International Journal of Engineering Research and Science & Technology

www.ijerst.org

ISSN : 2319-5991

Vol. 22 No. 2(2) (2026)



ijerst.editor@gmail.com

editor@ijerst.com

ISSN 2319-5991 www.ijerst.com
© 2026 IJERST. All Rights Reserved
Peer Reviewed, Referred & Indexed Journal

Research Paper

EXPERIMENTAL ANALYSIS OF BANANA FIBER REINFORCED COMPOSITES FOR LIGHT WEIGHT APPLICATIONS

[1 2 3 4 5] B.Tech Students, Department of Mechanical Engineering, RK College Of Engineering, Kethanakonda (V), Vijayawada, Amaravati-521456.

[6]Assistant Professor, Department of Mechanical Engineering, RK College Of Engineering, Kethanakonda (V), Vijayawada, Amaravati-521456.

[7]Associate Professor, Head of the Department, Department of Mechanical Engineering, RK College Of Engineering, Kethanakonda (V), Vijayawada, Amaravati-521456.

[1]T.SAI LOKESH , [2]R.SAI KRISHNA , [3]SK. SHAMSHEER ALI , [4]P. KADHARBABU, [5]K. MAHIMAKAR , [6]CH.D.V. NOOKA RAJU, [7]SRIRAMA MURTHY VUYYURU

ABSTRACT

The growing demand for sustainable and environmentally friendly materials has led to increased interest in natural fiber reinforced polymer composites as viable alternatives to conventional synthetic composites. These materials offer advantages such as low density, cost-effectiveness, biodegradability, and satisfactory mechanical performance. In this study, composite specimens were fabricated using epoxy resin as the matrix and natural fibers including banana, coir, and bamboo as reinforcements, along with 5% rice husk as a filler material to enhance performance.

Different hybrid combinations of fibers were developed to investigate their influence on mechanical properties. Standardized specimens were prepared according to ASTM specifications and subjected to tensile, flexural, impact, and hardness tests to evaluate their structural behavior. The experimental results were systematically compared across seven different composite configurations to identify the optimal material combination.

Furthermore, a lightweight protective helmet model was designed using CATIA and analyzed through finite element analysis in ANSYS to assess the real-time applicability of the developed composite material under practical loading conditions. The analysis focused on stress distribution, deformation, and overall structural integrity.

The findings demonstrate that hybrid natural fiber composites reinforced with rice husk exhibit improved mechanical characteristics, making them suitable for lightweight structural and protective applications. This study highlights the potential of eco-friendly composite materials as sustainable alternatives in engineering and industrial sectors.

Keywords: Natural Fiber Composites, Banana Fiber, Coir Fiber, Bamboo Fiber, Rice Husk, Mechanical Properties, CATIA, ANSYS, Hybrid Composites

1 INTRODUCTION

Natural fibers, derived from plant or animal sources, are inherently polymeric in their chemical makeup. In contrast, mineral-based natural fibers exhibit properties similar to crystalline ceramics. One key characteristic of natural fibers is their heterogeneous composition, comprising a mix of chemical and physical elements. Synthetic fibers, on the other hand, can be grouped into categories such as polymers, metals, ceramics, and glass. A specialized subgroup within synthetic fibers is known as whiskers—short, monocrystalline structures known for their exceptional strength, approaching theoretical maxima due to the lack of imperfections like dislocations and grain boundaries. Typically produced through vapor-phase growth, whiskers have diameters in the micrometer range and lengths extending several millimeters, resulting in aspect ratios from 50 to as high as 10,000. However, one limitation of whiskers is the inconsistency in their dimensions and mechanical properties. In recent years, European research has focused heavily on natural fibers for advanced composite applications. The automotive industry, in particular, has begun

incorporating natural fibers such as flax, hemp, and sisal into composites based on polyester or polypropylene. The primary drivers for this shift include cost savings, weight reduction, and eco-conscious branding that highlights the use of renewable materials, rather than strictly performance-based considerations. Currently, these natural fiber composites are primarily utilized in non-structural components like door panels and rear shelves. Extensive studies have been carried out on the behavior of composite materials during machining operations, particularly drilling. Drilling remains a standard procedure in secondary processing of fiber-reinforced composites, as it is essential for assembling structures. However, the combination of tough, abrasive fibers with a soft matrix presents challenges in selecting optimal cutting conditions. Experimental data reveals that during machining, composites show 3 minimal plastic deformation, and their fracture resistance is significantly lower—up to 100 times less—than that of common steels. In industries such as aerospace, twist drills are commonly employed to create rivet and bolt holes in structural assemblies. A major concern during drilling is delamination, which occurs due to thrust forces and can compromise material integrity. This issue has spurred extensive research aimed at understanding and minimizing its effects.

ADVANTAGES OF NATURAL FIBERS

- They have fire-resistant properties.
- When burned, natural fibers do not emit toxic gases.
- Natural fibers are cost-effective and affordable.
- These fibers absorb sweat and moisture, making clothing comfortable during hot weather.
- Natural fibers are skin-friendly and biodegradable.

