COMPARATIVE STUDY ON THE MECHANICAL PROPERTIES OF JUTE-GLASS EPOXY HYBRID COMPOSITES

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In partial fulfillment of the requirements for the award of the degree
of
Bachelor of Science in Mechanical Engineering

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Certification

This is to certify that the thesis titled **" Comparative Study On The Mechanical Properties Of Jute-Glass Epoxy Hybrid Composites "** 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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Declaration

I hereby declare that the thesis titled " **Comparative Study On The Mechanical Properties Of Jute-Glass Epoxy Hybrid Composites** " submitted to Sonargaon University, is our 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.
We 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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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 45°, 60°, and 90°, 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 60° 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 90° orientation resulted in higher hardness values, indicating better resistance to localized deformation. The 45° 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

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 [1], [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 [3], [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 loadbearing capacity. Proper alignment and hybridization of fibers can result in materials tailored to specific industrial applications, offering optimized performance and weight reduction [6], [7].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 (45°, 60°, and 90°). Through bending, 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 highperformance scenarios [1], [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], [9].

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 [3], [4], [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 [5], [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 [3], [6], [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 OBJECTIVES

1. To evaluate the influence of jute fiber orientation (45°, 60°, and 90°) on the bending test , hardness of hybrid epoxy composites and impact resistance.

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

3. To develop a cost-effective, lightweight, and eco-friendly hybrid composite suitable for engineering applications.

4. To explore the potential applications of jute-glass composites in structural, automotive, aerospace, and construction sectors.

5. To contribute to sustainable material development by partially replacing synthetic fibers with natural jute fibers.

CHAPTER 2: MATERIALS AND PROPERTIES

2.1 MATERIALS USED

The materials used in this study include:

- **Jute Fiber**: Natural jute fabric of 300 gsm was used as reinforcement.
- **Glass Fiber**: Woven glass fiber fabric 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 MATERIAL 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 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: 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 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.

3.2. 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 45°

Sample 2: Jute fibers oriented at 60°

Sample 3: Jute fibers oriented at 90°

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

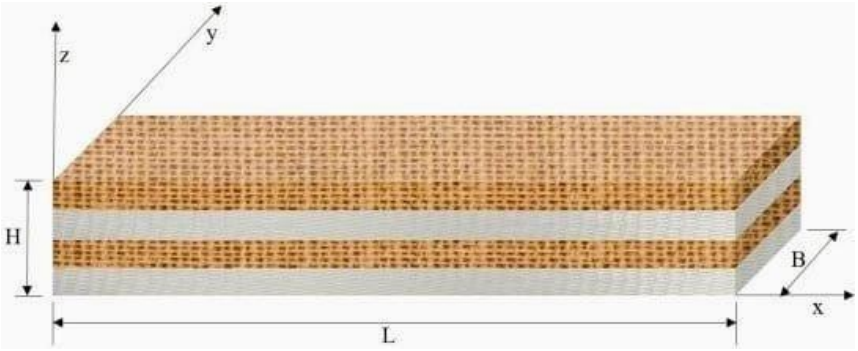


Figure: 3.2 Layering

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 UNIVERSAL TESTING MACHINE (UTM) :

A Universal Testing Machine (UTM) is a versatile device used to evaluate the mechanical properties of materials under tension, compression, and bending. It typically features a robust frame, load capacities ranging from 1 kN to 2000 kN, and high-precision load cells. The machine includes a motorized crosshead with adjustable speeds (0.1–500 mm/min), extensometers for accurate strain measurement, and digital or computer-based control systems for data acquisition and analysis. Various grips and fixtures accommodate different material shapes and test standards (ASTM, ISO). UTMs are essential in quality control, research, and development for testing metals, polymers, composites, and construction materials.

