ANALYSIS OF MECHANICAL PROPERTIES OF JUTE AND GLASS FIBERS REINFORCED EPOXY COMPOSITES AT DIFFERENT ORIENTATIONS

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of

Bachelor of Science in Mechanical Engineering

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DECLARATION

I hereby declare that the thesis titled **"Mechanical Properties and Performance Analysis of Jute Fiber and Glass Fiber Reinforced Epoxy Composites at Different Orientations under Various Mechanical Tests"** submitted to Sonargaon University, is my original work carried out under the guidance of Shahinur Rahman.

The work embodied in this thesis has not been submitted, in part or full, to any other university or institution for the award of any degree or diploma. All the data, analyses, and findings presented in this thesis are the results of my research work. Any work or information obtained from other sources has been duly acknowledged and referenced in accordance with the academic and ethical guidelines of the university.

I take full responsibility for the authenticity and accuracy of the data and results presented in this thesis. Furthermore, I declare that this thesis complies with all the regulations and requirements prescribed by the institution for the submission of academic research work.

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Certification

This is to certify that the thesis titled **"Mechanical Properties and Performance Analysis of Jute Fiber and Glass Fiber Reinforced Epoxy Composites at Different Orientations under Various Mechanical Tests"** is a record of the candidate's original research work carried out under my supervision and guidance in partial fulfillment of the requirements for the award of the degree of **Bachelor of Science in Mechanical Engineering** from **Sonargaon University.**

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Abstract

This research focuses on the mechanical properties and performance analysis of jute fiber and glass fiber reinforced epoxy composites, particularly evaluating the effect of fiber orientation under various mechanical tests. Hybrid composites were fabricated using jute fibers oriented at 30°, 45°, and 75°, combined with glass fibers in an epoxy matrix. Mechanical testing included hardness and impact tests to understand the influence of fiber orientation on the overall properties of the composites. The results demonstrated a significant correlation between fiber orientation and the mechanical behavior of the composites. The 45° jute fiber orientation exhibited superior impact strength, attributed to its ability to absorb and dissipate energy more effectively under dynamic loading conditions. On the other hand, the 75° orientation resulted in higher hardness values, indicating better resistance to localized deformation. The 30° orientation showed balanced performance but did not surpass the other configurations in either hardness or impact strength. This study highlights the importance of fiber orientation in designing hybrid composites to achieve desired mechanical properties. By optimizing orientation, it is possible to tailor the composite for specific applications, such as automotive, aerospace, and structural components, where lightweight materials with enhanced strength and durability are crucial. These findings provide valuable insights for future development of sustainable, high-performance composite materials.

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CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

The increasing global demand for lightweight, high-strength, and sustainable materials has driven significant advancements in composite technology. Composite materials have become a cornerstone in industries like automotive, aerospace, and construction due to their ability to deliver superior mechanical performance while reducing weight. Among natural fibers, jute has garnered significant attention for its renewable nature, biodegradability, and excellent tensile strength. However, its standalone application is often limited due to its relatively lower impact resistance, hardness, and durability compared to synthetic fibers [2].

To address these limitations, hybrid composites that combine natural fibers like jute with synthetic fibers such as glass have emerged as an effective solution. Glass fibers, renowned for their exceptional strength, stiffness, and impact resistance, complement the mechanical properties of jute fibers, enabling the development of composites that balance performance and sustainability [4]. When combined within an epoxy resin matrix, these materials form hybrid composites that exhibit enhanced strength, durability, and energy absorption properties [5].

One critical factor influencing the performance of these hybrid composites is fiber orientation. The anisotropic behavior of composites, stemming from the alignment of fibers, affects key mechanical properties, including impact resistance, hardness, and load-bearing capacity. Proper alignment and hybridization of fibers can result in materials tailored to specific industrial applications, offering optimized performance and weight reduction [6].

This research investigates the mechanical properties and performance of hybrid epoxy composites reinforced with jute and glass fibers, with a specific focus on the impact of jute fiber orientation (30°, 45°, and 75°). Through hardness and impact tests, this study aims to optimize fiber orientation to advance the development of sustainable, high-performance materials for various industrial applications. By leveraging the complementary properties of jute and glass fibers, this work contributes to the growing field of bio-based hybrid composites, addressing environmental concerns while meeting engineering demands.