2 LITERATURE REVIEW

Liu et al. (2024) highlighted bamboo fibers as promising reinforcements in composite materials, owing to their high strength-to-weight ratio, affordability, and renewable nature. Numerous studies have examined the mechanical behavior of bamboo fibers and their composites. For instance, investigations into bamboo fiber-reinforced polymer composites revealed that incorporating bamboo fibers enhances mechanical properties, particularly stiffness and strength. Bamboo fibers are noted for their high tensile strength, rigidity, and good dimensional stability. Some research even compared bamboo fibers to glass fibers, finding similar tensile strength. However, issues such as moisture absorption and vulnerability to biological degradation remain challenges. Wang et al. (2023) examined the effects of alkali treatment on bamboo fiberreinforced polypropylene composites, reporting improvements in tensile strength and modulus attributed to better fiber-matrix adhesion. Alongside bamboo, natural fibers like coir (from coconut husks) and banana fibers have recently attracted attention as sustainable, cost-effective, lightweight, and biodegradable alternatives to synthetic reinforcements like glass or carbon fibers. This review summarizes existing research on the testing and performance of bamboo, coir, and banana fiber composites. John et al. (2022) discussed coir fibers, which exhibit excellent tensile strength, abrasion resistance, and biodegradability, making them suitable for composite reinforcement. Studies investigating coir fiber composites, such as evaluations of tensile, flexural, and impact properties in coir fiber-reinforced epoxy composites, demonstrated that coir fibers improve toughness and impact resistance. Sreekala et al. (2021) further explored the role of fiber treatments and composite processing techniques, finding that surface modifications like alkali and silane treatments enhance the tensile strength and modulus of coir 14 fiber-reinforced polypropylene composites. Jayamani et al. (2020) focused on banana fibers, obtained from banana plant pseudo stems, which possess high tensile strength, stiffness, and thermal stability—qualities desirable for composite reinforcement. Research on banana fiber-reinforced polyester composites showed significant improvements in tensile and flexural properties with increased fiber content. Sathish Kumar et al. (2015) investigated the effects of fiber orientation, matrix properties, and processing parameters on banana fiber composites. His work revealed that composites with aligned fibers outperformed those with randomly oriented fibers in tensile and flexural strength. Overall, bamboo, coir, and banana fibers present valuable opportunities as reinforcements in composites due to their distinctive properties and sustainability. Existing research has largely focused on mechanical characterization, performance evaluation, and processing optimization of these natural fiber composites. Future studies should

explore advanced processing methods, fiber-matrix interface enhancements, and broaden applications across sectors such as automotive, construction, and aerospace.

3 MATERIAL USED

BANANA FIBER

Banana natural fiber, also referred to as banana fiber or abaca fiber, is sourced from the pseudostems of banana plants (*Musa* species). Unlike the edible fruit that grows from the plant's main stem, the fiber is extracted from the outer layers of the pseudostem.

The extraction process involves several steps. Initially, the outer sheaths of the pseudostems are harvested and peeled back to reveal the fibrous material. These fibers are then separated either manually or using mechanical methods and thoroughly cleaned to remove impurities. Once cleaned, the fibers are dried to enhance their strength and overall durability.



FIGURE 1 BANANA FIBER

Banana fibers are known for their natural sheen, excellent tensile strength, and flexibility. Typically light golden or beige in color, they possess a fine texture and are composed primarily of cellulose and lignin, which contribute to their mechanical robustness.

Traditionally, banana fiber has been utilized in regions where banana cultivation is common. Its applications include textiles such as ropes, mats, and fabrics, as well as uses in papermaking, handicrafts, and eco-friendly packaging solutions.



FIGURE 2 MECHANICAL PROCESS OF BANANA FIBER EXTRACTING

A key advantage of banana fiber is its environmentally friendly nature. Banana plants grow quickly and need little water or chemical treatment, making the fiber a renewable and sustainable resource. Moreover, harvesting banana fiber offers farmers an extra income stream and promotes the efficient use of agricultural by-products. Overall, banana fiber is a versatile and eco-conscious material widely used in industries like textiles, handicrafts, and packaging. Its sustainable qualities and distinctive properties position it as a promising alternative to synthetic fibers in many applications.



FIGURE 3 APPLICATIONS OF BANANA FIBERS

MECHANICAL PROPERTIES OF BANANA FIBER

Similar to bamboo fiber, banana fiber is a natural material exhibiting various mechanical properties. However, these properties can differ depending on factors such as the banana plant variety, processing techniques, and environmental influences. Below

are approximate values for some key mechanical properties of banana fiber:

Fiber	Tensile Strength (MPa)	Young's Modulus (GPa)	Elongation at Break (%)	Key Characteristics
Banana	529 - 914	27 - 38	1 - 3	High strength, good stiffness, low flexibility
Bamboo	1200 - 3000	10 - 45	1 - 5	Extremely high strength, high stiffness, moderate flexibility
Coir	200 - 400	4 - 8	15 - 40	Moderate strength, low stiffness, high flexibility

Table 1MECHANICAL PROPERTIES OF FIBERS

RICE HUSK

Rice husk, a widely available agricultural byproduct, has attracted interest as a natural fiber in numerous applications owing to its renewable and biodegradable properties.



FIGURE 4 RICE HUSK

PROPERTIES OF RICE HUSK

Origin: Rice husk is the protective outer covering of rice grains, removed during the milling process. It is a fibrous substance mainly composed of cellulose, hemicellulose, lignin, and silica.

Availability: Generated in substantial volumes worldwide as a byproduct of rice milling, rice husk is especially plentiful in rice-producing regions, making it a valuable resource for various industrial uses.

Sustainability: Being a natural agricultural residue, rice husk is both renewable and eco-friendly. Its ability to decompose naturally makes it biodegradable, thereby minimizing environmental impact.

Physical Characteristics: The fibers of rice husk are lightweight with a hollow structure, which results in low density and good thermal insulation. They also exhibit moderate levels of tensile strength and rigidity.

Chemical Characteristics: Rich in silica, rice husk fibers possess natural resistance to microbial decay and moisture. However, the high silica content may pose challenges during processing and blending with specific polymers.

APPLICATIONS OF RICE HUSK

Rice husk fibers find application across a wide range of industries, including:

Construction and Building: Rice husk is used as a filler or reinforcing agent in composite materials for producing panels, boards, roofing sheets, and insulation products.

Automotive Industry: Composites containing rice husk are employed in interior automotive parts like dashboards, door panels, and seat backs to reduce overall weight and enhance environmental sustainability.

Packaging Sector: Rice husk fibers are integrated into biodegradable packaging items—such as trays, containers, and bags—helping to decrease dependence on non-renewable materials.

Horticulture and Gardening: Owing to its water-holding capacity and ability to enhance soil texture, rice husk serves as a valuable growing medium in horticultural applications.

