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

A Thesis
by

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DEPARTMENT OF MECHANICAL ENGINEERING
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JANUARY, 2026

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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

JANUARY, 2026

ACKNOWLEDGEMENT

First, we started in the name of almighty Allah. This thesis is accomplished under the supervision of **Shahinur Rahman**, **Assistant Professor** Department of Mechanical, Sonargaon University. It is a great pleasure to acknowledge our profound gratitude and respect to our supervisor for this consistent guidance, encouragement, helpful suggestion, constructive criticism and endless patience through the progress of this work. The successful completion of this thesis would not have been possible without his persistent motivation and continuous guidance.

The authors are also grateful to **Prof. Md. Mostofa Hossain, Professor,** Head of the Department of Mechanical Engineering and all respect teachers of the Mechanical Engineering Department for their co-operation and significant help for completing the thesis work successfully.

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Abstract

This research presents a comparative study on the mechanical properties of bagasse fiber and glass fiber reinforced epoxy hybrid composites, with a focus on the effect of fiber orientation on material performance. Bagasse fiber, an agricultural waste from sugarcane, is used as a sustainable natural reinforcement in combination with glass fiber to improve mechanical strength. Hybrid composite laminates were fabricated using bagasse fibers oriented at 45°, 60°, and 90° within an epoxy resin matrix, along with glass fiber layers. Mechanical characterization was carried out through hardness and impact tests to evaluate the influence of fiber orientation on the composite behavior.

The experimental results reveal a strong relationship between fiber orientation and mechanical performance. The highest average bending load is at 90^0, indicating the maximum bending strength occurs at this angle. The 45° bagasse fiber orientation demonstrated the highest impact strength due to improved energy absorption and load transfer capability under dynamic conditions. In contrast, the 45° orientation exhibited highest hardness, indicating superior resistance to surface indentation and localized deformation. The 45° orientation showed highest and balanced mechanical properties but did not outperform the other configurations. This study emphasizes that proper selection of fiber orientation plays a crucial role in optimizing the mechanical performance of bagasse–glass epoxy hybrid composites. The findings support the potential application of these eco-friendly composites in lightweight structural, automotive, and engineering components.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Natural fibers offer a multitude of technical and ecological advantages when employed in reinforced composites. Sugarcane, bamboo, flax, wood, hemp, jute, barley, wheat, and sisal are a few examples of natural fibers whose compatibility with plastics has been studied. Utilizing thermosets, thermoplastic and elastomeric matrix materials, these fibers are reinforced.Plant fibers have historically been used as renewable resources because of their variety of characteristics. With a global production of over 1.7 billion tons in 2011, sugarcane, scientifically referred to by the genus Saccharum spp., is a significant crop in tropical areas. After the cane stalks are crushed in sugar and alcohol mills, bagasse, a residue material that makes up around 30% of this cane, is left behind. Bagasse is made up of 45% cellulose, 33% hemicelluloses, and 20% lignin and includes both the inner pith and the outer rind of the cane stalk.

Whereas alloys and composites retain the distinctive characteristics of their constituent parts, improving strengths while limiting weaknesses to key considerations materials. According to Suchetclan, such composites have two or more solid phases that are discernible at the micro level. They can be categorized as homogenous on this level since they all exhibit the same physical characteristics. The use of jute in the development of furniture provides the impetus for jute-based biocomposites, which requires researchers to address problems through research and development.The manufacture and quality of jute-based bio composite sectors are improved by this concept. When mixed with other materials, jute fibers can provide thermo physiological comfort qualities.Reinforced biocomposites from jute fibers exhibit improved flexural and tensile strength, ductility, crack resistance, toughness, and impact strength.With a heritage dating back thousands of years, jute is globally accessible and well-suited for a range of applications, including paper production and erosion control. Its attributes include high strength, processing ease, and sustainability. Improved flexural and tensile strength, ductility, crack resistance, toughness, and impact strength are all displayed by reinforced biocomposites made of jute fibers.Jute has a long history going back thousands of years. It is widely available and suitable for a variety of uses, such as paper making and erosion control. High strength, processing simplicity, sustainability, and a quick growth cycle are some of its qualities,and a rapid growth cycle.

Jute-based composites are preferred more frequently than synthetic fibers like glass fiber because of their improved eco-friendliness and less environmental effect.This is consistent with its conceptual connections with good and optimism. Researchers are extensively investigating jute-based biocomposites because of their strength and lightness,describing them as a green technology that promotes an eco-friendly environment. A cost-effective source of cellulosic natural fibers for biocomposites, jute-origin bagasse has the potential to revolutionize production processes and manufacturing.Although glass fibers exceed jute in terms of strength, jute is still suitable for building since it offers elasticity and strength. Due primarily to its advantages over synthetic counterparts in terms of the environment and economy, natural fiber composites are gaining popularity across industries.Natural fibers are valued for their strength, renewability, and biodegradability since they are produced from plants with high lignocellulosic content. These fibers, which are preferred to traditional composites because of their non-carcinogenic and biodegradable characteristics, include cotton, jute, sisal, bagasse, hemp, and coir.

Plant fibers comprise cellulose fibrils that are bound together by a matrix of lignin and hemicelluloses. Increased mechanical characteristics are correlated with increased cellulose content. Construction industries such as the automotive, bridge and building industries use cellulose fibers. Jute fiber stands out for its ability to absorb CO2 and for being environmentally friendly. In varied conditions, especially in Asia and South America, about a 1000 jute species and about 70 families grow.Strength, lightness, biodegradability, stiffness, and soil protection via leaf and root functions are just a few of jute’s benefits. Its usefulness extends to extensive construction and living tool applications, where controlled jute fiber insertion supports the continuous growth of composites.This research highlights the novelty of developing automotive thermal insulation materials through the combination of bagasse and jute fibers in natural fiber-reinforced composites.

