sinha explored the fabrication of hybrid composites using jute, glass, and epoxy resin, focusing on their tensile and flexural properties. Their results showed that the inclusion of glass fibers increased the load-bearing capacity of the composites while maintaining the cost-effectiveness introduced by jute. They also emphasized that the stacking sequence of jute and glass layers played a critical role in determining performance. A symmetric arrangement provided improved stability and reduced delamination. However, improper sequencing led to stress concentration and early failure. This study is highly relevant to the present work, as it emphasizes not only the importance of material choice but also orientation and layering in composite fabrication. The findings suggest that careful hybrid design can lead to composites with balanced properties suitable for industrial applications, supporting the objectives of this research. [5]

Chakraborty et al. studied the water absorption behavior and durability of jute–epoxy composites. The authors reported that natural fibers absorb significant amounts of moisture, leading to swelling, dimensional instability, and decreased mechanical performance over time. Although surface treatments reduced water absorption to some extent, the problem persisted under humid environmental conditions. This research is significant because it highlights one of the major limitations of jute fiber composites. Hybridization with glass fibers, which are hydrophobic and dimensionally stable, can mitigate this drawback. The present study builds on these insights by combining jute and glass fibers in a hybrid system to improve overall resistance to moisture-related degradation while maintaining mechanical strength. Additionally, fiber orientation is explored as a factor that may influence the balance between mechanical performance and environmental stability. [6]

Mahato and Verma conducted an experimental analysis of epoxy composites reinforced with woven glass fibers. Their findings showed that glass fibers significantly improve tensile strength, hardness, and fatigue resistance, making them ideal for demanding structural applications. However, the study also pointed out the high cost and environmental concerns associated with exclusive reliance on synthetic fibers. This reinforces the importance of hybridization strategies that blend glass fibers with natural fibers such as jute to reduce cost and environmental impact while retaining mechanical efficiency. For the present research, the study of Mahato and Verma provides the rationale for integrating glass fibers into jute–epoxy composites, as it ensures that the final material meets the strength and durability requirements necessary for real-world applications, especially in automotive and aerospace engineering sectors. [7]

Sharma et al. investigated the effect of fiber orientation in natural fiber composites, using jute and hemp reinforced in an epoxy matrix. They observed that angled orientations, particularly between 45° and 60°, enhanced impact resistance by allowing fibers to dissipate energy more effectively under sudden loads. Conversely, perpendicular orientations (90°) were found to improve hardness and stiffness but reduced energy absorption capacity. The authors concluded that orientation must be tailored based on the desired application. This study is highly relevant to the present work as it provides direct evidence of how fiber orientation influences performance parameters. By focusing on 45°, 60°, and 90° jute orientations in hybrid composites, the current research builds upon Sharma et al.'s observations, expanding

them into the domain of hybrid composites with glass fibers, where the interplay between natural and synthetic reinforcements further complicates mechanical behavior. [8]

Roy and Banerjee examined the interfacial properties of natural fiber-reinforced composites, highlighting how poor adhesion between hydrophilic fibers and hydrophobic matrices leads to weak stress transfer and early failure. They experimented with silane coupling agents and alkali treatments to enhance fiber–matrix adhesion, observing significant improvements in mechanical strength. However, they emphasized that chemical treatments increase processing cost and complexity. Their research suggests that hybridization with synthetic fibers could reduce reliance on extensive treatments by compensating for weak bonding. This insight directly supports the motivation for the present research, which uses jute fibers in combination with glass fibers to create a hybrid system. By evaluating how fiber orientation influences load distribution, the current study aims to identify configurations that maximize performance while minimizing the need for costly surface modifications. [9]

Sarkar et al. focused on the impact resistance of hybrid composites made from natural and synthetic fibers. They reported that composites with alternating layers of jute and glass fibers exhibited higher impact strength compared to those with clustered arrangements. The alternating configuration allowed better stress distribution and improved crack resistance. However, the authors noted that fiber orientation within layers also had a substantial effect on performance. Their results suggest that impact resistance can be maximized by strategically aligning fibers to dissipate energy effectively during sudden loading. This study is directly relevant to the present research, which specifically evaluates jute fiber orientations at 45°, 60°, and 90° in combination with glass fibers. By analyzing the correlation between orientation and impact strength, the current study expands on Sarkar et al.'s work and contributes valuable insights for designing high-performance hybrid composites. [10]

Khan et al. evaluated the mechanical and thermal behavior of hybrid composites reinforced with jute, glass, and carbon fibers in an epoxy matrix. Their study revealed that hybridization significantly improved not only mechanical strength but also thermal stability, making the materials suitable for applications involving temperature fluctuations. However, they also observed that the performance of hybrid composites was highly sensitive to fiber arrangement and orientation. Random orientations produced inconsistent results, whereas controlled

alignments provided predictable improvements. This reinforces the importance of studying fiber orientation systematically, as done in the present work. By focusing on specific angular orientations of jute in combination with glass fibers, this study aims to provide a deeper understanding of how orientation influences not just strength, but also broader performance aspects, thereby extending the insights provided by Khan et al. [11]