EPOXY RESIN:

Epoxy resins are extensively utilized in fiber-reinforced composites owing to their strong adhesion, exceptional strength, and long-lasting durability. They exhibit excellent chemical

resistance and can be customized to suit a wide range of applications. These composites are frequently employed in industries such as aerospace, automotive, marine, and construction. Epoxy resin is a key member of the thermosetting resin family, which also includes polymers like unsaturated polyester resins, phenol-formaldehyde resins, and amino resins. Thermosetting polymers, when heated, undergo a curing process that creates a covalently cross-linked and thermally stable network, resulting in a rigid, infusible, and insoluble material. These polymers are typically amorphous and offer valuable properties such as high tensile strength and modulus, ease of processing, excellent thermal and chemical resistance, and dimensional stability.

The term 'epoxy resin' refers to both the uncured prepolymer and the final cured material. The prepolymer is characterized by the presence of a three-membered ring known as the epoxy, epoxide, oxirane, or ethoxyline group.



FIGURE 5 EPOXY RESIN

Property	Value
Viscosity (cP)	12,000 - 13,000
Density (g/cm3)	1.16
Tensile Strength (MPa)	73
Elongation (%)	4
Flexural Strength (MPa)	60
Heat Distortion Temperature (oC)	100

Table 2 PROPERTIES OF EPOXY RESIN

HARDENER

A hardener was employed as a binder during the fabrication process. It features low viscosity, cures at room temperature, and provides strong mechanical performance along with good resistance to both atmospheric and chemical degradation. One such hardener is HY951, also known as Aradur HY951, which is a low-viscosity, unfilled epoxy casting resin system. It cures effectively at ambient temperatures and allows for a high filler loading capacity. HY951 is recognized for its mechanical strength, chemical and weather resistance, and excellent electrical insulating properties.



FIGURE 6 EPOXY (LY 556) AND HARDENER (HY951)

DESIGN PROCEDURE IN CATIA:

Begin by opening the Sketcher Workbench and creating a point using the profile toolbar with dimensions of 50 x 50. The helmet design process in CATIA starts with a conceptual sketch in the Sketcher Workbench, where the basic 2D profile is drawn according to ergonomic measurements. This sketch is then transferred to the Part Design Workbench to develop a 3D solid model using features such as Pad, Shell, and Fillet. Following this, the Generative Shape Design Workbench is employed to refine the helmet's aerodynamic contours and smooth curves for improved aesthetics and airflow. The inner foam lining and ventilation holes are modeled separately and subsequently assembled in the Assembly Workbench to ensure correct fitting of all components. Finally, material properties are assigned to simulate realistic textures and densities, as illustrated in the figures below.

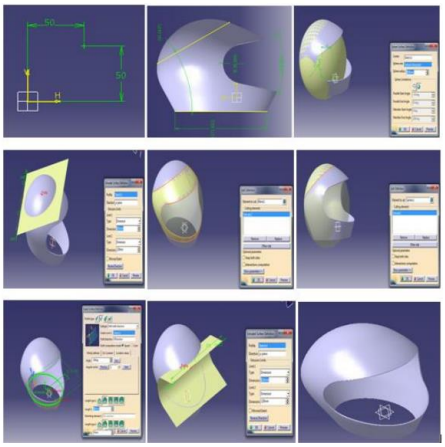


FIGURE 7 DESIGN IN CATIA

4 FABRICATION BY HAND LAYUP PROCESS AND SPECIMEN PREPARTION

HAND LAY UP PROCESS

The hand lay-up method is the most basic and cost-effective technique for processing composite materials. It requires minimal infrastructure and equipment, making it accessible and widely used. To evaluate the mechanical properties of fiber-resin composites, the standard testing procedure ASTM-D790M-86 is followed.

For fabrication, the mold is prepared using a smooth, transparent film. Double-sided tape is applied to the film according to the required dimensions to define the mold area. This setup serves as the base for laying the composite material.

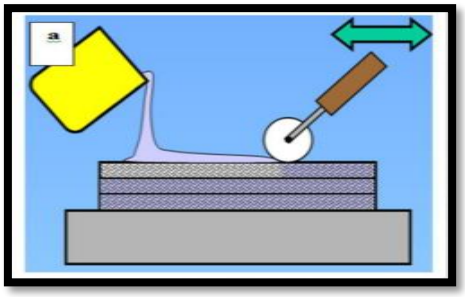


FIGURE 8 HAND LAYUP PROCESS

Reinforcement fibers, in the form of long strands, are cut according to the mold dimensions and laid onto the surface of a thin plastic sheet. The thermosetting polymer, in liquid form, is thoroughly mixed in the correct ratio with the recommended hardener (curing agent) and then poured over the clear plastic surface. Using a brush, the mixture is evenly spread across the surface.

A second layer of fiber is then placed over the applied resin, followed by another layer of the polymer. This assembly is covered with another thin plastic sheet. A squeezer is gently moved over the top sheet to remove any trapped air and ensure uniform contact.

The prepared mold is then left to cure at room temperature for 24 hours.

After curing, test specimens are cut from the fabricated sheets according to ASTM standards:

- For tensile testing: 165 mm in length, 12.5 mm in width, and 4 mm in thickness
- For flexural testing: 100 mm in length, 25 mm in width, and 4 mm in thickness
- For impact testing: 63.5 mm in length, 12.36 mm in width, and 6 mm in thickness

4SPECIMENS PREPARATION

Fabrication of Composite Laminates Using Natural Fibers and Rice Husk

Composite specimens were fabricated using different combinations of natural fibers — banana, coir, bamboo, and their hybrid forms — each reinforced with 5% rice husk by weight. The hand lay-up technique was employed for the fabrication process. For all samples, epoxy resin (LY556) was used as the matrix and mixed with 10 grams of hardener (HY951) per 100 grams of epoxy. A total of six fiber sheets, each weighing 300 GSM, were

used to achieve a uniform 4 mm thickness, suitable for tensile, impact, flexural, and hardness testing.

The composite laminates were fabricated using a hand lay-up technique under controlled room temperature conditions. Initially, natural fibers were uniformly cut into dimensions of 230 mm × 300 mm and arranged layer by layer. A matrix mixture was prepared by combining epoxy resin (LY556) with hardener (HY951), into which 5% rice husk particles were uniformly dispersed to enhance the filler properties. This resin mixture was then evenly applied between each fiber layer using a brush to ensure proper impregnation and bonding. The stacked laminates were compacted to remove air voids, covered with a plastic sheet, and allowed to cure at ambient conditions for 24 hours to achieve proper solidification.