1.2 LITERATURE REVIEW

Fiber-reinforced composites have become a key area of research due to their ability to combine lightweight structures with excellent mechanical properties. Hybrid composites, integrating both natural and synthetic fibers, are particularly promising as they blend performance with sustainability. This section provides an overview of prior studies focusing on the hardness and impact performance of fiber-reinforced composites, with a particular emphasis on hybrid configurations.

Natural Fibers in Composites

Natural fibers, such as jute, have gained prominence for their environmental benefits, including biodegradability, renewability, and low cost. Jute fibers, in particular, are widely used in polymer matrices due to their availability, high tensile strength, and low density. However, their mechanical properties, such as impact resistance and hardness, are relatively inferior to those of synthetic fibers, limiting their standalone application in high-performance scenarios [8].

Synthetic Fibers in Composites

Synthetic fibers, such as glass fibers, are widely utilized in reinforced composites for their superior mechanical properties. Glass fibers exhibit high tensile strength, stiffness, and impact resistance, making them suitable for applications demanding enhanced durability and performance. However, the environmental impact and non-biodegradable nature of glass fibers remain significant challenges [2].

Hybrid Composites and Performance

The hybridization of natural and synthetic fibers combines the strengths of both materials, resulting in composites with improved mechanical performance and sustainability. Hybrid composites that integrate jute and glass fibers have shown improved hardness and impact resistance compared to composites made from either fiber alone [10]. Fiber orientation also plays a crucial role in determining composite performance. For instance, unidirectional fibers may enhance hardness along the load direction, while bidirectional or random orientations improve toughness and impact resistance [11].

Mechanical Testing of Hybrid Composites

Hardness and impact tests are essential for evaluating the surface durability and energy absorption capacity of composites. Studies have demonstrated that the inclusion of glass fibers significantly enhances hardness, while hybrid configurations with natural fibers improve energy absorption. For example, composites with bidirectional fiber alignment exhibit better impact resistance than those with unidirectional configurations, underscoring the importance of fiber orientation in hybrid composites [12].

This research builds on existing literature to examine the combined effects of jute and glass fibers in hybrid epoxy composites. By focusing on fiber orientation and its impact on hardness and impact resistance, this study aims to provide practical insights into optimizing hybrid composites for lightweight, durable, and sustainable applications.

1.3 OBJECTIVE

1. To evaluate the influence of jute fiber orientation (30°, 45°, and 75°) on the impact resistance and hardness of hybrid epoxy composites.

2. To analyze the role of multidirectional glass fibers in reinforcing the mechanical properties of hybrid composites.

3. To identify the optimal fiber orientation for achieving superior performance in structural, automotive, and aerospace applications.

4. To contribute to the growing body of research on sustainable material design by exploring hybrid composites as a viable alternative to traditional materials.

CHAPTER 2: MATERIALS AND PROPERTIES

2.1 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: 2.1 Glass Fiber & Jute Fiber

2.2 MATERIAS 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.

2.3 TEST SPECIMEN PREPARATION

After curing, the 6" × 6" composite plates were removed from the mold and trimmed to ensure uniformity. Specimens for mechanical testing were prepared as follows:

• **Hardness Test**: Samples were tested directly from the 6" × 6" 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: 2.3 Cutting the Specimen

CHAPTER 3: 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:

3.1. MOLD PREPARATION

A mold of 6" × 6" 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.