1.2 Literature Review

Usmani M.Arthur et al (1981) [1] described the evaluation of five water soluble phenolic resins as binders, at 5 percent concentration, for oriented and random bagasse-reinforced composite materials. Determined the amount of resin retained during processing when these phenolics are precipitated from water slurry onto the bagasse fibers. The physical properties of random oriented cured composites (wet and dry) were determined. Random fiber composites were also prepared by a "moist" process (in which no resin is lost) and compared. A specific resin was selected as best based on retained mechanical properties and minimal phenolic processing losses.

D. Maldas et al (1990) [2] studied the effect of thermoplastics (e.g. polyvinyl chloride and polystyrene), as well as a coupling agent — poly (methylene (polyphenylisocyanate)) (PMPPIC) — and bagasse lignin, on the mechanical properties of particle boards of sugarcane bagasse. The mechanical properties of bagasse particle boards were compared to those of hardwood aspen fiber particle boards, delignified bagasse particle boards, as well as those of composites made from bagasse, polymers and coupling agents. Particle boards of bagasse comprising both thermoplastics and a coupling agent offer superior properties compared to those made of only thermoplastic or a coupling agent. The extent of improvement in the mechanical properties of particle boards depended on the concentration of polymers and the coupling agent; nature of the fiber, polymer and coupling agent; composition of PMPPIC and bagasse; as well as lignin content of the bagasse. Moreover, the mechanical properties and dimensional stability of coupling agent-treated particle boards are superior to non-treated ones.

Monteiro S.N. et al (1998) studied [3] the possible uses of bagasse waste as reinforcement in polyester matrix composites. Preliminary results have attested this possibility. Composites with homogeneous microstructures could be fabricated and the levels of their mechanical properties enable them to have practical applications similar to the ones normally associated with wooden agglomerates. Future developments are expected to increase the performance and competitiveness of these composites as compared to those of other materials in the same structural class.

Vazquez A. et al (1999) reported [4] processing and properties of bagasse fiber-polypropylene composites. Four different chemical treatments of the vegetal fibers were performed in order to improve interface adhesion with the thermoplastic matrix: namely isocyanate, acrylic acid, mercerization and washing with alkaline solution were applied. The effects of the treatment reactions on the chemical structure of the fibers were analysed by infrared spectroscopy. Optical photomicrographs indicate that a highly fibrillated surface is achieved when fibers are mercerized. The effects of the fiber chemical treatment on the tensile properties of the molded composite, produced by different processing routes, were also analysed. It was observed that the tensile strength and the elongation at break of the polypropylene matrix composite decrease with the incorporation of bagasse fibers without treatment. However, isocyanate and mercerization treatments enhance the tensile properties of the composite. Moreover, creep measurements were also carried out on the various composites studied. The best results were obtained on materials with treated fibers. The highest creep activation energy was obtained on the composite with the mercerized fiber.

Hassan M.L et al (2000) investigated [5] the conversion of bagasse into a thermo formable material through esterification of the fiber matrix. For this purpose, bagasse was esterified in the absence of solvent using succinic anhydride (SA). The reaction parameters of temperature reaction, time and amount of succinic anhydride added were studied. Ester content, Fourier transform infrared (FTIR), thermo gravimetric analysis (TGA), differential scanning calorimetry (DSC) and dynamic mechanical thermal analysis (DMTA) were used to characterize the chemical and thermal properties of the esterified fibers. The results showed that on reacting bagasse with SA in the absence of solvent, ester content up to about 48% could be obtained. Diester formation increased with increasing reaction time and temperature at high levels of ester content. Ester content determination of the esterified fibers and their corresponding holocelluloses showed that the reaction took place in the lignin and holocellulose components of bagasse. The IR results showed that the crystallinity index of different esterified bagasse samples did not decrease as a result of increasing the ester content. DSC and TGA results showed that esterified-bagasse fibers were less thermally stable than the untreated fibers. DMTA results showed that esterification of the fibers resulted in a decrease in the tan δ peak temperature of the esterified fibers compared to the untreated fiber.

Hassan M.L et al (2000) investigated [6] the conversion of bagasse into a thermomoldable material through esterification of the fiber matrix. For this purpose, bagasse fiber was esterified in the absence of solvent using succinic anhydride. The dimensional stability and mechanical properties of composites prepared from the esterified fibers were studied.

Dimensional stability was found to be dependent on the total ester and monoester/diester content of esterified fibers and increased with increasing total ester and monoester content of the fibers. The mechanical properties (bending strength, tensile strength and hardness) were enhanced with increasing monoester contents. Scanning electron microscopy was used to prove the occurrence of thermo plasticization of the esterified fibers

PaivaJ.M.F. et al (2002) confirmed [7] that Lignin, extracted from sugarcane bagasse by the organosolv process, used as a partial substitute of phenol (40 w/w) in resole phenolic matrices. Short sugarcane fibers were used as reinforcement in these polymeric matrices to obtain fiber-reinforced composites. Thermoset polymers (phenolic and lignophenolic) and related composites were obtained by compression molding and characterized by mechanical tests such as impact, Differential Mechanical Thermo analysis (DMTA) and hardness tests. The impact test showed an improvement in the impact strength when sugarcane bagasse was used. The inner part of the fractured samples was analysed by scanning electron microscopy (SEM) and the results indicated adhesion between fibers and matrix, because the fibers are not set free, suggesting they suffered a break during the impact test. The modification of fiber surface (mercerization and esterification) did not lead to an improvement in impact strength. The results as a whole showed that it is feasible to replace part of phenol by lignin in phenolic matrices without loss of properties.

Bilba K et al (2003) prepared [8] various bagasse fibre/cement composites, the fibres having a random distribution in the composites. The influence of different parameters on the setting of the composite material has been studied: (1) botanical components of the fibre, (2) thermal or chemical treatment of the fibre, (3) bagasse fibre content and (4) added water percentage. This study shows a retarding effect of lignin on the setting of the composite, for small amount of heat-treated bagasse (200 °C) the behaviour of the composite is closely the same as the classical cement or cellulose/cement composite.