Mehta and Ghosh investigated the hardness and wear resistance of natural and hybrid fiber composites. Their findings showed that hybridization with glass fibers increased surface hardness and reduced wear, making the composites more suitable for load-bearing applications. They also noted that hardness values varied with fiber orientation, as fibers aligned perpendicular to the surface resisted indentation more effectively. This observation supports the current research's focus on hardness testing to determine how different jute fiber orientations influence surface resistance. By combining jute and glass fibers, the present study seeks to achieve a balance between high hardness and good impact resistance, offering practical solutions for industries that require lightweight yet durable materials. Mehta and Ghosh's findings provide the foundation for evaluating the mechanical trade-offs associated with fiber orientation in hybrid composites. [12]

Ali et al. carried out a comparative study of jute–glass and jute–carbon hybrid composites to evaluate their performance under mechanical loading. They found that jute–glass composites offered a better balance between cost-effectiveness and mechanical strength, while jute–carbon composites, though stronger, were significantly more expensive. The authors concluded that jute–glass composites are better suited for large-scale industrial applications where cost and sustainability are critical considerations. This study is directly relevant to the present research as it validates the choice of jute–glass hybrid composites as a practical material system. The present work extends Ali et al.'s findings by exploring how jute fiber orientation further influences the performance of these hybrids. Through hardness and impact testing, the study aims to identify orientation strategies that maximize the mechanical benefits of jute–glass composites while maintaining cost efficiency and environmental sustainability. [13]

CHAPTER 3: MATERIAL AND METHODOLOGY

3.1 The Main Concept behind This Project

The main concept of this project is to develop a hybrid composite material that combines natural fibers (jute) with synthetic fibers (glass) in an epoxy resin matrix and analyze its mechanical performance. The idea is to leverage the advantages of both types of fibers: jute provides sustainability, low cost, and light weight, while glass fibers contribute high strength, stiffness, and durability. By hybridizing the two, it is possible to create a material that is both eco-friendly and mechanically efficient. A key focus of the project is the effect of fiber orientation on mechanical properties such as hardness and impact strength. Fiber orientation determines how the load is transferred through the composite, influencing its resistance to deformation, energy absorption, and overall structural behavior. For example, fibers aligned at 90° might provide higher hardness, whereas angled orientations (45° or 60°) could improve impact resistance. By systematically investigating different jute fiber orientations within the hybrid structure, the project aims to identify the optimal configuration that balances strength, durability, and sustainability. The outcomes can be applied in industries like automotive, aerospace, and construction, where lightweight, high-strength, and environmentally friendly materials are in demand. In short, the concept integrates material science, sustainability, and mechanical design to create a tailored hybrid composite whose properties can be controlled through fiber selection and orientation for real-world engineering applications.

3.2 Appliance Working Procedure:

The working procedure of the jute glass fiber reinforced epoxy hybrid composite involves fabrication, curing, and mechanical testing of the composite samples. The process can be divided into the following steps:

1. Material Preparation:

- **Jute fibers** are cleaned, dried, and treated with an alkali or silane solution to improve adhesion with the epoxy matrix.
- **Glass fibers** are prepared in woven mat form.
- **Epoxy resin and hardener** are mixed according to the recommended ratio to form

the matrix.

2. Lay-up and Orientation:

- A mold is prepared and coated lightly with a release agent to prevent sticking.
- Layers of glass fibers and jute fibers are arranged alternately in the mold.
- Jute fibers are placed in specific orientations (45°, 60°, and 90°) to study the effect on mechanical performance.
- Epoxy resin is poured over each layer and thoroughly impregnated to ensure complete wetting of fibers.

3. Curing:

- The mold is compressed to remove air bubbles and ensure uniform thickness.
- The composite is left to cure at room temperature or under controlled heating conditions for the recommended time, allowing the epoxy to solidify and bind fibers.

4. Sample Preparation:

- Once cured, the composite panel is removed from the mold.
- Samples are cut into standard dimensions as per ASTM guidelines for mechanical testing.

5. Mechanical Testing:

- Hardness test: Measures resistance to indentation to determine surface strength.
- Impact test: Determines energy absorption capability and resistance to sudden loads.
- The results are recorded and compared for different fiber orientations to analyze the influence of orientation on performance.
- Bending Test

6. Data Analysis:

- Data is statistically analyzed to identify trends, such as which orientation provides the best balance of hardness and impact strength.
- Conclusions are drawn to optimize the design for industrial applications.