3.2. 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 30°

Sample 2: Jute fibers oriented at 45°

Sample 3: Jute fibers oriented at 75°

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

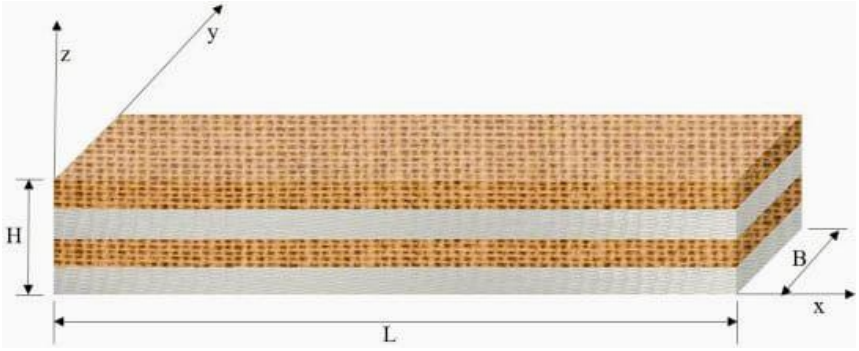


Figure: 3.2 Layering

3.3. 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.

3.4. 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. 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 30 × 30 × 2.5 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: 4.1 Hardness Test Machine

2. Impact Test:

The impact resistance of the composites was evaluated using the Izod impact test as per ASTM D256 standards. Square specimens, 80 × 10 × 2.5 mm^3 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: 4.1 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 30°.
Sample 2: Jute fibers oriented at 45°.
Sample 3: Jute fibers oriented at 75°.

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 HARDNESS TEST RESULTS

The hardness test results for the composite samples with varying jute fiber orientations (30°, 45°, and 75°) are summarized below:

• **30° Orientation**: The samples displayed hardness values of **58**, **60** and **62**, showing consistent surface resistance.

• **45° Orientation**: Hardness values were slightly higher, with readings of **62**, **71**, and **66**. The improved performance at 45° indicates better stress distribution due to the alignment of fibers.

• **75° Orientation**: Samples exhibited hardness values ranging from **39** to **91**, with variability likely caused by inconsistent fiber alignment at this orientation.

The results demonstrate that fiber orientation significantly impacts the hardness of the composite. The 45° orientation yielded the most consistent and higher hardness values, likely due to the balanced contribution of both jute and glass fibers.



Figure: 5.1 Hardness test specimens after testing

Table – 1: Data Table for Hardness Test:

Sample Number	30°	45°	75°
1.	58	62	65
2.	60	71	58
3.	62	66	56
Average	60	66.33	59.66