A total of seven different composite configurations were prepared, each with a final thickness of 4 mm using six layers (300 GSM) of fibers. These include banana fiber reinforced composite, coir fiber reinforced composite, and bamboo fiber reinforced composite, each combined with 5% rice husk filler. In addition, hybrid composites such as banana–coir, bamboo–coir, and banana–bamboo were developed to study the combined effect of different natural fibers. Furthermore, a triple hybrid composite consisting of banana, bamboo, and coir fibers was also fabricated. All composites utilized the same epoxy matrix system (LY556 with HY951 hardener), ensuring consistency in processing conditions and enabling effective comparison of mechanical performance among different fiber combinations.



Figure 9 Complete Sequential Process For Fabrication (1) Spreading Of Epoxy Resin And Hardener Mixture (2) Brushing Resin (3) Taking Fiber Sheet (4) Roller Effect On Fibers (5) Adding Another Layer (6) Final Outcome Of Fiber.

5 MECHANICAL TESTINGS AND EXPERIMENTAL SETUPASTM STANDARDS OF TESTING COMPOSITES

The mechanical properties of the natural fiber composite (NFC) materials were evaluated through tensile, flexural, impact, and hardness tests in accordance with the respective ASTM standards: ASTM D638 for tensile testing, ASTM D790 for flexural testing, ASTM D256 for impact testing, and ASTM D2240 for hardness testing.

For the tensile test, specimens were fabricated with dimensions of 200 mm in length, 25 mm in width, and 0.5 mm in thickness. The test was performed using an electronic tensometer, where tensile stress was applied by pulling the specimen ends in opposite directions. All seven types of specimens were tested, with four samples evaluated for each variant, resulting in a total of 28 tensile tests. The average of the best three results from each group was used to assess the tensile performance of the material.

The flexural test followed a similar approach, using specimens with the same dimensions (200 mm × 25 mm × 0.5 mm). During testing, each specimen was subjected to a combination of tensile and compressive stresses. Again, seven samples per

variant were tested, and the top three average values were considered to determine the flexural strength.

For the impact test, specimens were prepared with dimensions of 55 mm in length, 13 mm in width, and 0.5 mm in thickness. For the hardness test, specimens measured 30 mm × 30 mm × 0.5 mm. These tests were conducted to further analyze the overall mechanical behavior and durability of the NFC materials.

TENSILE TEST ON NATURAL FIBERS SPECIEMENS

- A 2-ton limits electronic tensometeris a device used to measure the tensile strength of materials. It works by applying a force to a sample of the material and measuring the amount of force it can withstand before breaking.
- Tensile strength is the ability of a material to resist breaking under tension. It is an important property for many materials, such as metals, plastics, and fibers.
- Natural fibers are fibers that are derived from plants or animals. They are often used in textiles, ropes, and other applications where strength and flexibility are important.

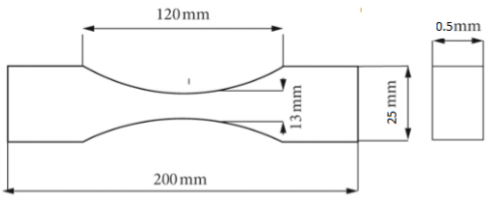


FIGURE 10 ASTM DIMENSIONS OF TENSILE SPECIMENS

There are various types of tensometers available, but they all operate based on the same fundamental principle. The test specimen is secured between two grips, and one grip is gradually pulled away from the other. This action applies a tensile force to the specimen, while the tensometer records the force required to cause failure. The choice of tensometer for testing natural fibers depends on the specific characteristics of the fibers. For instance, fibers with high strength require a tensometer with a greater capacity, whereas fibers with lower strength can be tested using a tensometer with a smaller capacity.



FIGURE 11 TENSOMETER

FLEXURAL TEST ON NATURAL FIBERS SPECIEMENS

A flexural test, commonly known as a bending test, is a mechanical method used to assess the flexural properties of materials. When applied to natural fibers, this test offers important insights into their behavior under bending stresses.

The main goal of a flexural test on natural fibers is to measure their bending strength, flexural modulus (modulus of elasticity in bending), and related characteristics. This data is crucial for understanding how natural fibers respond to bending forces, which is important for applications in textiles, composite manufacturing, paper production, and construction materials.

Typically, the flexural test involves placing the sample on two supports set a specific distance apart (the span). A bending force is then applied at the center of the sample using a loading device or a universal testing machine (UTM). The test parameters, including loading rate and conditions,

should follow established standards such as ASTM or ISO to ensure accurate and consistent results.

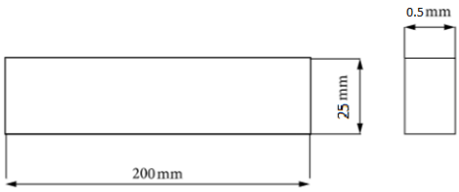


FIGURE 12 ASTM DIMENSIONS OF FLEXURAL SPECIMENS

During a flexural test, various parameters are recorded to evaluate the mechanical behavior of natural fibers. These include the maximum load the sample can withstand before breaking (flexural strength), the amount of deformation or displacement at different load levels, and the slope of the stress-strain curve within the elastic region (flexural modulus). These measurements help reveal the material's resistance to bending and its stiffness. Overall, performing flexural tests on natural fibers yields essential data for understanding their mechanical performance under bending stresses. This knowledge enables researchers, engineers, and manufacturers to design and develop enhanced materials and products for diverse applications.



FIGURE 13 TENSOMETER

EXPERIMENTAL SETUP SPECIFICATIONS

IMPACT TEST ON NATURAL FIBERS SPECIEMENS

Performing an impact test on natural fiber specimens according to ASTM D256 involves assessing the material's ability to withstand sudden shocks or impact forces. The procedure typically includes the following steps:

First, prepare the natural fiber specimens by cutting them to the dimensions specified in ASTM D256, ensuring they are free from defects or imperfections that could influence the results. Next, set up the impact testing device—usually a pendulum impact tester or equivalent—following the standard's guidelines. Calibrate the equipment to guarantee precise measurement of the impact energy.