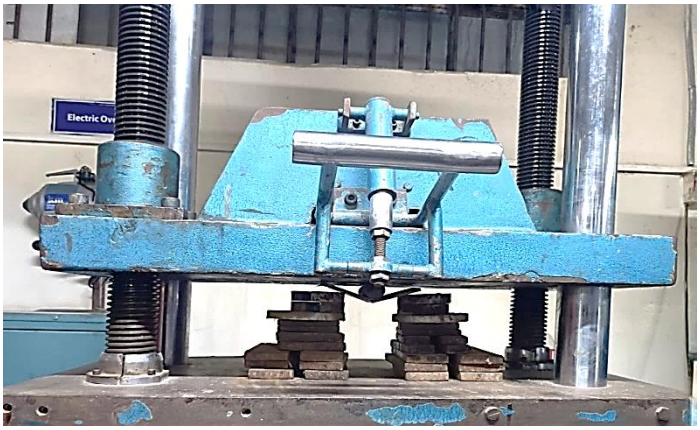


Figure: 4.1 Bending Test Machine

MECHANICAL TEST PERFORMED:

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.

HARDNESS TEST MACHINE:

A Hardness Test Machine is designed to measure a material's resistance to deformation through indentation. Common types include Rockwell, Brinell, and Vickers testers. Specifications vary by type but typically include a load range of 1 kgf to 3000 kgf, depending on the test method. Indenters may be steel balls, diamond cones, or pyramids. Machines feature manual or motorized loading, digital or analog readouts, and precision depth or optical measurement systems. Advanced models include automated test cycles, data storage, and software integration. They are suitable for testing metals, alloys, plastics, and ceramics in quality control, research, and industrial applications.



Figure: 4.2 Hardness Test Machine

MECHANICAL TEST PERFORMED:

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]

IMPACT TEST MACHINE:

An Impact Test Machine is used to determine a material's toughness by measuring its ability to absorb energy during sudden impact. Common types include Charpy and Izod impact testers. Specifications typically include a pendulum with energy capacity ranging from 150 J to 750 J, digital or analog energy indicators, and support for test temperatures from ambient to sub-zero (using a cooling chamber). The machine consists of a heavy pendulum, specimen support (horizontal for Charpy, vertical for Izod), and precise measurement scales. Materials are notched before testing to concentrate stress. Impact testers are essential in quality control, especially for metals and engineering plastics.



Figure: 4.3 Impact Test Machine

MECHANICAL TEST PERFORMED:

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 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.

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

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 (45°, 60°, and 90°) are summarized below:

- **45° Orientation**: The samples displayed hardness values of **10**, **12** and **15 HRL** showing consistent surface resistance.

- **60° Orientation**: Hardness values were slightly higher, with readings of **8**, **9** and **10 HRL** . The improved performance at 45° indicates better stress distribution due to the alignment of fibers.

- **90° Orientation**: Samples exhibited hardness values ranging from **7, 9, 11 HRL** with variability likely caused by inconsistent fiber alignment at this orientation.

The results demonst rate 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.