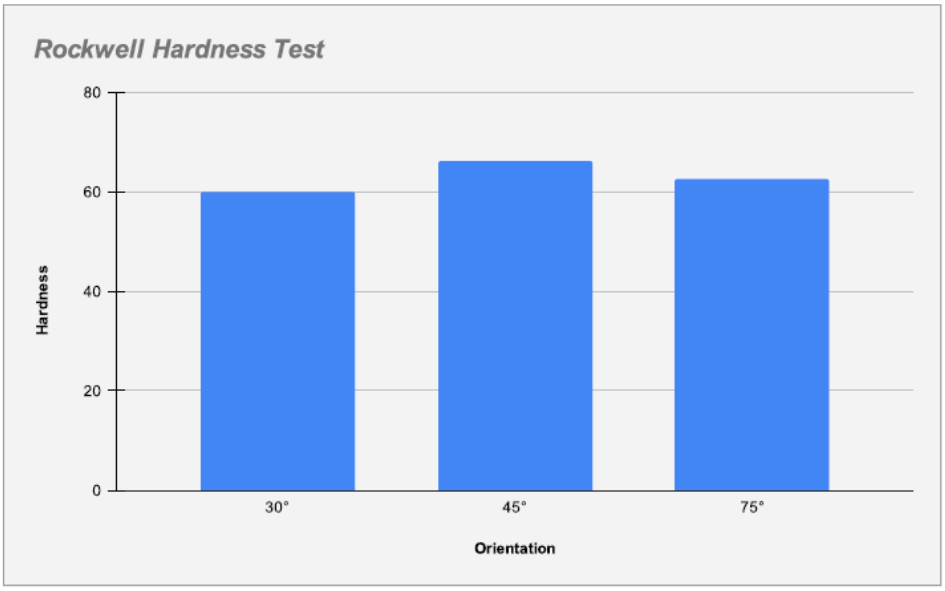


Figure: 5.1.1 Bar graph of rockwell hardness test

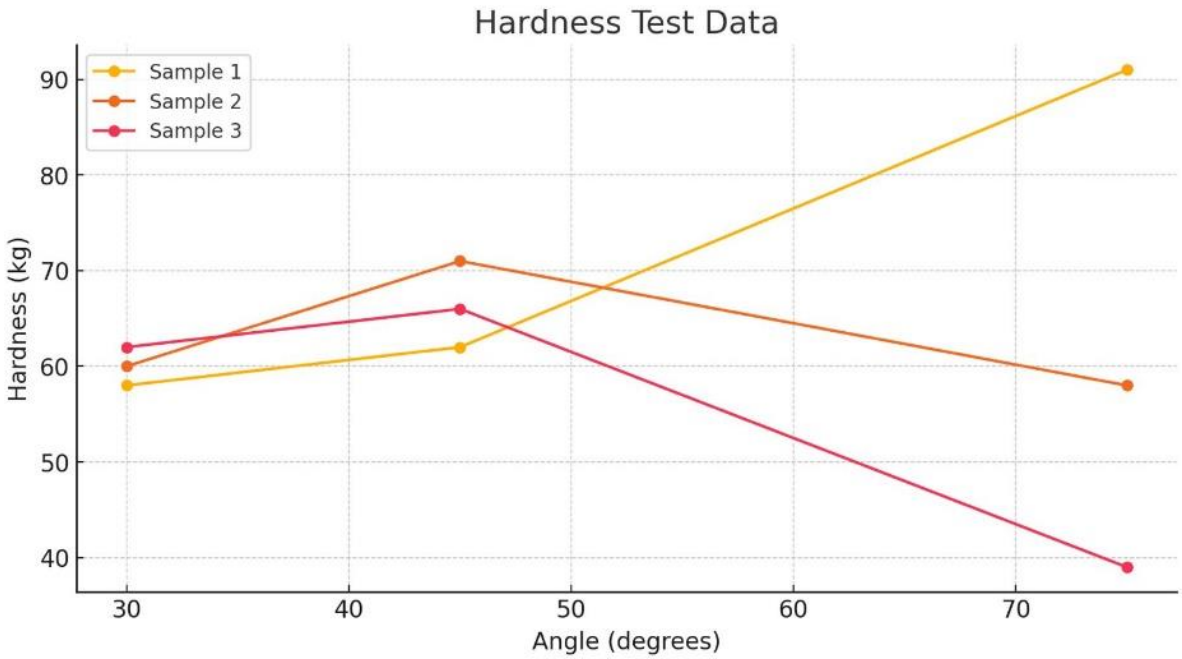


Figure 5.1.2: Line graph of hardness test.

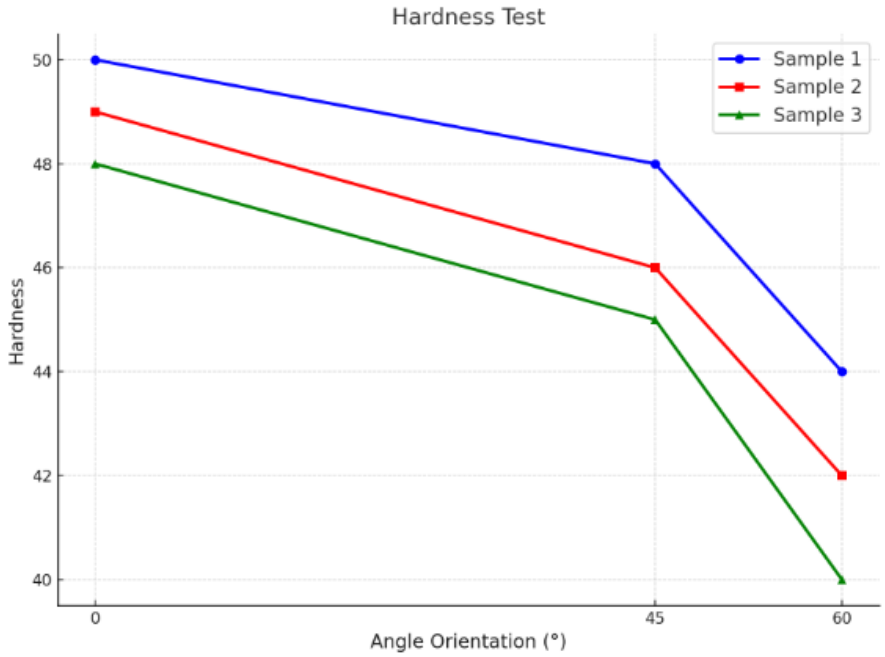


Figure 5.1.3: Line graph of hardness test [13]