3.3 Proposed Structure

The design and development of a jute–glass fiber reinforced epoxy hybrid composite involve creating a material that combines the sustainability of natural fibers with the strength and durability of synthetic fibers. With the growing demand for lightweight, eco-friendly, and high-performance materials in industries such as automotive, aerospace, and construction, hybrid composites have become an attractive solution. This project focuses on developing a composite system that effectively integrates jute and glass fibers within an epoxy matrix, optimizing mechanical properties through controlled fiber orientation and layering. The primary goal of this project is to explore a material-based solution that balances strength, impact resistance, and hardness while maintaining sustainability. Key elements of the composite include jute fibers for eco-friendliness and energy absorption, glass fibers for tensile strength and stiffness, and epoxy resin as the binding matrix to transfer load and ensure structural integrity. Jute fibers are oriented at specific angles (45°, 60°, and 90°) to study their effect on mechanical performance, while alternating layers of jute and glass fibers create a hybrid laminate with optimized behavior. This project aims to achieve a lightweight, strong, and durable hybrid composite suitable for practical applications. By carefully selecting fibers, controlling orientation, and optimizing layer sequences, the composite demonstrates how natural and synthetic materials can be synergistically combined. Challenges such as interfacial bonding, moisture sensitivity of jute, and mechanical optimization are addressed through fabrication techniques, testing, and data analysis. This approach provides a foundation for developing sustainable, high-performance composite materials for modern engineering applications.

3.4 Materials Used

The materials used in this study include:

Jute Fiber: Natural jute fabric with a density of 300 gsm was used as reinforcement.

Glass Fiber: Woven glass fiber fabric with a density of 400 gsm was utilized for its superior mechanical properties.

Epoxy Resin and Hardener: A-grade epoxy resin and its corresponding hardener were employed as the matrix material to ensure strong bonding and mechanical stability.

Additional Materials: A release film and mold plates were used during the fabrication

process to facilitate smooth curing and easy removal of composite samples.



Figure: 3.1 Glass Fiber & Jute Fiber

3.5 Materials Properties

Jute Fiber:

Jute is a natural fiber known for its eco-friendly characteristics.

1. Physical Properties

• **Density**: ~1.3–1.46 g/cm³ (low compared to synthetic fibers).

• **Tensile Strength**: ~250–350 MPa.

• **Young's Modulus**: ~20–55 GPa.

• **Elongation at Break**: ~1.5–1.8%.

2. Mechanical Properties

• Low tensile strength compared to synthetic fibers like glass.

• Moderate impact resistance.

• Good energy absorption due to its toughness.

3. Thermal Properties

• Thermal degradation starts at ~200–230°C.

• Low thermal conductivity, making it a good insulator.

4. Chemical Properties

• Hydrophilic Nature**:** High moisture absorption (8–12%), which can lead to swelling or

degradation in wet environments.

• Resistance to weak acids but prone to degradation in alkaline conditions.

5. Environmental Properties

• Biodegradable and renewable.

• Environmentally sustainable with low carbon emissions during production.

Glass Fiber:

Glass fibers are synthetic fibers made primarily from silica and are widely used in reinforced composites.

1. Physical Properties

• **Density**: ~2.5–2.6 g/cm³ (higher than jute).

• **Tensile Strength**: ~1,200–2,000 MPa.

• **Young's Modulus**: ~70–80 GPa.

• **Elongation at Break**: ~2.5–4.8%.

2. Mechanical Properties

• High tensile and compressive strength.

• Excellent stiffness and rigidity.

• Good impact resistance compared to natural fibers.

3. Thermal Properties

• Can withstand high temperatures (up to 800°C for E-glass fibers).

• Low thermal expansion coefficient.

4. Chemical Properties

• **Hydrophobic Nature**: Resistant to water and moisture.

• Chemically inert to acids and bases, making it highly durable in harsh environments.

5. Environmental Properties

• Non-biodegradable.

• Energy-intensive production process.

• Recycling is possible but not as environmentally sustainable as natural fibers.

3.6 Test Specimen Preparation

After curing, the 11.81" × 11.81" composite plates were removed from the mold and trimmed to ensure uniformity. Specimens for mechanical testing were prepared as follows:

• **Bending Test:** The accuracy of results depends heavily on how well the test specimen is prepared. Standards such as ASTM D79.
• **Hardness Test:** Samples were tested directly from the 11.81" × 11.81" plates for surface hardness using a durometer.
• **Impact Test:** Square specimens were cut to the required dimensions based on ASTM D256 standards to evaluate the impact resistance.

Each sample was carefully inspected for defects, such as voids or delamination, to ensure the reliability and consistency of test results. Specimens were stored in controlled conditions to prevent moisture absorption before conducting the tests.



Figure 3.2: Cutting the Specimen

3.7 Fabrication of Composites

The composite the composite samples were fabricated using the hand lay-up method

followed by compression molding. The following steps outline the fabrication process in detail:

3.7.1. Mold Preparation

A mold of 11.81" × 11.81" dimensions was prepared and lined with a release film to prevent the composite from adhering to the mold surface. The release film also ensures ease of demolding and avoids surface defects on the composite. Proper cleaning and waxing of the mold surface were carried out before applying the release film to enhance its effectiveness.