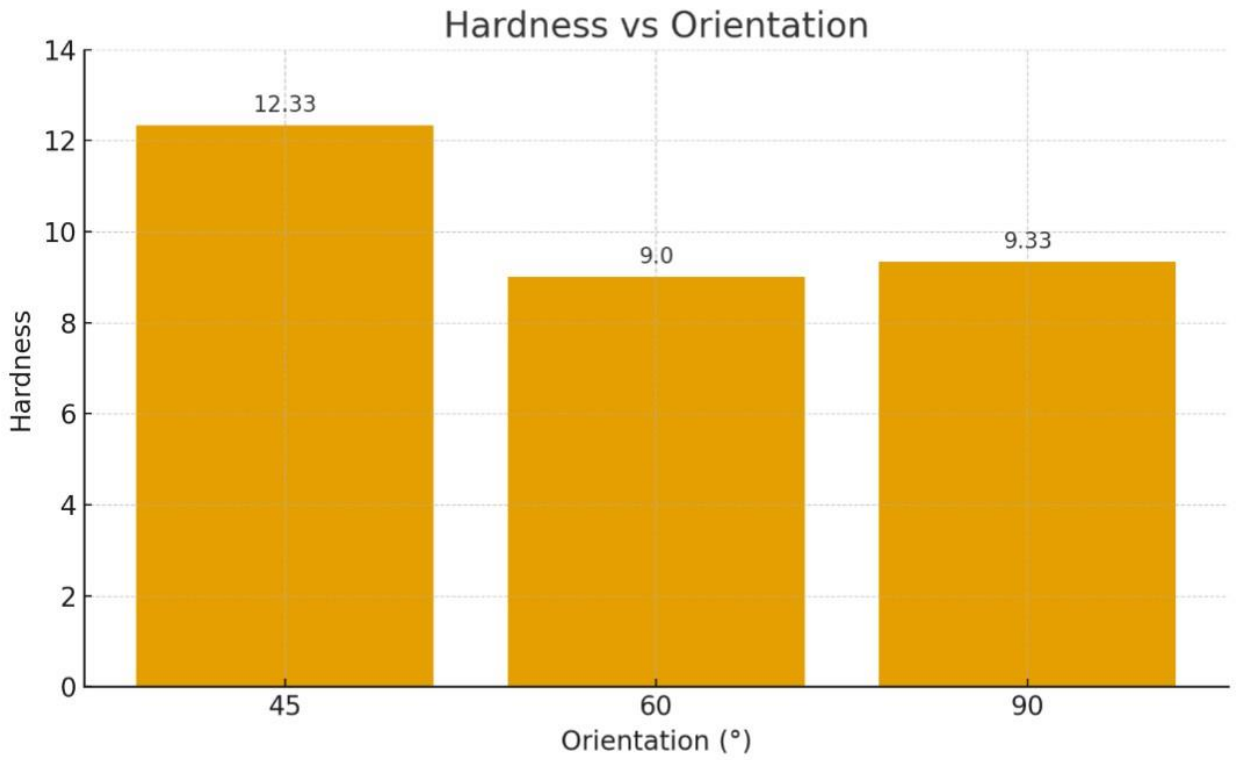


Figure: 5.1 Hardness test specimens after testing

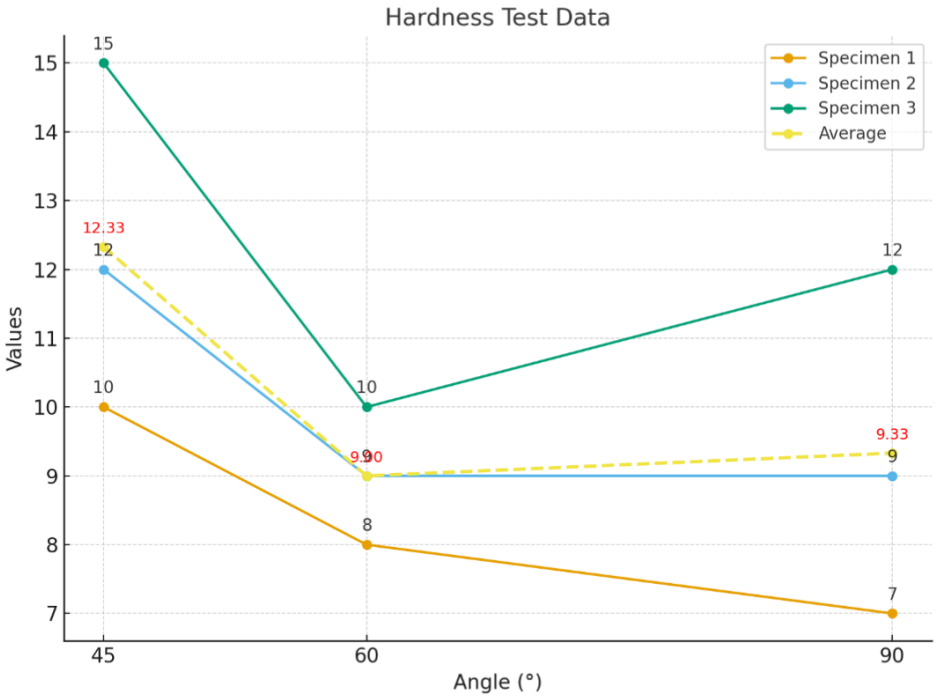
Data Table for Hardness Test:

Specimen No.	1	2	3	Average
45°(HRL)	10	12	15	12.33
60°°(HRL)	8	9	10	9
90°°(HRL)	7	9	12	9.33

Table: 5.1 Data Table of Hardness Test



Graph Chart : 5.1 Graph Chart of Hardness Test



Line Graph: 5.1 Line Graph of Hardness Test

Line Graph shows the hardness test result at 45^{o}, 60^{o} and 90^{o} .

Comparison:

1. At **45°**, our results and the reference results show high hardness, with our configuration showing slightly better performance (12.33)
2. At **60°** (our result) vs. **90°** (reference), the hardness is comparable, with **90°** yielding slightly lower values (~ 9).
3. **90°** orientation provides better hardness (~ 9.33) than **0°** orientation (~10).

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:

- **45° Orientation**: Impact energies recorded were **3 ft-lb**, **3.25 ft-lb**.

- **60° Orientation**: Samples exhibited higher energy absorption, with values of **1.5 ft-lb, 1.75 ft-lb.**

- This orientation provided better impact resistance, likely due to optimized load transfer between fibers.

- **90° Orientation**: The samples showed varying energy absorption, with values of **1.25 ft-lb, 1.50 ft-lb** . Despite higher absorption in some cases, variability suggests potential misalignment or uneven stress distribution at this angle.



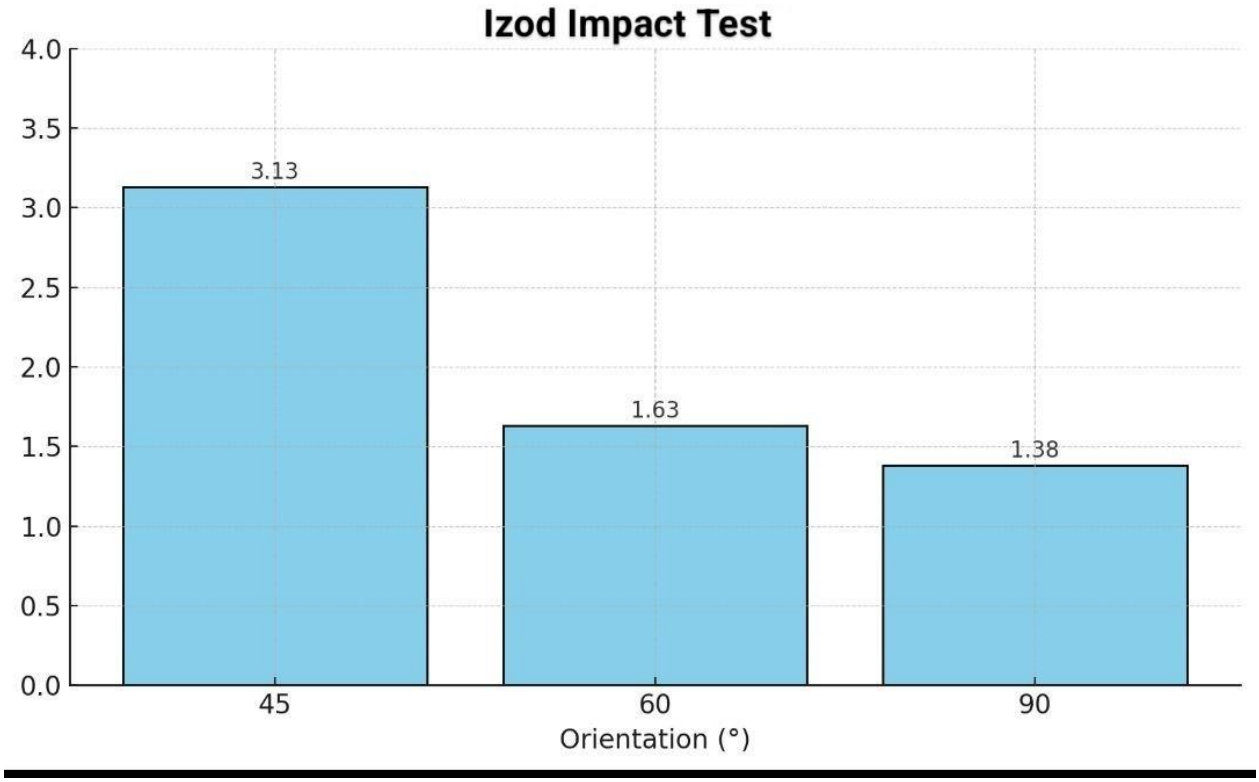
Figure: 5.2 Impact test specimens showing fracture patterns after testing