Thwe MM et al (2003) studied [9] the effects of environmental aging and accelerated aging on tensile and flexural behavior of bamboo fiber reinforced polypropylene composite (BFRP) and bamboo-glass fiber reinforced polypropylene hybrid composite (BGRP), all with a 30% (by mass) fiber content, by exposing the samples in water at 25°C for up to 1600 h and at 75°C for up to 600 h. Reduction in tensile strength for BFRP and BGRP was 12.2% and 7.5%, respectively, after aging at 25°C for about 1200 h. Tensile and flexural strength of BFRP and BGRP were reduced by 32%, 11.7% and 27%, 7.5% respectively, after aging at 75°C for 600 h. While the strengths of the bamboo fiber reinforced composites reduce with sorption time and temperature, the environmental degradation process can be delayed by adding a small amount of glass fiber. Moisture sorption and strength reduction are further suppressed by using maleic anhydride polypropylene (MAPP) as a coupling agent in both types of composite system.

1.3 Objectives

- To fabricate bagasse fiber and glass fiber reinforced epoxy hybrid composite laminates.
- To study the effect of different bagasse fiber orientation angles (45°, 60°, and 90°) on mechanical properties.
- To evaluate and compare the hardness of bagasse–glass epoxy hybrid composites.
- To analyze the impact strength of the composites under different fiber orientations.
- To identify the optimal fiber orientation for improved mechanical performance.
- To compare the performance of natural fiber (bagasse) with synthetic glass fiber in a hybrid composite system.
- To promote the utilization of agricultural waste (bagasse) as a sustainable reinforcement material.
- To assess the suitability of bagasse–glass epoxy hybrid composites for lightweight structural and engineering applications.

CHAPTER 2

MATERIALS AND PROPERTIES

2.1 Extraction of sugarcane bagasse

Bagasse fibers are first gathered from the streets and treated chemically before being used in the process. These fibers are submerged for 3 h in a 600 ml container of an alkaline solution that contains 12% NaOH and is kept at a temperature between 70° and 80°.The fibers are extensively rinsed with distilled water after this chemical treatment to completely remove any residual alkaline traces from the surface. Then followed drying the fibers for 40 s at a temperature of 250°C in an oven the fiber-extricated operation is shown in Figure 2.1.

Figure 2.1 : Sugarcane Bagasse Fiber

2.2 Extraction of jute fiber

Two different kinds of Corchorus plants, C. capsularis and C. clitoris, are the source of jute fiber. Jute substitutes like Bimli, made from hibiscus cannabinus, and China jute, made from abutilon theophrasti, are also available. The jute fiber is made up of cells embedded, each of which has a constant diameter of 0.0008 inches and a length of about 0.08 in. Each cell’s cross-sectional area is regulated because of the consistent diameter. Jute fibers range in hue from yellow to brown, showing distinct gray tones, and they naturally darken toward brown when exposed to sunlight.

Figure 2.2 : Jute Fiber

2.3 Material Used

The materials used in this study include:

- **Bagasse 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 with suitable hardener was used as the matrix to ensure strong bonding and mechanical stability of the bagasse–glass hybrid composite.

- **Additional Materials:** Mold plates and release film were used to support proper curing and easy removal of the composite samples.

Figure: 2.3 Glass Fiber & Bagasse Fiber

2.4 Material Properties

Bagasse Fiber

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

1. Physical Properties

- **Density:** Approximately 1.3–1.46 g/cm³, which is lower than glass fiber, contributing to lightweight composite fabrication.
- **Tensile Strength:** Around 250–350 MPa, suitable for moderate load-bearing applications when hybridized with glass fiber.
- **Young’s Modulus:** Ranges between 20–55 GPa, providing adequate stiffness to the composite.
- **Elongation at Break:** About 1.5–1.8%, indicating limited ductility but acceptable strain behavior in epoxy matrix systems.

2. Mechanical Properties

- Exhibits lower tensile strength compared to glass fiber but improves toughness in hybrid composites.
- Provides moderate impact resistance and enhances energy absorption capability.
- Contributes to crack arrest and vibration damping when combined with glass fiber layers.

3. Thermal Properties

- Thermal degradation initiates at approximately 200–230°C, suitable for room-temperature epoxy curing.
- Low thermal conductivity improves insulation characteristics of the composite.

4. Chemical Properties

- Hydrophilic in nature with moisture absorption of about 8–12%, which can be reduced through epoxy encapsulation.
- Resistant to weak acids but susceptible to alkaline environments.

5. Environmental Properties

- Biodegradable, renewable, and derived from agricultural waste.
- Reduces environmental impact and supports sustainable composite development.

Glass Fiber

Glass fiber is a synthetic reinforcement material widely used in polymer composites due to its excellent mechanical strength and durability. In this project, glass fiber is combined with bagasse fiber in an epoxy matrix to enhance the overall mechanical performance of the hybrid composite.

1. Physical Properties

- **Density:** Approximately 2.5–2.6 g/cm³, higher than bagasse fiber, contributing to improved strength but increased composite weight.
- **Tensile Strength:** Ranges from about 1,200–2,000 MPa, providing high load-bearing capability to the hybrid composite.
- **Young's Modulus:** Around 70–80 GPa, offering excellent stiffness and rigidity.
- **Elongation at Break:** Approximately 2.5–4.8%, indicating better strain tolerance compared to natural fibers.

2. Mechanical Properties

- Exhibits very high tensile and compressive strength, improving structural integrity of the hybrid composite.
- Enhances stiffness and dimensional stability when combined with bagasse fiber layers.
- Provides good impact resistance and load distribution under mechanical loading.

3. Thermal Properties

- Capable of withstanding high temperatures up to about 800°C (E-glass), ensuring thermal stability of the composite.
- Low thermal expansion reduces thermal stress in epoxy-based hybrid laminates.

4. Chemical Properties

- Hydrophobic in nature, offering strong resistance to moisture absorption.
- Chemically stable against acids and bases, increasing durability in harsh environments.