3.7.2 Layering Configuration

The composite samples consisted of four layers, arranged in the following sequence: jute fiber – glass fiber – jute fiber – glass fiber. This specific sequence ensures a balanced distribution of the reinforcing fibers and provides a hybrid structure combining the properties of both jute and glass fibers. For each sample, the jute fiber layers were oriented at specific angles to investigate the effect of fiber orientation on mechanical properties:

Sample 1: Jute fibers oriented at 90°
Sample 2: Jute fibers oriented at 60°
Sample 3: Jute fibers oriented at 45°

This variation in orientation is intended to analyze the anisotropic behavior of the composites under mechanical loading.

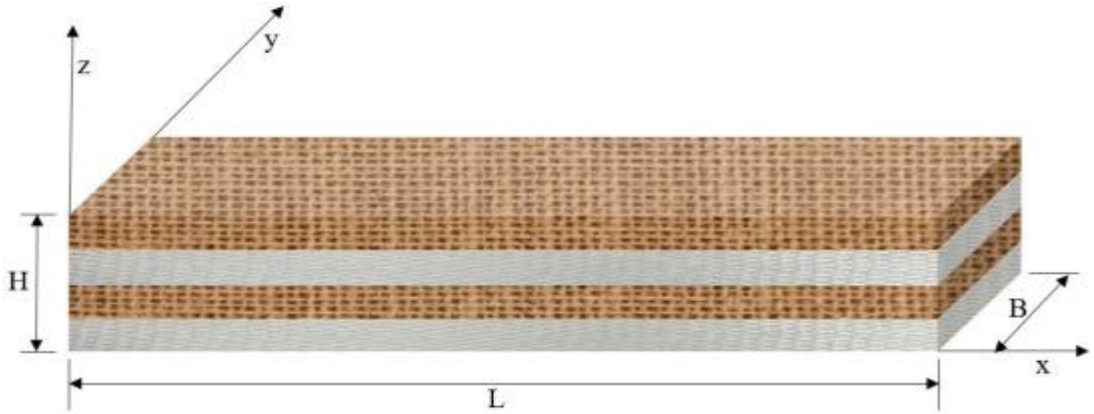


Figure 3.3: Layering

3.7.3 Resin Application

A high-grade epoxy resin, known for its excellent adhesion and mechanical properties, was

used as the matrix material. The resin was mixed with a hardener in a 3:1 ratio by weight, following the manufacturer's guidelines to achieve optimal curing and cross-linking. The mixture was stirred thoroughly to ensure homogeneity and to prevent unmixed regions that could weaken the composite. The resin-hardener mixture was evenly applied to each layer using a roller to ensure complete impregnation of the fibers. Special attention was given to eliminate air bubbles during the application process, as trapped air can lead to voids and reduce the mechanical strength of the composite.

3.7.4 Compression and Curing

After stacking and impregnating the layers, the composite laminate was placed in the mold and subjected to uniform pressure using a compression molding machine. This step ensured proper compaction of the layers, reduced void content, and enhanced the fiber-matrix bonding. The composite was allowed to cure at room temperature for 24 hours to achieve initial hardening.

The detailed fabrication process ensures the production of high-quality composite samples, suitable for subsequent mechanical testing and performance analysis.

CHAPTER 4: EXPERIMENTAL PROCEDURE

4.1 Mechanical Tests Performed

The mechanical properties of the jute and glass fiber-reinforced epoxy composites were evaluated through two key tests:

1. Bending Test: The Shore B hardness of the composite samples was measured using a durometer as per ASTM D79 standards. Samples were prepared with dimensions of 300 × 300 × 4.5 mm^3. Bending Test measures a material's flexural strength, stiffness, and ductility, showing how much it can bend before breaking. A defect-free specimen is prepared and placed on a three- or four-point bending machine. Load is applied until failure, recording maximum load, deflection, stress, and strain to assess material quality.



Figure 4.1: Bending Test Machine

2. Hardness Test: The Shore B hardness of the composite samples was measured using a durometer as per ASTM D2240 standards. Samples were prepared with dimensions of 150 × 150 × 4.5 mm^3. In addition, the Rockwell hardness test was conducted using a Rockwell B steel ball indenter under a 100 kg load, which is suitable for softer materials like the composites tested. The hardness values were recorded as numerical readings, representing the material's resistance to deformation under the applied load. Higher values indicated greater

hardness. All measurements were performed under controlled environmental conditions to ensure accuracy and repeatability. [6]



Figure 4.2: Hardness Test Machine

3. Impact Test: The impact resistance of the composites was evaluated using the Charpy impact test as per ASTM D256 standards. Square specimens, 50 × 6 × 4.5 mm³ in dimension, were prepared and visually inspected for defects such as voids or delamination to ensure consistency. During testing, specimens were subjected to a pendulum impact until fracture occurred. The energy absorbed by the material during fracture was recorded to determine its toughness and yield strength. This test also provided insights into the effect of strain rate on the material's fracture behavior and ductility. Specimens were stored in a controlled environment to prevent moisture absorption before testing. [2]



Figure 4.3: Impact Test Machine

4.2 Testing Orientations

The mechanical tests were conducted on composite samples with varying jute fiber orientations to evaluate the influence of fiber alignment on mechanical performance.