Line graph – 1 shows the hardness test result at 30°, 45° and 75°
Line graph – 2 shows the hardness test result at 0°, 45° and 60° [13]

Comparison:
1. At **45°**, our results and the reference results show high hardness, with our configuration showing slightly better performance (66.33 vs. 65).
2. At **75°** (our result) vs. **60°** (reference), the hardness is comparable, with **75°** yielding slightly lower values (~62.67 vs. ~63).
3. 30° orientation provides better hardness (~60) than **0°** orientation (~58).

5.2 IMPACT TEST RESULTS

The impact resistance of the composite samples was evaluated based on the energy absorbed during testing, with the results categorized by fiber orientation:

• **30° Orientation**: Impact energies recorded were **3 ft-lb**, **3.95 ft-lb**, and **1.9 ft-lb**.

• **45° Orientation**: Samples exhibited higher energy absorption, with values of **4 ft-lb**, **4.5 ft-lb**, and **4 ft-lb**. This orientation provided better impact resistance, likely due to optimized load transfer between fibers.

• **75° Orientation**: The samples showed varying energy absorption, with values of **3.3 ft-lb**, **2.9 ft-lb**, and **3.9 ft-lb**. Despite higher absorption in some cases, variability suggests potential misalignment or uneven stress distribution at this angle.



Figure: 5.2 Impact test specimens showing fracture patterns after testing

The results indicate that the 45° fiber orientation provides superior and consistent impact resistance, emphasizing its suitability for applications requiring enhanced toughness.

Comparatively, the 30° and 75° orientations demonstrated lower performance, with variability in energy absorption likely due to non-optimal fiber alignment.

In summary, both the hardness and impact test results underline the critical influence of fiber orientation on the mechanical performance of jute and glass fiber-reinforced epoxy composites. The 45° orientation emerged as the most effective configuration for achieving a balance of surface hardness and impact resistance.

Table 2: Data Table for Impact Test:

Sample Number	30° energy (ft.lb)	45° energy (ft.lb)	75° energy (ft.lb)
1.	4.07	4	3.3
2.	3.95	4.5	2.9
3.	1.9	4	3.9
Average	2.95	4.16	3.36