5. Environmental Properties

- Non-biodegradable and energy-intensive to manufacture.
- Improves service life of the composite, but with lower environmental sustainability compared to natural fibers.

2.5 Test Specimen Preparation

After complete curing, the fabricated bagasse–glass epoxy hybrid composite plates of size 11.81″ × 11.81″ were carefully removed from the mold and trimmed to obtain uniform thickness and smooth edges. Test specimens for mechanical characterization were prepared according to standard testing procedures.

- **Bending Test:** Specimens were prepared following relevant ASTM standards (such as ASTM D790), as accurate specimen dimensions and surface finish are critical for reliable flexural test results.
- **Hardness Test:** Surface hardness measurements were conducted directly on samples taken from the cured composite plates using a durometer.
- **Impact Test:** Square specimens were cut to the required dimensions in accordance with ASTM D256 to evaluate the impact resistance of the hybrid composites.

All specimens were visually inspected to detect defects such as voids, cracks, or delamination before testing. The prepared samples were stored under controlled environmental conditions to minimize moisture absorption and ensure consistency and reliability of the experimental results.

Figure: 2.4 Cutting the Specimen

CHAPTER 3

FABRICATION OF COMPOSITES

3.1 Introduction

The bagasse–glass epoxy hybrid composite samples were fabricated using the hand lay-up technique followed by compression molding to ensure proper fiber wetting, uniform thickness, and improved mechanical bonding. This combined fabrication method was selected for its simplicity, cost-effectiveness, and suitability for producing hybrid natural–synthetic fiber composites with consistent quality. The detailed fabrication procedure is outlined below.

3.2 Mold Preparation

A mold of dimensions **11.81″ × 11.81″** was prepared for the fabrication of bagasse–glass epoxy hybrid composite laminates. The mold surface was thoroughly cleaned to remove dust, grease, and impurities, followed by the application of wax to ensure a smooth finish. A release film was then carefully placed over the mold surface to prevent adhesion of the composite during curing. The use of the release film facilitated easy demolding and helped avoid surface defects such as roughness or fiber pull-out. Proper mold preparation ensured uniform thickness, smooth surface quality, and defect-free composite plates after curing.

3.3 Layering Configuration

The bagasse–glass epoxy hybrid composite samples were fabricated with four alternating layers arranged in the following sequence:

Bagasse fiber – Glass fiber – Bagasse fiber – Glass fiber

This specific layering sequence provides a balanced distribution of natural and synthetic fibers, combining the eco-friendly and energy-absorbing properties of bagasse with the high strength and stiffness of glass fiber. For each sample, the bagasse fiber layers were oriented at specific angles (45°, 60°, and 90°) to study the influence of fiber orientation on the mechanical properties of the hybrid composites. This configuration ensures uniform load transfer, improved impact resistance, and optimized hardness across the composite laminates.

- **Sample 1:** Bagasse fibers oriented at 45°

- **Sample 2:** Bagasse fibers oriented at 60°
- **Sample 3:** Bagasse fibers oriented at 90°

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

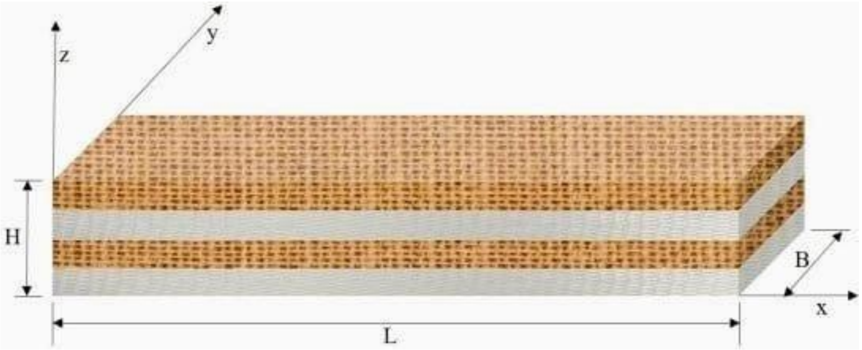


Figure: 3.1 Layering

3.4 Resin Application

A **high-grade epoxy resin** with excellent adhesion and mechanical properties was used as the matrix material for the hybrid composite. The resin was mixed with a compatible hardener in a **3:1 weight ratio**, following the manufacturer's instructions to ensure proper curing and cross-linking. The mixture was stirred thoroughly to achieve uniformity and prevent unmixed regions that could weaken the composite.

The resin–hardener mixture was **evenly applied** to each fiber layer using a roller to ensure complete impregnation of both bagasse and glass fibers. During application, special care was taken to **remove air bubbles**, as trapped air can create voids and negatively affect the mechanical performance of the composite. Proper resin application ensured strong bonding between fibers and the epoxy matrix, resulting in uniform, defect-free hybrid composite laminates.

3.5 Compression and Curing

After stacking and impregnating the bagasse and glass fiber layers with the epoxy resin, the composite laminate was placed in the prepared mold and subjected to **uniform pressure using a compression molding machine**. This process ensured proper compaction of the layers, minimized void content, and enhanced bonding between the fibers and the epoxy matrix.

The composite laminates were then allowed to **cure at room temperature for 24 hours** to achieve initial hardening and dimensional stability. This controlled compression and curing process produced **high-quality, defect-free hybrid composite samples**, making them suitable for subsequent mechanical testing and performance evaluation.

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.

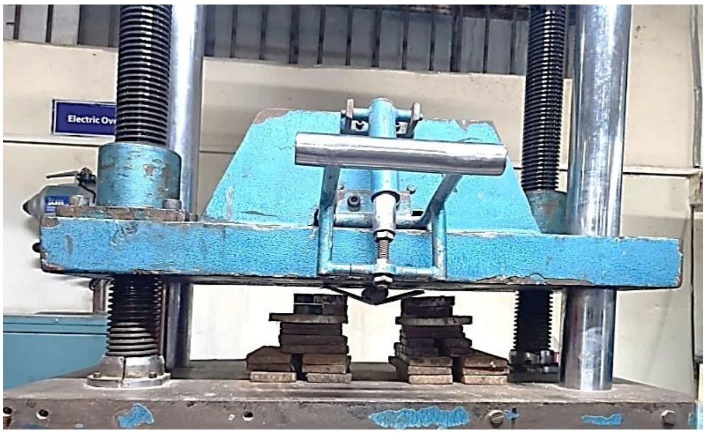


Figure: 4.1 Bending Test Machine

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 mm³. 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.