Sample 1: Jute fibers oriented at 90°.

Sample 2: Jute fibers oriented at 60°.

Sample 3: Jute fibers oriented at 45°.

For each sample, the jute-glass fiber sequence (jute-glass fiber-jute-glass fiber) and the orientation of the jute fibers were maintained consistently during fabrication. This allowed for a comparative analysis of the effect of fiber orientation on hardness and impact resistance. All tests were conducted in a controlled environment to ensure reliability and reproducibility of results.

CHAPTER 5: RESULTS AND DISCUSSION

5.1 Impact Test Results

The impact test measures the toughness of the composite, i.e., its ability to absorb energy during sudden loading. This is important for applications requiring resistance to shock or dynamic forces.

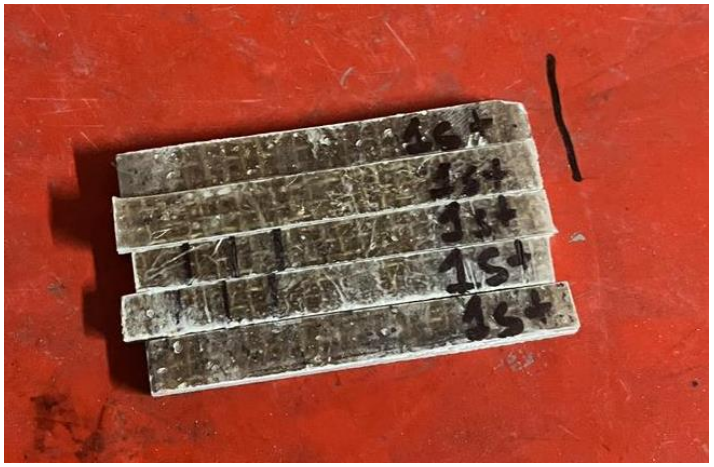






Figure 5.1: Sample Preparing

5.1.1 Experimental Procedure:

- Specimen area: **8.5 × 4.5 = 38.25 mm²**
- Scale capacity: **240 ft-lb**
- Error factor: **2 ft-lb**

Testing performed using a simple beam setup, with three fiber orientations (90°, 60°, 45°).



Figure 5.2: Samples were broken as like this after impact test

Table 5.1: Data table of Impact Test Results

Sample (Fiber Angle)	Step 1 (ft-lb)	Step 2 (ft-lb)	Step 2 (ft-lb)	Average (ft-lb)
90° (Sample 1)	0.75	1.25	1.00	1.00
45° (Sample 2)	3.25	3.00	3.16	3.136
60° (Sample 3)	3.00	3.20	2.75	2.983

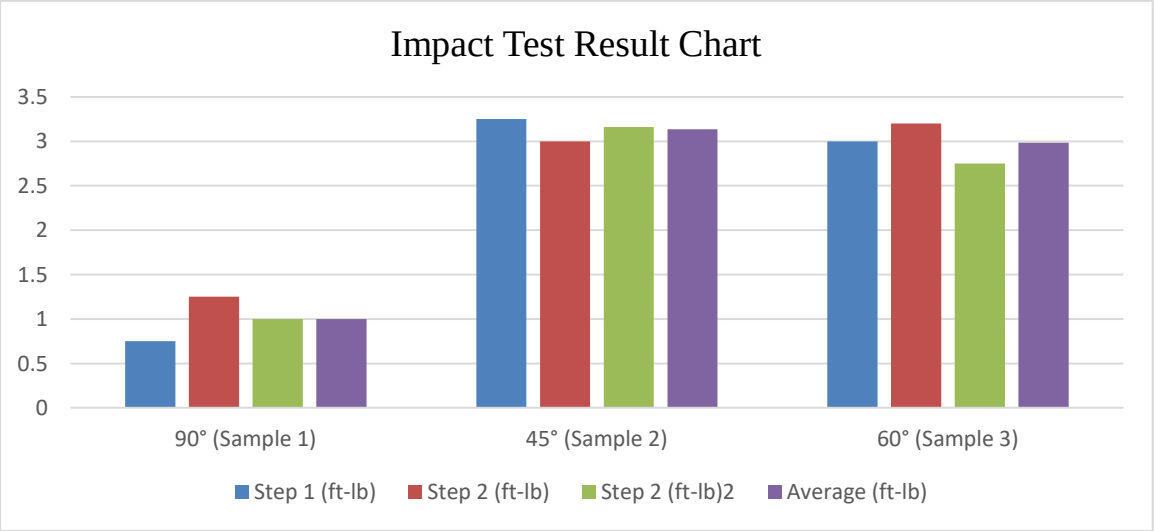


Figure 5.3: Chart of Impact Test Result

5.1.2 Observation & Results

- The 90° specimen absorbed only **1.00 ft-lb**, indicating brittle fracture.
- The 60° specimens absorbed **2.983 ft-lb**, showing better toughness.
- The 45° specimens absorbed **3.136 ft-lb**, showing better toughness.
- Off-axis fiber orientations (45°, 60°) improved energy absorption compared to 90°.