Place the specimen in the designated position on the testing apparatus, then adjust the pendulum or striker to its starting point. Release the pendulum so it swings and strikes the specimen. Measure the energy absorbed by the specimen during the impact, which is calculated based on the pendulum's kinetic energy before and after striking.

To ensure reliability and accuracy, conduct the test on multiple specimens and use the average of the results for analysis.

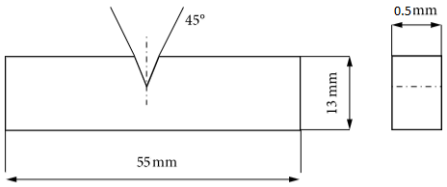


FIGURE 15 ASTM DIMENSIONS OF IMPACT SPECIMENS

Determine the impact strength or energy absorption of the natural fiber specimens using the data obtained from the test. Compare these results against specified standards or the performance of other materials to assess the effectiveness of the natural fibers. Examine any failure patterns observed during testing, such as cracking, fractures, or deformation. Compile a detailed test report that outlines the testing procedure, equipment utilized, results, and any

observations or deviations from the standard protocol. Be sure to include information on specimen dimensions, conditioning conditions, and the calculations employed to evaluate impact strength.



FIGURE 16 IMPACT TESTER EXPERIMENTAL SETUP SPECIFICATIONS

Analyze the test results with respect to the intended use of the natural fibers. Greater impact strength values suggest improved resistance to sudden forces, which can be beneficial for specific applications. Take into account factors that might affect impact performance, including fiber type, manufacturing processes, and environmental conditions. Adhering to ASTM D256 standards ensures a precise evaluation of the impact resistance of natural fiber specimens, offering essential insights for material selection, product development, and quality assurance.



FIGURE 17 IMPACT TESTER

HARDNESS TEST ON NATURAL FIBERS SPECIEMENS

Conducting a hardness test on natural fiber specimens following ASTM D785 involves measuring the material's resistance to indentation using a durometer. The process includes:

Preparing the specimens according to the dimensions specified in ASTM D785, which usually requires disc- or block-shaped samples. Ensure the specimens are free from surface defects or irregularities that might influence the results.

Set up the durometer or hardness tester as per ASTM D785 guidelines, including calibrating the device and confirming the testing surface is flat and smooth. Select the appropriate durometer type and scale based on the expected hardness range of the natural fiber specimens.

Condition the specimens under standard laboratory conditions—controlled temperature and humidity—for a set duration to reach moisture equilibrium. Place each conditioned specimen on a stable, flat surface.

Align the durometer probe perpendicular to the specimen's surface and apply the specified force to indent the sample. Record the indentation depth or the hardness value shown by the durometer.

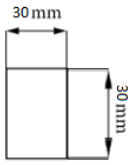


FIGURE 18 ASTM DIMENSIONS OF HARDNESS SPECIMENS

Conduct the hardness test on multiple specimens to obtain an average value and verify consistency. Calculate the hardness of the natural fiber samples based on the recorded measurements. Hardness is usually expressed in units such as durometer Shore hardness (e.g., Shore A or Shore D). Compare the results against specified standards or other materials to assess the performance of the natural fibers. Examine

any differences in hardness values across various specimens or production batches.

Prepare a detailed test report that includes the testing procedure, equipment used, results obtained, and any observations or deviations from the standard method. Be sure to document specimen dimensions, conditioning conditions, and the hardness values measured



FIGURE 19 HARDNESS TESTING MACHINE

Analyze the test results based on the intended use of the natural fibers. Higher hardness values reflect increased resistance to indentation, which may be advantageous for specific applications. Take into account factors that can affect hardness, including fiber type, density, and processing techniques. By adhering to ASTM D785 standards, you can reliably evaluate the hardness of natural fiber specimens, offering essential data for material selection, product development, and quality assurance.

6 RESULTS AND DISCUSSION

MECHANICAL CHARACTERISTICS OF COMPOSITES

The properties of Bamboo, Coir, Banana, Bamboo/Pineapple, Banana/Coir, Coir/Bamboo, and Bamboo/Coir/Banana hybrid epoxy composites, each reinforced with 5% rice husk, are presented in the table below. Each composite was tested individually, with details of their processing and the conducted tests provided in the previous chapter. The mechanical properties of synthetic fiber-reinforced composites largely depend on factors such as chemical and structural composition, fiber type, soil conditions, as well as the atmospheric conditions present during specimen fabrication..

S.NO	COMPOSITE	TENSILE TEST(MPa)		FLEXURAL TEST(MPa)		IMPACT TEST	HARDNESS
		LOAD(N)	ELONGATION(mm)	LOAD(N)	ELONGATION(mm)	(J)	NUMBER
1	PURE BAMBOO+5% RICE HUSK	1760	1.3	380	2.2	28.4	28
2	PURE BANANA+5% RICE HUSK	2230	1.4	340	2.9	30.2	23
3	PURE COIR+5% RICE HUSK	2060	1.4	350	2.3	28.6	28
4	BAMBOO+BANANA+ 5% RICE HUSK	1995	1.5	310	2.1	26	24
5	BANANA+COIR+5% RICE HUSK	2750	1.9	450	3.1	31.5	26
6	COIR+BAMBOO+5% RICE HUSK	1650	1.3	380	2.4	27.4	25
7	BANANA+COIR+BAMBOO+ 5% RICE HUSK	2280	1.8	320	2.6	29.5	19

Table 3TESTING RESULTS

This section presents the outcomes of different characterization tests, covering tensile strength, flexural strength, impact strength, and hardness. The findings have been thoroughly analyzed and discussed. Using the tabulated data, multiple graphs have been created and are displayed in the figures to visually represent the composites' performance.