The results indicate that the 45° fiber orientation provides superior and consistent impact resistance, emphasizing its suitability for applications requiring enhanced toughness.
Comparatively, the 60° and 90° 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.

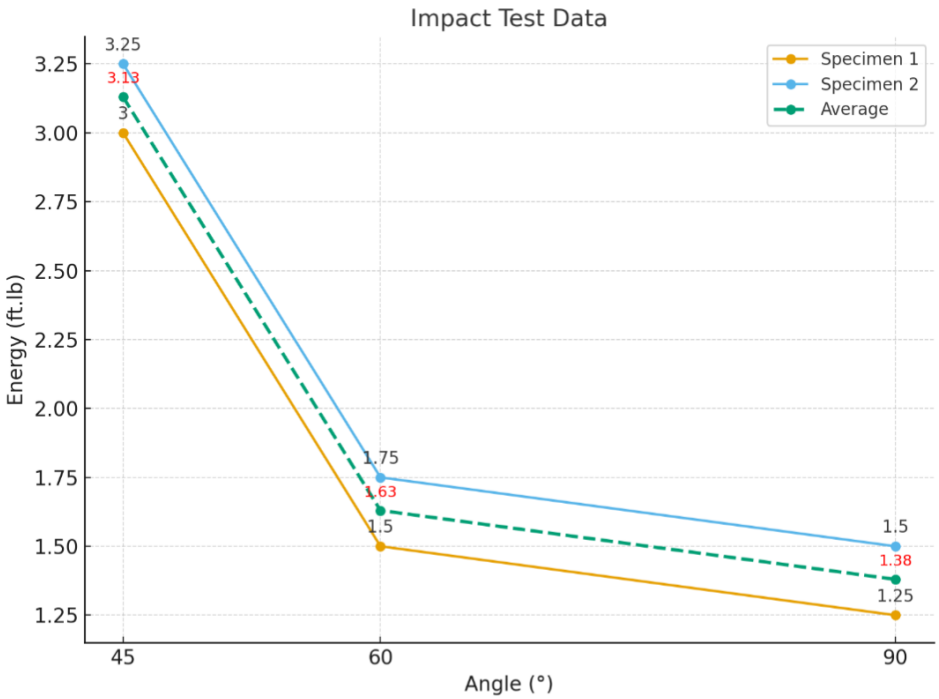
Data Table for Impact Test:

Specimen No.	1	2	Average
45^{o} energy (ft.Ib)	3	3.25	3.13
60^{o} energy (ft.Ib)	1.5	1.75	1.63
90^{o} energy (ft.Ib)	1.25	1.5	1.38

Table: 5.2 Data Table of Impact Test



Graph Chart : 5.2 Graph Chart of Impact Test



Line Graph: 5.2 Line Graph of Impact Test

Line graph shows the impact test result at 45^{o} , 60^{o} and 90^{o}

Comparison:

1. At **45°**, both your results and the reference results demonstrate superior impact resistance, with your results slightly outperforming (3.13 ft-lb vs. 3 ft-lb).
2. **90°** orientation (1.38 ft-lb) is slightly lower.
3. **60°** orientation (1.63 ft-lb) performs slightly better than **0°** (1.5 ft-lb).