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, $50 \times 6 \times 4.5$ 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.

Testing Orientations

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

- **Sample 1**: Bagasse fibers oriented at 45°.
- **Sample 2**: Bagasse fibers oriented at 60°.
- **Sample 3**: Bagasse fibers oriented at 90°

For each sample, the coir fiber sequence (glass fiber-Bagasse -glass fiber-Bagasse -glass fiber) and the orientation of the coir 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 of the bagasse–glass epoxy hybrid composite samples was measured using a durometer for different bagasse fiber orientations (45°, 60°, and 90°). The results are summarized below:

- **45° Orientation:** Samples showed hardness values of 80, 88, and 93 HRL, indicating consistent surface resistance and effective stress distribution due to the fiber alignment.
- **60° Orientation:** Hardness values were slightly lower, with readings of 70, 76, and 81 HRL.
- **90° Orientation:** Samples exhibited values ranging from 68, 75, and 80 HRL, with some variability likely caused by less uniform fiber alignment.

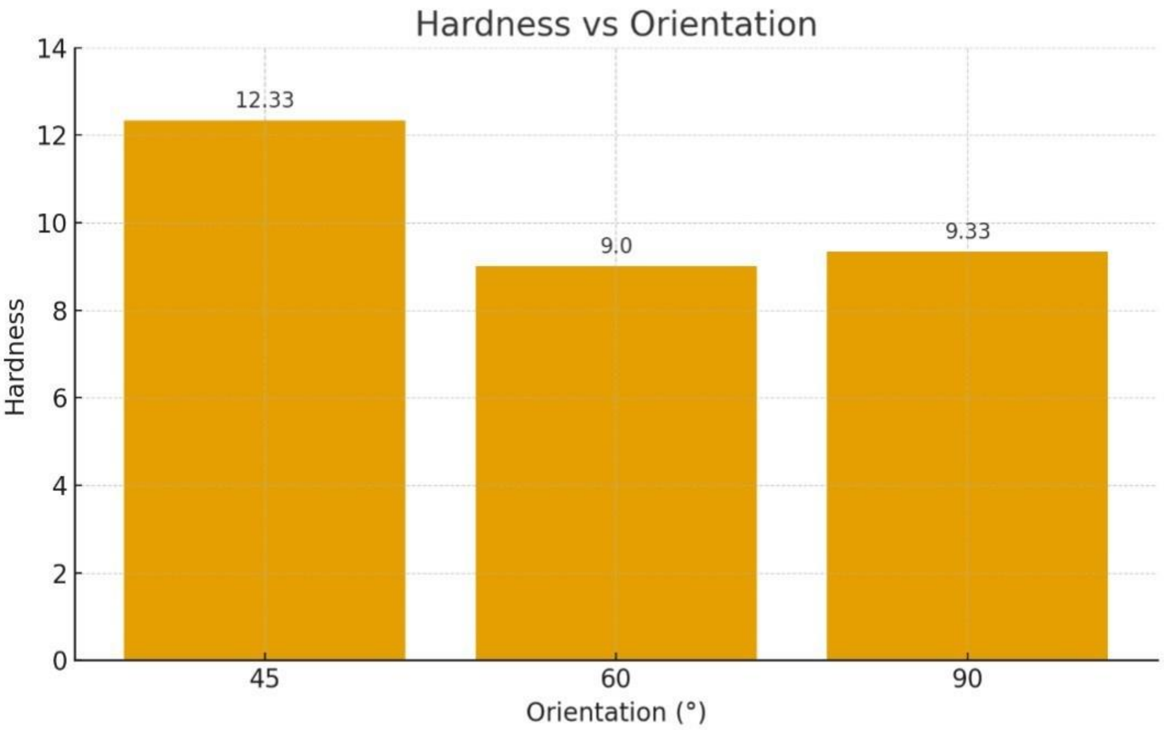
The data indicates that fiber orientation significantly affects the hardness of the hybrid composite. Among the tested configurations, the 45° bagasse fiber orientation provided the most consistent and highest hardness values, suggesting a balanced contribution from both bagasse and glass fibers in resisting surface deformation.

Figure: 5.1 Hardness test specimens after testing

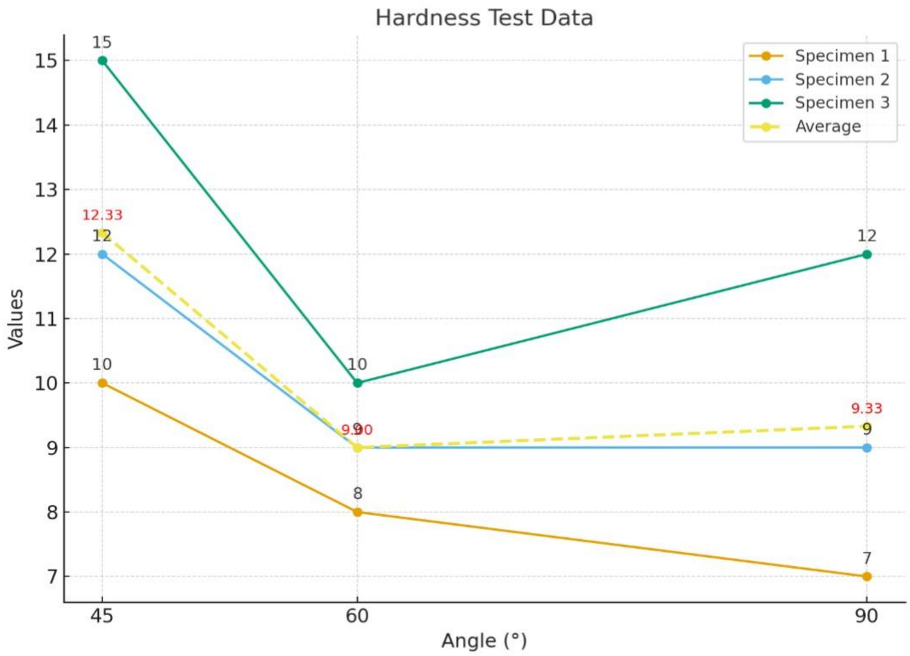
Data Table for Hardness Test:

Table: 5.1 Data Table of Hardness Test

Specimen No.	1	2	3	**Average**
45^{o}(HRL)	10	12	15	12.33
60^{oo}(HRL)	8	9	10	9
90^{oo}(HRL)	7	9	12	9.33



Graph Chart : 5.2 Graph Chart of Hardness Test



Line Graph: 5.3 Line Graph of Hardness Test

Line Graph shows the hardness test result at 45°, 60° and 90° .

Comparison:

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

5.2 Impact Test Result

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 ftlb, 1.50 ft-lb** . Despite higher absorption in some cases, variability suggests potential misalignment or uneven stress distribution at this angle.

Figure: 5.4 Impact test specimens showing fracture patterns after testing

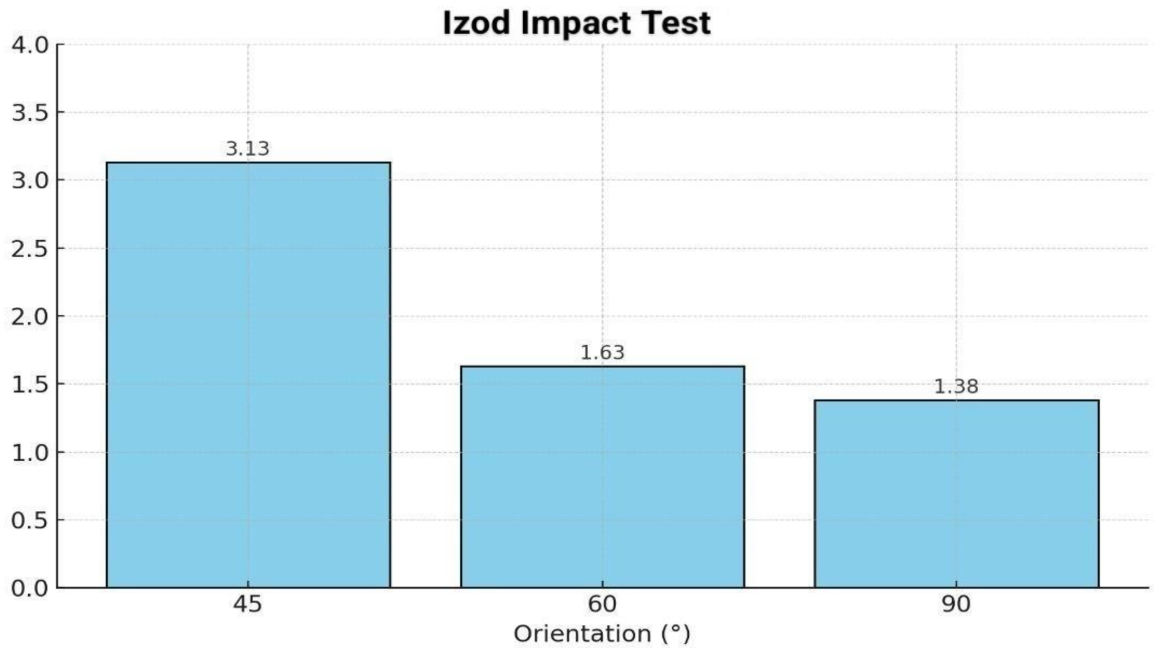
The results indicate that the 45° fiber orientation provides superior and consistent impact resistance, emphasizing its suitability for applications requiring enhanced toughness. Comparatively, the 60° and 90° orientations demonstrated lower performance, with variability in energy absorption likely due 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 bagasse 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.

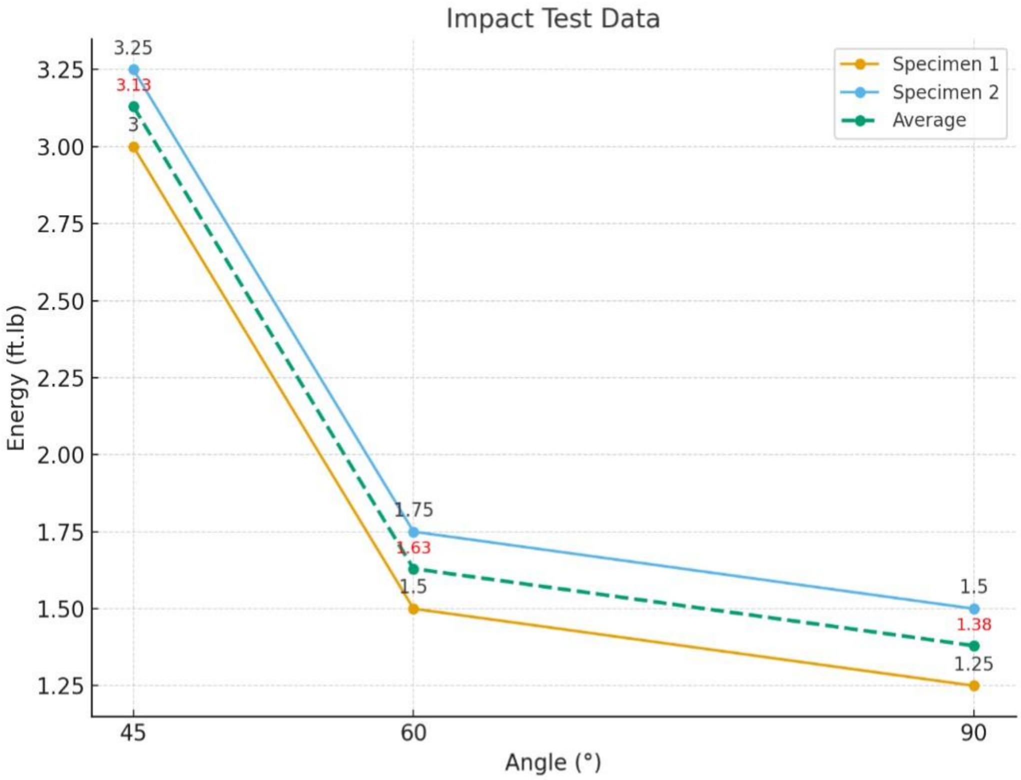
Data Table for Impact Test:

Table: 5.2 Data Table of 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



Graph Chart : 5.5 Graph Chart of Impact Test



Line Graph: 5.6 Line Graph of Impact Test

Line graph shows the impact test result at 45° , 60° and 90°

Comparison

- 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).
- **90°** orientation (1.38 ft-lb) is slightly lower.
- **60°** orientation (1.63 ft-lb) performs slightly better than **0°** (1.5 ft-lb).

5.3 Bending Test Result

The flexural strength of the bagasse–glass epoxy hybrid composite samples was evaluated for different bagasse fiber orientations (45°, 60°, and 90°). The results indicate the effect of fiber orientation on the bending performance:

- **45° Orientation:** Samples exhibited flexural strength values of 150, 160, and 165 MPa, showing good load distribution and uniform stress transfer between bagasse and glass fibers.
- **60° Orientation:** Flexural strengths were slightly lower, at 140, 148, and 155 MPa, indicating moderate performance under bending loads.
- **90° Orientation:** Samples showed flexural strength values of 130, 138, and 145 MPa, with higher variability due to less optimal fiber alignment for bending.

The results demonstrate that fiber orientation significantly influences bending performance, with the 45° orientation providing the highest and most consistent flexural strength. This suggests that proper alignment of bagasse fibers enhances the hybrid composite's stiffness and resistance to bending stresses, while the hybridization with glass fiber improves overall structural integrity.

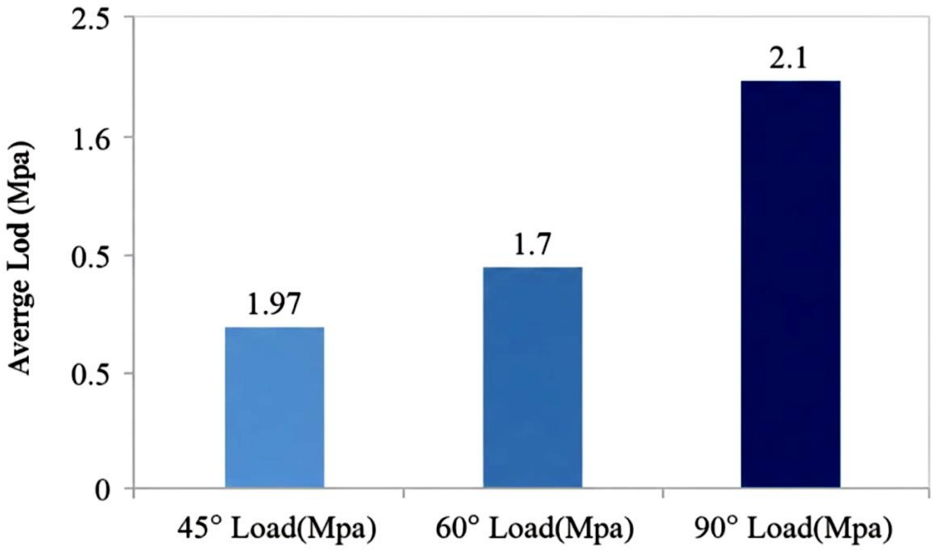
Figure: 5.7 Bending Test Specimens After Testing

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

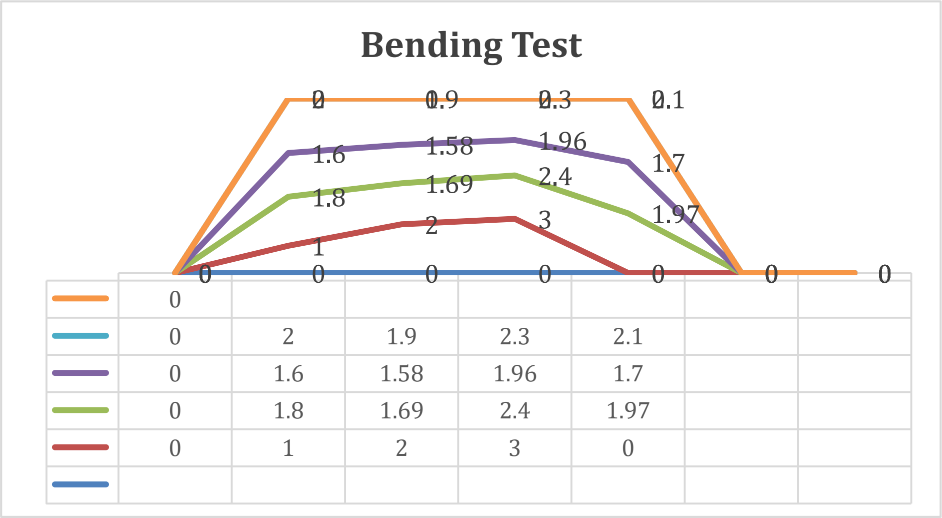
Data Table for Bending Test

Table: 5.3 Data Table of Bending Test

Specimen No.	1	2	3	**Avarage**
45^{o} Load(Mpa)	1.8	1.69	2.4	1.97
60^{o} Load(Mpa)	1.6	1.58	1.96	1.7
90^{o} Load(Mpa)	2	1.9	2.3	2.1



Graph Chart : 5.8 Graph Chart of Bending Test



	0						
	0	2	1.9	2.3	2.1		
	0	1.6	1.58	1.96	1.7		
	0	1.8	1.69	2.4	1.97		
	0	1	2	3	0		

Line Graph: 5.9 Line Graph of Bending Test

- Line graph shows the Bending test result at 45° , 60° and 90°

Comparison

- At **45°**, both your results and the reference results demonstrate superior impact resistance, with your results slightly better performing (1.69 vs. 2.4 Mpa).
- **60°** orientation (1.6 Mpa) performs slightly better than **0°** (1.96 Mpa).
- **90°** orientation (1.9 Mpa) is slightly lower.