TENSILE TEST CALCULATIONS

The fabrication and testing phases of this project were successfully completed, focusing on the tensile properties of composites reinforced with Bamboo, Coir, Banana, Bamboo/Pineapple, Banana/Coir, Coir/Bamboo, and Bamboo/Coir/Banana fibers, each containing 5% rice husk. All fiber composites were fabricated using the hand lay-up method. The tensile strength was determined using the following relation:

$$\text{Tensile stress } \sigma_t = \frac{tensile\ load}{area\ of\ cross-section} = \frac{P}{A}\ \text{N/mm}^2$$

Where, P=Load

A=Area of cross section

As per results peak load (N) values of tensile specimens,

S.NO	COMPOSITE	TENSILE TEST(MPa) LOAD(N)
1	PURE BAMBOO+5% RICE HUSK	1760
2	PURE BANANA+5% RICE HUSK	2230
3	PURE COIR+5% RICE HUSK	2060
4	BAMBOO+BANANA+ 5% RICE HUSK	1995
5	BANANA+COIR+5% RICE HUSK	2750
6	COIR+BAMBOO+5% RICE HUSK	1650
7	BANANA+COIR+BAMBOO+ 5% RICE HUSK	2280

Table 4PEAK LOADS OF TENSILE SPECIMENS

Bamboo: $\sigma_t = \frac{1760}{165\times44} = 2.43$ N/mm^2

Banana: $\sigma_t = \frac{2230}{165\times44} = 3.09$ N/mm^2

Coir: $\sigma_t = \frac{2060}{165\times44} = 2.85$ N/mm^2

Bamboo/Banana: $\sigma_t = \frac{1995}{165\times44} = 2.76$ N/mm^2

Banana/Coir: $\sigma_t = \frac{2750}{165\times44} = 3.81$ N/mm^2

Bamboo/ Coir: $\sigma_t = \frac{1650}{165\times44} = 2.28$ N/mm^2

Bamboo/Banana/Coir: $\sigma_t = \frac{2280}{165\times44} = 3.15$ N/mm^2

The percentage of elongation is calculated by the follow equation

$$\% \text{ elongation} = \frac{change\ in\ length}{original\ length} \times 100$$

As per results displacements (mm) values of tensile specimens,

S.NO	COMPOSITE	TENSILE TEST(MPa) ELONGATION(mm)
1	PURE BAMBOO+5% RICE HUSK	1.3
2	PURE BANANA+5% RICE HUSK	1.4
3	PURE COIR+5% RICE HUSK	1.4
4	BAMBOO+BANANA+ 5% RICE HUSK	1.5
5	BANANA+COIR+5% RICE HUSK	1.9
6	COIR+BAMBOO+5% RICE HUSK	1.3
7	BANANA+COIR+BAMBOO+ 5% RICE HUSK	1.8

Table 5DISPLACEMENTS OF TENSILE SPECIMENS

Bamboo: % of elongation $= \frac{1.3}{164} \times 100 = 0.79\%$

Coir: % of elongation $= \frac{1.4}{164} \times 100 = 0.85\%$

Banana: % of elongation $= \frac{1.4}{164} \times 100 = 0.85\%$

Bamboo/Banana: % of elongation $= \frac{1.5}{164} \times 100 = 0.91\%$

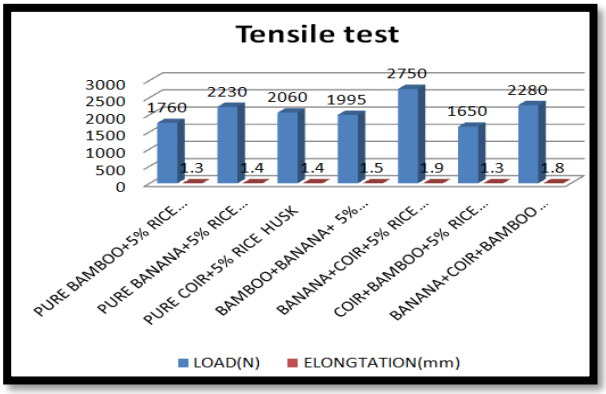
Banana/Coir: % of elongation $= \frac{1.9}{164} \times 100 = 1.15\%$

Coir/Bamboo: % of elongation $= \frac{1.3}{164} \times 100 = 0.79\%$

Bamboo/Banana/Coir: % of elongation $= \frac{1.8}{164} \times 100 = 1.09\%$

S.NO	COMPOSITE	TENSILE TEST			
		LOAD(N)	ELONGTATION(mm)	TENSILE STREES(N/mm2)	% ELONGTATION
1	PURE BAMBOO+5% RICE HUSK	1760	1.3	2.43	0.79
2	PURE BANANA+5% RICE HUSK	2230	1.4	3.09	0.85
3	PURE COIR+5% RICE HUSK	2060	1.4	2.85	0.85
4	BAMBOO+BANANA+ 5% RICE HUSK	1995	1.5	2.76	0.91
5	BANANA+COIR+5% RICE HUSK	2750	1.9	3.81	1.15
6	COIR+BAMBOO+5% RICE HUSK	1650	1.3	2.28	0.79
7	BANANA+COIR+BAMBOO+ 5% RICE HUSK	2280	1.8	3.15	1.09

Table 6TENSILE TEST RESULTS



GRAPH:1 TENSILE TEST RESULTS

Based on the tensile strength results, it was concluded that the BANANA/COIR FIBER composite with 5% rice husk exhibits the highest tensile strength among all the tested composites.