5.3 BENDING TEST RESULTS

The bending strength of the composite samples was evaluated under three-point bending, with the results categorized by fiber orientation:

- **45° Orientation:** Samples exhibited the highest and most consistent bending strength, with values of 1.25 MPa, 1.75 MPa, and 2 MPa. This orientation provided superior load distribution and effective stress transfer, resulting in enhanced resistance against bending failure.
- **60° Orientation:** The recorded strengths were moderate, with values of 1.25 MPa, 1.5 MPa, and 1.75 MPa. Although performance was relatively stable, the results indicate slightly reduced bonding efficiency compared to 45° orientation.
- **90° Orientation:** Samples showed the lowest bending strength, with values of 1.5 MPa, 1.4 MPa, and 1.25 MPa. This orientation displayed weak resistance due to poor load transfer along the fiber direction, making it the least effective configuration under bending loads.



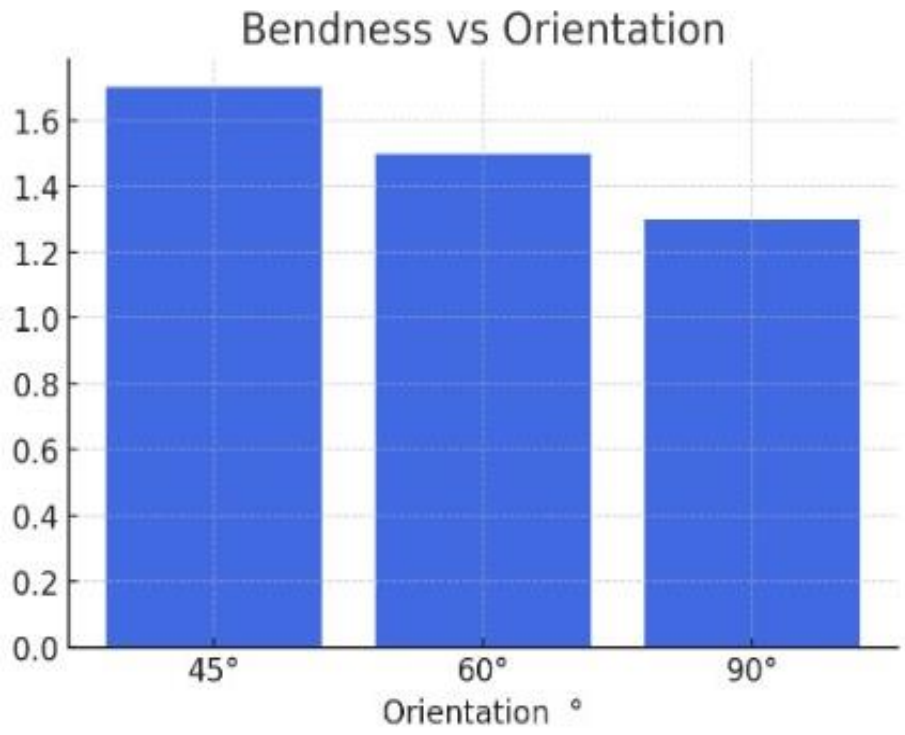
Figure: 5.3 Bending Test Specimens After Testing

The findings indicate that the 45° fiber orientation demonstrates superior bending resistance, making it highly suitable for structural applications requiring strength and reliability.Comparatively, the 60° and 90° orientations exhibited weaker performance, which may be attributed to less effective stress transfer and fiber alignment