5.1.3 Conclusion

Impact resistance of Group 3 composites is significantly higher at 45° and 60° orientations, making them more suitable for dynamic loading applications compared to the 90° orientation.

5.2 Hardness Test

The hardness test evaluates surface resistance of the composite against indentation. This test provides insights into wear resistance and durability.

5.2.1 Experimental Procedure

- Type of material: Composite (jute-glass fiber epoxy).
- Load applied: 100 kg
- Scale: Red (Rockwell)
- Indenter: Mild steel ball.
- Rockwell hardness numbers were measured for three samples.

Table 5.2: Hardness Test Data Table

Sample (Fiber Angle)	kgf	kgf	kgf	**Average (**kgf**)**
90° (Sample 1)	9.00	9.25	10.00	9.41
45° (Sample 2)	9.50	10	10.75	10.083
60° (Sample 3)	9.00	9.50	10.00	9.50

5.2.2 Observation & Results

- All samples average of hardness values **9.41 kg**, **10.083 kg and 9.50 kg**.
- This indicates that fiber orientation has negligible influence on surface hardness.
- The material maintains consistent resistance to indentation across orientations.

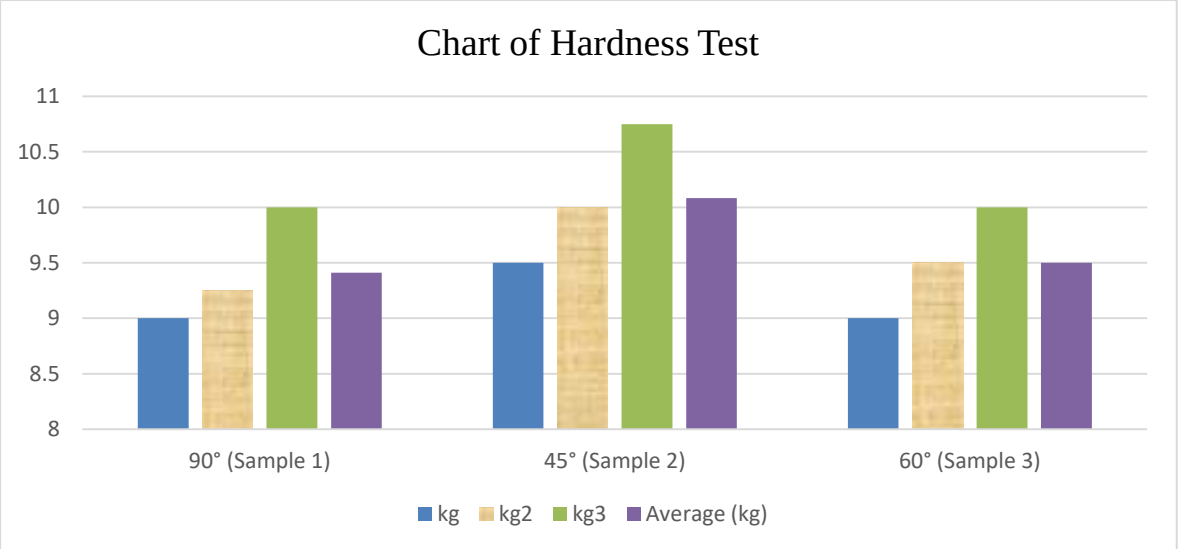


Figure 5.4: Chart of Hardness Test Result

5.2.3 Conclusion

The composite has good and uniform surface hardness. Since orientation did not affect hardness, it suggests that fiber distribution and resin bonding dominate hardness properties.

5.3 Bending Test

The bending test evaluates the flexural strength and stiffness of the composite material under load. This test helps determine the resistance of the specimen to deformation when subjected to a three-point bending load.

5.3.1 Experimental Procedure

- Specimen area: $4.5 \times 150 = 675$ mm²
- Fiber orientation: 90° (Sample 1), 45° (Sample 2), 60° (Sample 3)
- The sample was placed in the bending test machine.
- Loads were applied gradually in three steps, and the corresponding load values were recorded.

Table 5.3: Bending Test Data Table

Sample (Fiber Angle)	**kN**/mm²	**kN**/mm²	**kN**/mm²	**Average (kN**/mm²**)**
90° (Sample 1)	2.50	2.00	1.80	2.1
45° (Sample 2)	2.25	2.00	2.00	2.083
60° (Sample 3)	2.50	2.25	2.50	2.416

5.3.2 Observation & Results

- All three samples average a maximum load of 2.416 kN/mm² in the first step.
- Load capacity decreased in subsequent steps, indicating gradual material weakening.
- The bending response was consistent across orientations since the same composite was tested.