FLEXURAL TEST CALCULATIONS

The fabrication and testing phases of this project were successfully completed. The flexural strength of composites made from Bamboo, Coir,

Banana, Bamboo/Pineapple, Banana/Coir, Coir/Bamboo, and Bamboo/Coir/Banana fibers with 5% rice husk in all compositions were fabricated using the hand lay-up method. The flexural strength was determined using the following formula:

$$\text{Flexural strength } S = \frac{3PL}{2bt^2}$$

Where, P= load in N

L= length between supports (70mm)

b= Width in mm

d= Thickness in mm

As per results peak load (N) values of flexural specimens,

S.NO	COMPOSITE	FLEXURAL TEST(MPa) LOAD(N)
1	PURE BAMBOO+5% RICE HUSK	380
2	PURE BANANA+5% RICE HUSK	340
3	PURE COIR+5% RICE HUSK	350
4	BAMBOO+BANANA+ 5% RICE HUSK	310
5	BANANA+COIR+5% RICE HUSK	450
6	COIR+BAMBOO+5% RICE HUSK	380
7	BANANA+COIR+BAMBOO+ 5% RICE HUSK	320

Table 7PEAK LOADS OF FLEXURAL SPECIMENS

Bamboo: $S_1 = \frac{3\times380\times70}{2\times25\times4\times4} = 99.75 N/mm^2$

Coir: $S_1 = \frac{3\times350\times70}{2\times25\times4\times4} = 91.87 N/mm^2$

Banana: $S_1 = \frac{3\times340\times70}{2\times25\times4\times4} = 89.25 N/mm^2$

Bamboo/Banana: $S_1 = \frac{3\times310\times70}{2\times25\times4\times4} = 81.37 N/mm^2$

Banana/Coir: $S_1 = \frac{3\times450\times70}{2\times25\times4\times4} = 118.12 N/mm^2$

Coir/Bamboo: $S_1 = \frac{3\times380\times70}{2\times25\times4\times4} = 99.75 N/mm^2$

Bamboo/Coir/Banana: $S_1 = \frac{3\times320\times70}{2\times25\times4\times4} = 84 N/mm^2$

The percentage of elongation is calculated by the follow equation,

$$\% \text{ elongation} = \frac{change\ in\ length}{original\ length} \times 100$$

S.NO	COMPOSITE	FLEXURAL TEST ELONGATION(mm)
1	PURE BAMBOO+5% RICE HUSK	2.2
2	PURE BANANA+5% RICE HUSK	2.9
3	PURE COIR+5% RICE HUSK	2.3
4	BAMBOO+BANANA+ 5% RICE HUSK	2.1
5	BANANA+COIR+5% RICE HUSK	3.1
6	COIR+BAMBOO+5% RICE HUSK	2.4
7	BANANA+COIR+BAMBOO+ 5% RICE HUSK	2.6

Table 8DISPLACEMENTS OF FLEXURAL SPECIMENS

Bamboo: % of elongation $= \frac{2.2}{164} \times 100 = 1.34\%$

Coir: % of elongation $= \frac{2.3}{164} \times 100 = 1.40\%$

Banana: % of elongation $= \frac{2.9}{164} \times 100 = 1.76\%$

Bamboo/Banana: % of elongation $= \frac{2.1}{164} \times 100 = 1.28\%$

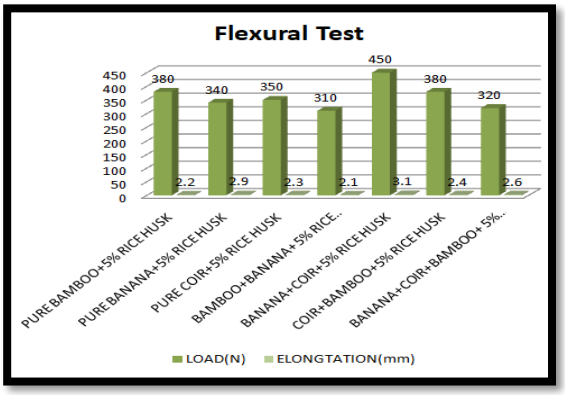
Banana/ Coir: % of elongation $= \frac{3.1}{164} \times 100 = 1.89\%$

Coir/Bamboo: % of elongation $= \frac{2.4}{164} \times 100 = 1.46\%$

Banana/Bamboo/Coir: % of elongation $= \frac{2.6}{164} \times 100 = 1.58\%$

S.NO	COMPOSITE	FLEXURAL TEST			
		LOAD(N)	ELONGTATION(mm)	FLEXURAL STREES(N/mm2)	% ELONGTATION
1	PURE BAMBOO+5% RICE HUSK	380	2.2	99.75	1.34
2	PURE BANANA+5% RICE HUSK	340	2.9	89.25	1.76
3	PURE COIR+5% RICE HUSK	350	2.3	91.87	1.4
4	BAMBOO+BANANA+ 5% RICE HUSK	310	2.1	81.37	1.28
5	BANANA+COIR+5% RICE HUSK	450	3.1	118.12	1.89
6	COIR+BAMBOO+5% RICE HUSK	380	2.4	99.75	1.46
7	BANANA+COIR+BAMBOO+ 5% RICE HUSK	320	2.6	84	1.58

Table 9FLEXURAL TEST RESULTS



GRAPH:2 FLEXURAL TEST RESULTS

Based on the flexural strength results, it was concluded that the BANANA/COIR FIBER composite with 5% rice husk exhibits higher flexural strength compared to the other composites.

IMPACT TEST CALCULATIONS

Fabrication and testing were successfully completed in this project, with a focus on the impact strength of Bamboo, Coir, Banana, Bamboo/Pineapple, Banana/Coir, Coir/Bamboo, and Bamboo/Coir/Banana composites, each containing 5% rice husk. All compositions were fabricated using the hand lay-

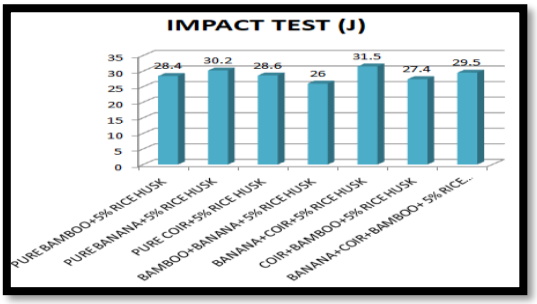
up method. The impact strength was determined using the following formula:

$$\sigma = \frac{2P}{A}$$

Where, P= Energy observed in J

A= Area in mm

FIGURE 1 BEFORE AND AFTER IMPACT STRENGTH SPECIMENS OF ALL MATERIALS

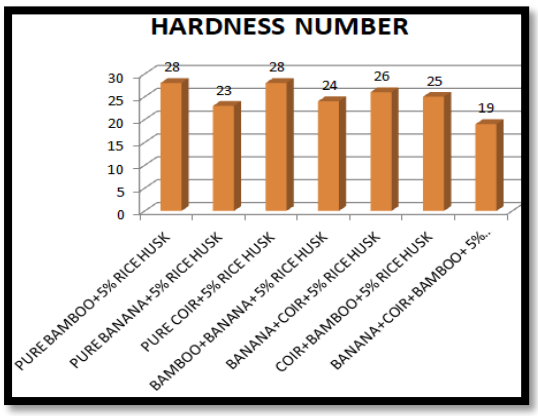


GRAPH:3 IMPACT TEST RESULTS

Based on the impact strength results, it was concluded that the BANANA/COIR FIBER composite with 5% rice husk exhibits higher impact strength compared to the other composites.