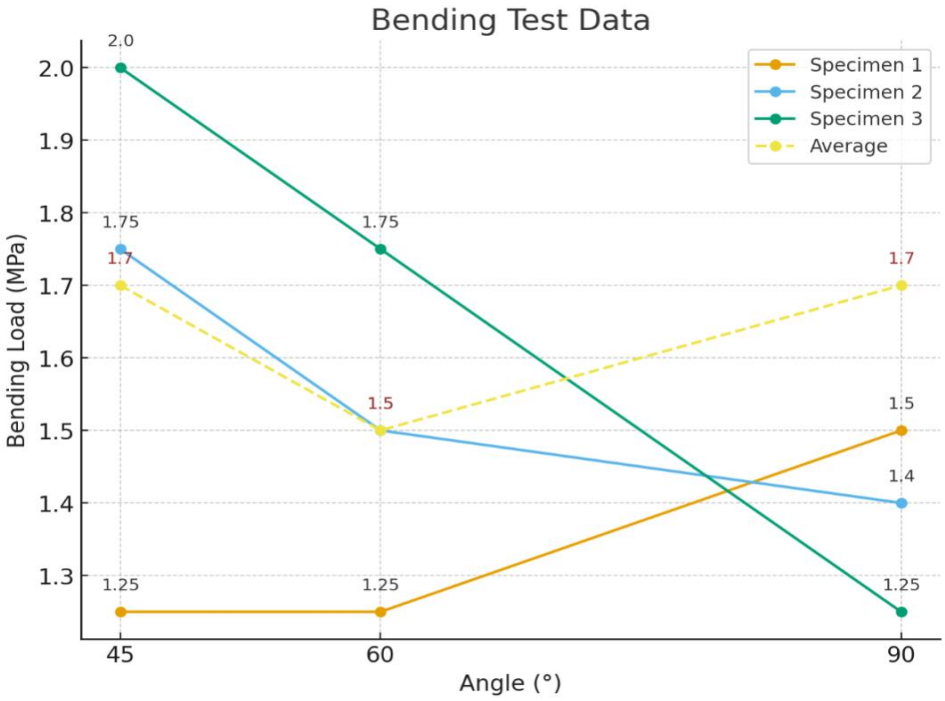
Data Table for Bending Test:

Specimen No.	1	2	3	**Avarage**
45^{o} Load(Mpa)	1.25	1.75	2	1.7
60^{o} Load(Mpa)	1.25	1.5	1.75	1.5
90^{o} Load(Mpa)	1.5	1.4	1.25	1.4

Table: 5.3 Data Table of Bending Test



Graph Chart : 5.3 Graph Chart of Bending Test



Line Graph: 5.3 Line Graph of Bending Test

Line graph shows the Bending test result at 45^{o} , 60^{o} and 90^{o}

Comparison:

1. At **45°**, both your results and the reference results demonstrate superior impact resistance, with your results slightly better performing (1.7 vs. 1.25 Mpa).
2. **90°** orientation (1.3 Mpa) is slightly lower.
3. **60°** orientation (1.5 Mpa) performs slightly better than **0°** (1.4 Mpa).

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 (45°, 60°, and 90°). The key findings are as follows:

Bending Test:
The 45° orientation demonstrated the highest and most consistent bending strength among the three configurations (average: 1.7 MPa), outperforming both the 60° and 90° orientations (average: 1.5 MPa and 1.4 MPa, respectively). This indicates superior load distribution and effective stress transfer at 45°, while the lower performance at 60° and 90° suggests reduced bonding efficiency and weaker resistance to bending loads.

Hardness Test:
The 45° orientation exhibited the highest hardness values among the three configurations (average: 12.33), clearly outperforming both the 60° and 90° orientations (average: 9.0 and 9.33, respectively). This indicates that the 45° fiber alignment provides superior resistance to surface indentation, while the relatively lower hardness at 60° and 90° suggests less effective stress distribution.