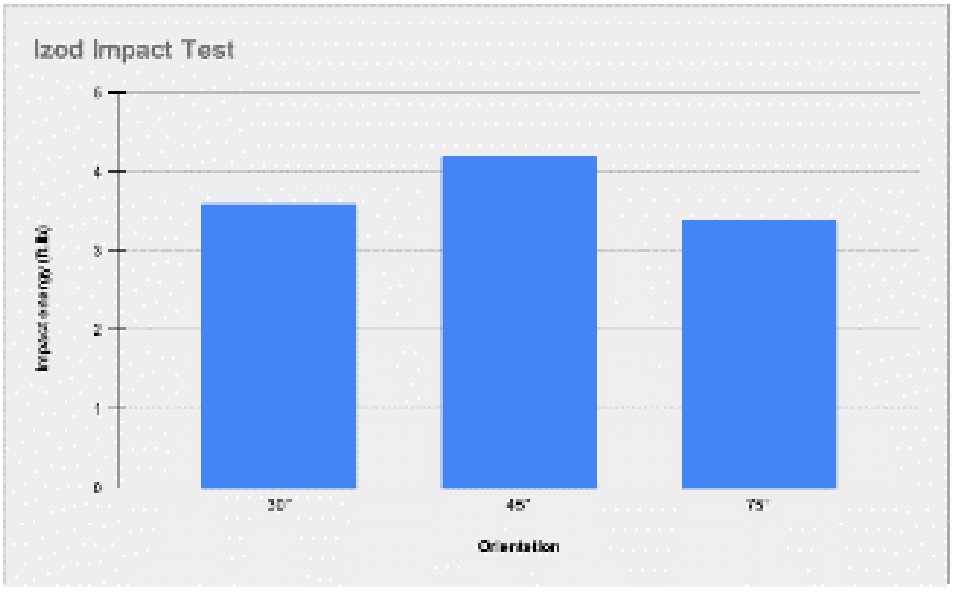


Figure: 5.1.4 Bar graph of impact test.

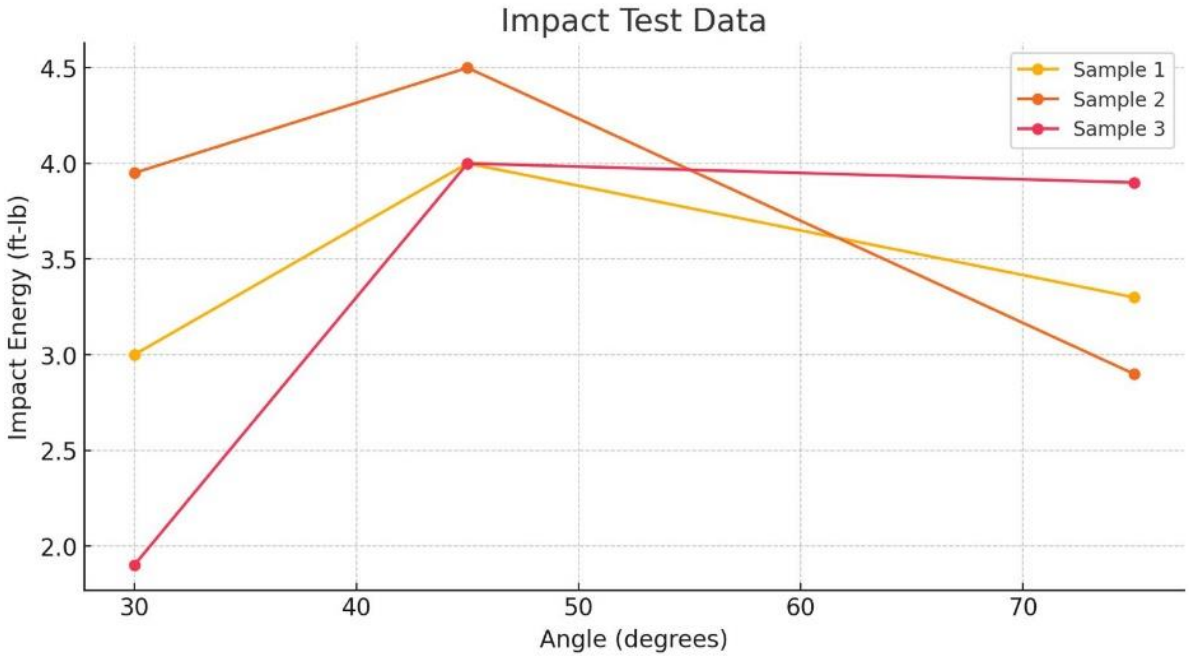


Figure 5.1.6: Line graph of impact test.