HARDNESS TEST CALCULATIONS

Brinell hardness values were measured for natural composites of Bamboo, Coir, Banana, Bamboo/Pineapple, Banana/Coir, Coir/Bamboo, and Bamboo/Coir/Banana, each reinforced with 5% rice husk and fabricated using the hand lay-up method.



GRAPH:4 HARDNESS TEST RESULTS

Based on the impact strength results, it was ultimately concluded that the pure Coir fiber reinforced with 5% rice husk exhibits higher tensile strength compared to the other composites.

CONCLUSION

This study successfully investigated the fabrication and mechanical performance of natural fiber–reinforced composites using Bamboo, Coir, Banana, and their hybrid combinations with a constant addition of 5% rice husk as filler material. The composites were developed using the hand lay-up technique with epoxy resin as the matrix, ensuring uniform distribution of fibers and filler.From the experimental results, it is evident that hybridization of natural fibers significantly influences the mechanical properties of the composites. Among all the combinations tested, the Banana–Coir composite reinforced with 5% rice husk exhibited superior performance in terms of tensile strength, flexural strength, impact strength, and hardness. The composite showed a tensile load of 2750 MPa, flexural strength of 118.12 N/mm², impact energy of 31.5 Joules, and hardness number of 26, indicating its enhanced load-bearing and energy-absorbing capabilities.Furthermore, numerical analysis revealed that the Banana–Coir–Rice Husk composite demonstrated a Von Mises stress of 22.125 MPa and a total deformation of 0.142 mm, confirming its structural stability and resistance under applied loading conditions. These results clearly indicate that the addition of rice husk and the hybridization of banana and coir fibers improve both strength and stiffness of the composite.

Overall, the study concludes that the Banana–Coir composite with 5% rice husk is the most efficient and promising material among the tested combinations. It offers a sustainable, eco-friendly, and cost-effective alternative to conventional synthetic composites, making it suitable for applications in automotive, construction, and lightweight structural components.

REFERENCES

- Nawab, Yasir (Ed.). *Textile Engineering – An Introduction*.
- Müssig, Jürg (Ed.). *Industrial Applications of Natural Fibers: Structure, Properties, and Technical Applications*.

- Khare, Ashok R. *Principles of Spinning: Fibers and Blow Room Cotton Processing in Spinning*.
- Manalo, A.C., et al. "Effects of Alkali Treatment and Elevated Temperature on the Mechanical Properties of Bamboo Fibre Polyester Composites." *Composites Part B: Engineering*, 2015.
- Huang, J., et al. "The Mechanical, Hygral, and Interfacial Strength of Continuous Bamboo Fiber Reinforced Epoxy Composites." *Composites Part B: Engineering*, 2019.
- Chen, H., Miao, M., & Ding, X. (2009). "Influence of Moisture Absorption on the Interfacial Strength of Bamboo/Vinyl Ester Composites." *Composites Part A: Applied Science and Manufacturing*, 40, 2013–2019. https://doi.org/10.1016/j.compositesa.2009.09.003
- Gibson, L. J. (2012). "The Hierarchical Structure and Mechanics of Plant Materials." *Journal of the Royal Society Interface*, 9, 2749–2766. https://doi.org/10.1098/rsif.2012.0341
- Hidalgo-Lopez, O. (2003). *Bamboo: The Gift of the Gods*. Bogotá: D'VINNI LTDA.
- Ichhaporia, P. K. (2008). *Composites from Natural Fibers*. Raleigh, NC: ProQuest.
- Ayrilmis, N., Jarusombuti, S., Fueangvivat, V., Bauchongkol, P., & White, R. H. (2011). "Coir Fiber Reinforced Polypropylene Composite Panel for Automotive Interior Applications." *Fibers and Polymers*, 12(7), 919–926. https://doi.org/10.1007/s12221-011-0919-1
- Karthikeyan, A., & Balamurugan, K. (2012). "Effect of Alkali Treatment and Fiber Length on Impact Behavior of Coir Fiber Reinforced Epoxy Composites." *Journal of Scientific and Industrial Research*, 71(9), 627–631.
- Parre, B., Karthikeyan, A., Balaji, &Udhayasankar, R. (2019). "Investigation of Chemical, Thermal, and Morphological Properties of Untreated and NaOH Treated Banana Fiber." *Materials Today: Proceedings*, 22, 1–6.
- Rahul, K., Shetty, M. H., Madhyastha, N. K., Kumara, B. P., D'Souza, K. P., & D'Souza, L. (2017). "Processing and Characterisation of Banana Fiber Reinforced Polymer Nanocomposite." *Nanoscience and Nanotechnology*, 7(2), 34–37.
- Balaji, D., Ramesh, M., Kannan, T., Deepan, S., Bhuvaneswari, V., & Rajeshkumar, L. (2021). "Experimental Investigation on Mechanical Properties of Banana/Snake Grass Fiber Reinforced Hybrid Composites." *Materials Today: Proceedings*, 42(2), 350–355.
- Shih, Y.-F., & Huang, C.-C. (2011). "Polylactic Acid (PLA)/Banana Fiber (BF) Biodegradable Green Composites." *Journal of Polymer Research*, 18(6), 2335–2340.