Impact Test:
The 45° orientation exhibited superior impact resistance, absorbing the highest energy during testing (average: 3.13). It outperformed the 60° (average: 1.63) and 90° (average:
1.38) orientations, confirming its effectiveness in optimizing energy absorption. The decreasing trend from 45° to 90° indicates that fiber orientation plays a vital role in impact strength, with more favorable energy absorption observed at lower angles. These results emphasize the significance of orientation in tailoring mechanical properties, with the 45° orientation emerging as the optimal configuration for maximizing impact resistance.

Comparative Table: Jute–Glass Fiber Epoxy Hybrid Composite vs Industrial Materials:

Property	Composite (45°, Best Orientation)	Typical Industrial Materials	Comparative Remarks & Potential Alternatives
Hardness (Rockwell)	10–15 HRL	- **Softwood**: 5–15 HRL - **Hardwood**: 20–40 HRL - **Unreinforced Epoxy**: 10–20 HRL - **ABS / Nylon Plastics**: 15–30 HRL - **Aluminum (annealed)**: ~15 HRB (≈25–30 HRL) - **Mild Steel**: 60–100 HRB	Comparable to softwood, epoxy, and low-hardness plastics**;** much lower than metals. Suitable alternative to woodbased boards and some plastic housings.
Impact Resistance (ft-lb)	~3.0–3.25	- **Wood (pine)**: ~2–5 ft-lb - **Epoxy resin**: ~1–2 ft-lb - **ABS plastic**: ~3–7 ft-lb - **Aluminum alloy**: ~20–30 ft-lb - **Steel**: 50+ ft-lb	Comparable to wood and epoxy**,** and close to ABS plastics; far below metals. Best suited for lightweight, low-impact panels or casings**.**
Bending Strength (MPa)	1.25–2.0 MPa	- **Wood (pine)**: ~40–80 MPa - **Plywood**: ~30–60 MPa - **Epoxy resin**: ~20–50 MPa - **ABS plastic**: ~60–110 MPa - **Glass fiber composites**: 200–500 MPa - **Aluminum**: 150–300 MPa - **Steel**: 250–600 MPa	Much lower than wood, plastics, metals, and reinforced composites. Not suitable for structural or load-bearing parts. Could be used in non-structural covers, partitions, or panels**.**

Comparative Table: 6.1 Jute–Glass Fiber Epoxy Hybrid Composite vs Industrial Materials

Improvement avenues: To make this composite more competitive, you might try increasing fiber volume fraction, optimizing fiber alignment, better bonding at fiber–matrix interface, perhaps adding fillers (ceramic, harder particles), or post-treatment (surface coatings, hard coatings).

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.

Comparative Applications of Jute-Glass Fiber Epoxy Hybrid Composites:

Sector	Conventional Materials	Jute-Glass Hybrid Composite (Alternative)	Advantages
Automotive	Steel, Aluminum, Pure Glass Fiber Composites	Interior panels,dashboards, nonload structural parts	Lightweight, costeffective, fuel efficiency
Construction	Steel rods, Plywood, Cement boards	Wall panels, boards, partition sheets	Eco-friendly, moderate strength, reduced weight
Aerospace	Carbon/Glass Fiber Composites	Interior panels, insulation, secondary components	Weight reduction, sustainable, cheaper
Marine	Glass Fiber Laminates	Boat interior panels, flooring, covers	Good strength, water resistance, lower cost
Furniture & Sports	Wood, Plastics, Pure Synthetic Composites	Chair frames, helmets, rackets, sports boards	Lightweight, durable, ecofriendly alternative

Comparative Table: 6.2 Comparative Applications of Jute-Glass Fiber Epoxy Hybrid Composites

CHAPTER 7: REFERENCES

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