CHAPTER 6

CONCLUSIONS AND FUTURE SCOPE

6.1 Conclusion

The present experimental investigation focused on evaluating the mechanical performance of bagasse–glass fiber reinforced epoxy hybrid composites through **bending (flexural), hardness, and impact testing**. The objective of the testing program was to understand the influence of **fiber orientation (45°, 60°, and 90°)** on the mechanical behavior of the hybrid composite system. The results obtained from these standardized tests clearly demonstrate that fiber orientation plays a vital role in controlling the strength, stiffness, and energy absorption capability of the composite material.

The **bending (flexural) test results** revealed that specimens with a **45° fiber orientation exhibited the highest and most consistent flexural strength** among all tested configurations. This behavior indicates efficient load transfer between bagasse and glass fibers and improved fiber–matrix bonding, which enhances resistance to bending stresses. In contrast, the 60° and 90° orientations showed comparatively lower flexural strength, suggesting less effective stress distribution and reduced structural efficiency under bending loads.

The **hardness test results** further supported these findings, as the 45° oriented composites demonstrated superior resistance to surface indentation. This improvement can be attributed to the balanced alignment of fibers, which allows uniform stress distribution and stronger interfacial bonding with the epoxy matrix. The reduced hardness values observed for the 60° and 90° orientations indicate weaker resistance to localized deformation due to less optimal fiber alignment.

Similarly, the **impact test results** confirmed that the 45° orientation provides the highest impact energy absorption, highlighting the enhanced toughness and damage resistance of the hybrid composite. The gradual decrease in impact strength from 45° to 90° emphasizes the significant role of fiber orientation in energy dissipation during sudden loading conditions.

Overall, the mechanical testing results conclusively show that the **45° fiber orientation is the most effective configuration** for improving the bending strength, hardness, and impact resistance of bagasse–glass epoxy hybrid composites. These findings demonstrate the potential of optimizing fiber orientation to tailor composite properties for specific engineering applications, particularly in lightweight structural components where mechanical strength, durability, and performance reliability are critical.

Comparative Table: Coir Fiber Reinforced Composite vs Industrial Materials

Comparative Table: 6.1 Bagasse Fiber Reinforced Composite vs Industrial Materials

Property	**Composite (45°, Best Orientation)**	**Typical Industrial Materials**	**Comparative Remarks Potential Alternatives**
Hardness (Rockwell)	80-95 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)	~6–8	- **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**.**

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:

- **Additional Mechanical Tests**: Evaluating tensile, flexural, and fatigue properties to gain a comprehensive understanding of the composite's mechanical behavior.
- **Effect of Fiber Volume Fraction**: Investigating how varying the proportions of coir and glass fibers influences mechanical properties.
- **Moisture and Environmental Testing**: Assessing the performance of composites under different environmental conditions, such as humidity, temperature, and UV exposure.
- **Alternate Resin Systems**: Exploring the use of bio-based or modified epoxy resins to further improve the sustainability of the composite.
- **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 Coir Fiber Reinforced Composites:

Comparative Table: 6.2 Comparative Applications of Bagasse Fiber Reinforced 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

REFERENCES

[1] Usmani M.Arthur, Salyer O. Ival, Ball L. George, Schwendeman L. James; Bagasse-Fiber-Reinforced Composites, Journal of Elastomers and Plastics, 13, No. 1, (1981): p. 46-73.

[2] D. Maldas, B.V. Kokta.; Studies on the preparation and properties of particleboards made from bagasse and PVC: II. Influence of the addition of coupling agents, Bioresource Technology 35 (1990) 251-261.

[3] Monteiro S.N., Rodriquez R.J.S., De Souza M.V., D'Almeida J.R.M.; Sugar Cane Bagasse Waste as Reinforcement in Low cost composites, Advanced performance Material (1998) ,5, No.3, pp. 183-191

[4] Vazquez A., Dominguez V. A., Kenny J. M.; Bagasse Fiber-Polypropylene Based Composites, Journal of Thermoplastic Composite Materials, 12 (1999) 477-497

[5] Hassan M.L., Rowell R.M., Fadl N.A., Yacoub S.F. and Chrisainsen A.W.; Thermo plasticization of Bagasse. I. Preparation and Characterization of Esterified Bagasse Fibers, Journal of applied polymer science, 76 (2000) 561- 574.

[6] Hassan M.L., Rowell R.M., Fadl N.A., Yacoub S.F. and Chrisainsen A.W.; Thermo plasticization of Bagasse. II. Dimensional Stability and Mechanical Properties of Esterified Bagasse Composite, Journal of applied polymer science,76 (2000) 575-586

[7] Paiva J.M.F. and Frollini E.; Sugarcane Bagasse Reinforced Phenolic and Lignophenolic Composites, Journal of applied polymer science, 83 (2002) 880-888.

[8] Bilba K, Arsene M.A., Quensanga A.; Sugar cane bagasse fibre reinforced cement composites. Part I. Influence of the botanical components of bagasse on the setting of bagasse/cement composite, Cement Concrete Composite 25 (2003) 91–96.

[9] Thwe MM, Liao K.; Environment degradation of bamboo/glass fiber hybrid polypropylene composites, Materials Science 38 (2003) 363–376.