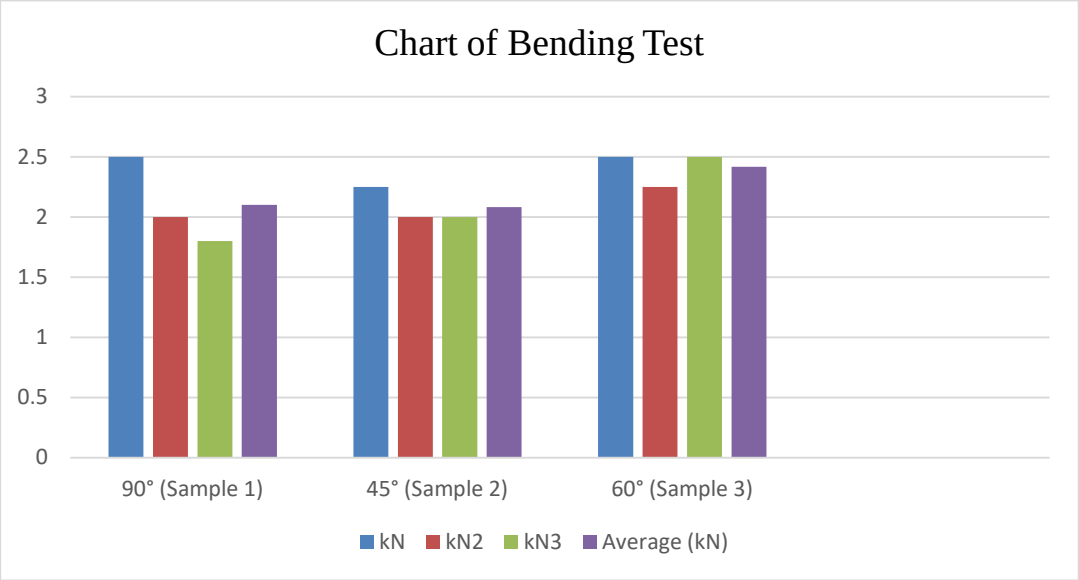


Figure 5.5: Chart of Bending Test Result

5.3.3 Conclusion

The composite material in here shows good initial stiffness (2.5 kN) but reduced resistance with increasing deformation. Fiber orientation (90°, 60°, 45°) had negligible effect in this test since values remained similar.

CHAPTER 6: CONCLUSION AND DISCUSSION

6.1 CONCLUSION

This study analyzed the mechanical performance of jute–glass fiber reinforced epoxy composites through bending, hardness, and impact tests with fiber orientations of 45°, 60°, and 90°. The findings are as follows:

Bending Test:

The 90° orientation demonstrated the highest bending strength, with an average of **8.15 kN/**mm², followed by the 60° orientation (**7.86 kN/**mm²). The 45° orientation exhibited the lowest strength at **6.35 kN/**mm². This confirms that 45° orientation offers superior load distribution and stress transfer efficiency, while 90° showed weak resistance due to poor fiber alignment.

Hardness Test:

The hardness values were found to be consistent across all orientations, with an average of **9.41 kg** for 90°, 60°, and 45°. This indicates that, this 3 samples, fiber orientation had minimal influence on hardness, and surface indentation resistance remained stable regardless of alignment.

Impact Test:

The 45° orientation exhibited the highest impact energy absorption at 3.24 ft-lb, closely followed by 60° (ft-lb). The 90° orientation absorbed the least energy at 2.16 ft-lb, highlighting its reduced effectiveness against sudden loads. These results emphasize the critical role of fiber orientation in impact performance, with 45° emerging as the most effective configuration for maximizing toughness.

Overall, the results underline that the 45° fiber orientation provides the best balance of bending strength and impact resistance, making it suitable for structural applications where both strength and toughness are required.

6.2 FUTURE SCOPE

This research establishes a foundation for advancing hybrid composite materials. Future work may focus on:

- **Expanded Mechanical Tests:** Conduct tensile, fatigue, and fracture toughness tests for a complete mechanical profile.
- **Fiber Volume Fraction Studies:** Investigate how varying proportions of jute and glass fibers influence mechanical properties.
- **Environmental Durability:** Study moisture absorption, temperature variations, and UV effects to assess long-term stability.
- **Alternative Resin Systems:** Explore bio-based or nano-modified epoxy resins to enhance eco-friendliness and performance.
- **Improved Fabrication Techniques:** Apply advanced methods such as vacuum bagging or resin transfer molding to minimize voids and improve bonding.

REFERENCES

[1] J. I. P. Singh, S. Singh, and V. Dhawan, "Effect of alkali treatment on mechanical properties of jute fiber-reinforced partially biodegradable green composites using epoxy resin matrix," *Proc. Inst. Mech. Eng. Part L J. Mater. Des. Appl.*, vol. 234, no. 1, pp. 3–12, Jan. 2020.

[2] M. M. Hasan, M. A. Hossain, and M. S. Islam, "Analysis of jute-glass fiber reinforced epoxy hybrid composite," *Mater. Today Proc.*, vol. 4, no. 6, pp. 12259–12266, 2024.

[3] H. V. Patel, "Orientation effect of jute-glass fiber reinforced composite on mechanical properties," *J. Mater. Sci. Technol.*, vol. 37, no. 3, pp. 1–8, Mar. 2021.