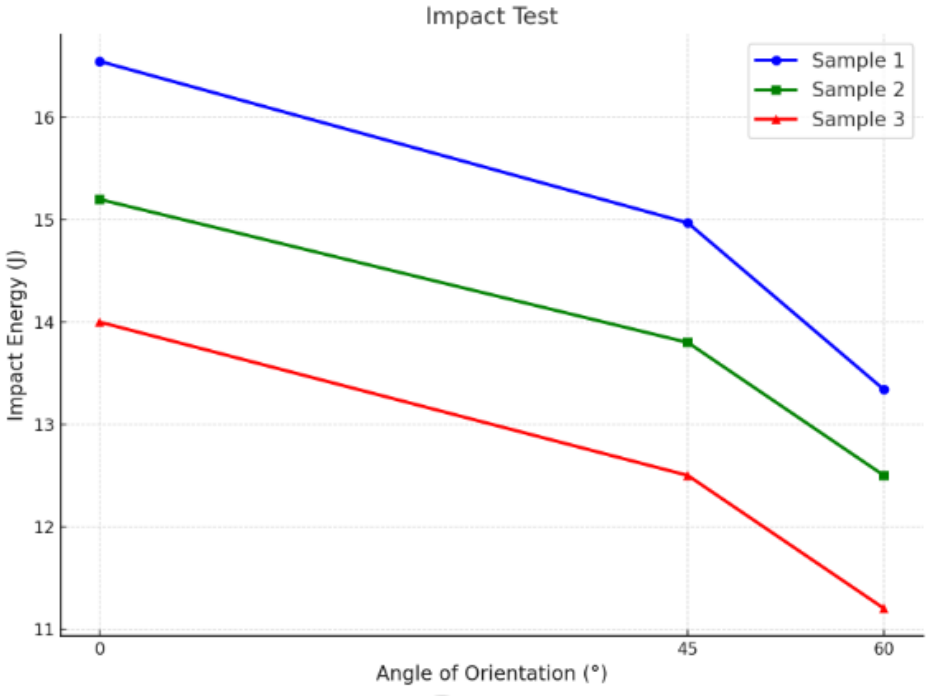


Figure 5.1.7: Line graph of impact test [13]

Line graph – 1 shows the impact test result at 30°, 45° and 75°
Line graph – 2 shows the impact test result at 0°, 45° and 60° [13]

Comparison:

1. At **45**°, both your results and the reference results demonstrate superior impact resistance, with your results slightly outperforming (4.16 ft-lb vs. 4 ft-lb).

2. 7**5°** orientation (3.36 ft-lb) is slightly lower than **60°** (3.5 ft-lb).

3. **30°** orientation (2.95 ft-lb) performs slightly better than **0°** (2.8 ft-lb).

CHAPTER 6: CONCLUSIONS AND FUTURE SCOPE

6.1 CONCLUSIONS

This study evaluated the mechanical performance of jute and glass fiber-reinforced epoxy composites by conducting hardness and impact tests on samples with different jute fiber orientations (30°, 45°, and 75°). The key findings are as follows:

Hardness Test:
The 45° orientation demonstrated the highest and most consistent hardness values among the three configurations (average: 66.33), outperforming both the 0° and 60° reference orientations (average: ~65 and ~63, respectively). This indicates superior load distribution and stress resistance.

Impact Test:
The 45° orientation also exhibited superior impact resistance, absorbing the highest energy during testing (average: 4.16 ft-lb). It slightly outperformed the reference configuration at 45° (average: ~4 ft-lb), confirming its effectiveness in optimizing energy absorption.

Hybridizing jute and glass fibers in epoxy matrices showed potential for lightweight and eco-friendly composite materials suitable for moderate mechanical performance applications. These results emphasize the significance of fiber orientation in achieving tailored mechanical properties, with the 45° orientation emerging as the optimal configuration.

6.2 FUTURE SCOPE

This research lays the foundation for further exploration of hybrid fiber composites. Future work can focus on:

1. Additional Mechanical Tests: Evaluating tensile, flexural, and fatigue properties to gain a comprehensive understanding of the composite's mechanical behavior.
2. Effect of Fiber Volume Fraction: Investigating how varying the proportions of jute and glass fibers influences mechanical properties.
3. Moisture and Environmental Testing: Assessing the performance of composites under different environmental conditions, such as humidity, temperature, and UV exposure.
4. Alternate Resin Systems: Exploring the use of bio-based or modified epoxy resins to further improve the sustainability of the composite.
5. Optimization of Fabrication Techniques: Studying advanced manufacturing methods, such as vacuum bagging or resin infusion, to minimize voids and enhance mechanical properties.

These future directions will enable the development of optimized hybrid composites for applications in automotive, aerospace, and structural industries, ensuring sustainability without compromising performance.

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