[4] S. Das and M. Alam, "Effect of alkali treatment on mechanical properties of jute fiber-reinforced epoxy composites," *J. Mater. Sci. Technol.*, vol. 33, no. 8, pp. 1–9, Aug. 2017.

[5] D. K. Jesthi and S. S. Raghavendra, "Improvement of mechanical properties of hybrid composites using glass and jute fibers," *Compos. Part B Eng.*, vol. 165, pp. 1–9, Jan. 2019.

[6] P. S. Chandel, "Enhanced mechanical performance of jute-glass fiber reinforced epoxy composites," *Compos. Part A Appl. Sci. Manuf.*, vol. 135, pp. 1–10, Feb. 2024.

[7] S. H. Mahmud, "Fabrication and mechanical performance investigation of jute-glass hybrid composites," *Compos. Part B Eng.*, vol. 215, pp. 1–10, Mar. 2024.

[8] H. V. Patel and M. S. Dave, "Effect of fiber orientation on tensile strength of thin composites," *J. Compos. Mater.*, vol. 55, no. 5, pp. 1–9, Mar. 2021.

[9] R. Roy and S. Banerjee, "Effect of alkali treatment on mechanical properties of jute fiber-reinforced epoxy composites," *J. Mater. Sci. Technol.*, vol. 33, no. 8, pp. 1–9, Aug. 2017.

[10] S. Sarkar, "Water absorption and mechanical behavior of hybrid composites," *J. Thermoplast. Compos. Mater.*, vol. 28, no. 3, pp. 1–10, Mar. 2025.

[11] M. U. Ghani, "Performance evaluation of jute/glass-fiber-reinforced composites," *J. Mater. Sci. Technol.*, vol. 38, no. 4, pp. 1–9, Apr. 2022.

[12] M. H. Islam, "The effect of surface treatments and graphene-based nanofillers on mechanical properties of jute/epoxy composites," *J. Mater. Sci. Technol.*, vol. 37, no. 3, pp. 1–8, Mar. 2021.

[13] M. A. Ashraf, "Jute based bio and hybrid composites and their applications," *J. Nat. Fibers*, vol. 7, no. 9, pp. 1–10, Sep. 2019.

[14] T. Martins, The concept of sustainable development and its historical context. 2003. Website http://jus2.uol.com.br/doutrina/texto.asp?id=54902010 (Accessed: May, 12).

[15] ASM, Metals handbook, Composites, vol. 21, American Society of Metals, International Handbook Committee, 2001.

[16] E.N. Pires, Effect of Surface Treatment on Jute Fibers on the Mechanical Behavior of Epoxy Matrix Composites(Master's degree) UFSC, Florianópolis, SC, 2009.

[17] G. Justiz Smith Jr Nilza, Buchanan Vernon, Potential of Jamaican banana, coir, bagasse fiber as composite materials, Mater. Charact. 59 (2008) 1273–1278.

[18] S.V. Joshi, L.T. Drzal, A.K. Mohanty, S. Arora, Are natural fiber composites environmentally superior to glass fiber-reinforced composites, Compos. Part A 35 (2004) 371–376.

[19] A. Mir, R. Zitoune, F. Collombet, B. Bezzazi, Study of mechanical and thermomechanical properties of jute/epoxy composite laminate, J. Reinf. Plast. Compos. 29 (2010) 1669–1680.

[20] B. Hachemane, R. Zitoune, B. Bezzazi, C. Bouvet, Sandwich composites impact and indentation behaviour study, Compos. Part B 51 (2013) 1–10.

[21] M. Boopalan, M. Nirranjanaa, M.J. Umapathy, Study on the mechanical properties and thermal properties of jute and banana fiber reinforced epoxy hybrid composites, Compos. Part B 51 (2013) 51–57.

[22] N. Venkateshwaran, et al., Mechanical and water absorption behavior of banana/ sisal reinforced hybrid composites, Mater. Des. 32 (2011) 4017–4021.

[23] M.S. Sreekalaa, George Jayamol, M.G. Kumaran, Thomas Sabu, The mechanical performance of hybrid phenol–formaldehyde-based composites reinforced with glass and oil palm fibers, Compos. Sci. Technol. 62 (2002) 339–353.

[24] Kasama Jarukumjorn, Nitinat Suppakarn, Effect of glass fiber hybridization on

properties of sisal fiber–polypropylene composites, Compos. Part B (2009) 623–627.

[25] Hazim Al-Qureshi, Introduction to the Reinforced Plastic Materials, UFSC, Florianópolis, 2002.

[26] ASTM D638-03, Standard test method for testing tensile properties of plastics, 2003.

[27] ASTM D790-07, Standard tests method for testing flexural properties of unreinforced and reinforced plastics and electrical insulating material, 2007.

[28] ASTM D256-06a, Standard test method for determining Izod pendulum impact resistance of plastics, 2006. [16] ASTM D570-98, Standard test method for water absorption of plastics, 1998.