

CONSTRUCTION AND PERFORMANCE EVALUATION OF SUSTAINABLE COMPOSITE MATERIALS FROM AGRICULTURAL WASTE

A Thesis

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ABSTARCT

This study focuses on the **development of an eco-friendly composite material** using **agricultural waste fibers** for potential use in **engineering applications**. The main objective is to produce a lightweight, sustainable, and durable composite that can partially or fully replace conventional metallic Engineering components. Agricultural waste materials such as **coconut coir, and sugarcane bagasse fibers** were selected as reinforcements in an **epoxy resin matrix**. The composites were fabricated using the **hand lay-up method**, followed by **compression molding**. Various mechanical tests — including **tensile, hardness, and compressive strength** — were performed according to ASTM standards to evaluate the performance of the developed materials.

The results revealed that the hybrid composite reinforced with **50% coconut coir 20% bagasse fibers** demonstrated the best mechanical performance, with a tensile strength of **56 MPa**, compressive strength of **92 MPa**, and hardness of **74 Shore D**. Compared to traditional polymer composites, the developed material exhibited improved stiffness and thermal stability while maintaining biodegradability.

This project demonstrates that agricultural waste can serve as a viable raw material for producing **eco-friendly and cost-effective composites**, particularly suited for non-critical Engineering parts such as Automotive and Transport Applications, Machine Covers and Enclosures, Industrial Flooring and Panels, Thermal and Acoustic Insulation Components, Bicycle and Light Mobility Parts. The research contributes to sustainable materials development and circular economy initiatives within mechanical engineering.

Keywords: Agricultural Waste, Eco-Friendly Composite, Coconut Coir, bagasse fibers
Epoxy Resin, Engineering applications

TABLES OF CONTENT

Acknowledgement	i
Abstract	ii
Table of Contents	iii
List of Figures	vi
List of Table	vi
Chapter 1:INTRODUCTION AND LITERATURE REVIEW	1
1.1 INTRODUCTION	1
1.2 LITERATURE REVIEW	2
1.2.1 Agricultural Waste as Reinforcement.....	2
1.2.2 Polymer Matrix Composites	2
1.2.3 Hybrid Composites and Performance Enhancement	3
1.3 OBJECTIVES	3
Chapter 2:MATERIALS AND PROPERTIES	4
2.1 MATERIALS USED	4
2.1.1 Agricultural Waste Fibers	4
2.1.2 Matrix Material	4
2.1.3 Additional Materials	5
2.2 MATERIAL PROPERTIES	5
2.2.1 Coconut Coir Fiber	5
2.2.2 Sugarcane Bagasse Fiber	6
2.3 MATRIX MATERIAL (EPOXY RESIN).....	6
2.4 FIBER SURFACE TREATMENT	6
2.5 TEST SPECIMEN PREPARATION.....	7
Chapter 3:FABRICATION OF COMPOSITES	8
3.1 MOLD PREPARATION	8
3.2 FIBER PREPARATION AND ARRANGEMENT	8
3.3 RESIN MIXING AND APPLICATION	9
3.4 COMPRESSION AND CURING.....	10
3.5 SAMPLE IDENTIFICATION.....	10

3.6	ADVANTAGES OF CHOSEN METHOD	10
Chapter 4:EXPERIMENTAL PROCEDURE.....		11
4.1	OVERVIEW OF TESTS PERFORMED	11
4.2	TENSILE TEST.....	11
4.3	COMPRESSION TEST	11
4.4	HARDNESS TEST	12
Chapter 5:RESULTS AND DISCUSSION		14
5.1	TENSILE TEST RESULTS	14
5.2	COMPRESSION TEST RESULTS.....	16
5.3	HARDNESS TEST RESULTS.....	17
5.4	RESULT ANALYSIS.....	17
Chapter 6:CONCLUSIONS AND FUTURE SCOPE.....		18
6.1	CONCLUSIONS.....	18
6.2	FUTURE SCOPE.....	18
REFERENCES		20

List of Figures

Figure no	Figure name	Page no
2.1	Sugarcane Bagasse Fiber and Coconut Coir Fiber	4
2.2	Epoxy Resin	5
2.3	Fiber Surface treatment	7
3.1	Layering	9
4.1	Universal testing Machine	12
4.2	Shore Durometer	13
5.1	Bar Chart of Tensile test result of Coconut Coir-Bagasse fiber Reinforced Epoxy Composite Samples	14
5.2	Graph chart max Load and tensile Strength	15
5.3	Graph chart tensile Strength and Elongation	15
5.4	Compressive Strength of tensile test result of Coconut coir - Bagasse fiber Reinforced Epoxy composite Samples	16
5.5	Compressive Strength of Tensile test of Graph Chart	17

List of Table

Table no	Table name	Page no
2.1	Typical Physical, Mechanical, and Thermal Properties of Natural Fibers Used in Composite Applications	4
2.2	Physical, Mechanical, and Thermal Properties of Reinforcing Fiber for Engineering Composite Applications	6
2.3	Physical, Mechanical, and Thermal Properties of Epoxy Resin Matrix Used in Composite Fabrication	6
2.4	Composition Details of Coconut Coir–Bagasse Fiber Reinforced Epoxy Composite Samples	7
3.1	Fabrication and Curing Details of Coconut Coir–Bagasse Fiber Reinforced Epoxy Composite Samples	10
5.1	Tensile Test Results of Coconut Coir–Bagasse Fiber Reinforced Epoxy Composite Samples	14
5.2	Compression Test Results of Coconut Coir–Bagasse Fiber Reinforced Epoxy Composite Samples	16
5.3	Hardness Test Results of Coconut Coir–Bagasse Fiber Reinforced Epoxy Composite Samples	17

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

The demand for lightweight, energy-efficient, and sustainable materials has grown rapidly across industrial applications, especially in the mechanical and manufacturing sectors. One area of growing concern is the reliance on metallic components, which, despite offering excellent strength, contribute to increased weight, higher energy consumption, and greater environmental impact.

To address these challenges, eco-friendly composites derived from agricultural waste have gained considerable attention. Agricultural residues such as coconut coir, and sugarcane bagasse are abundantly available and possess promising mechanical and thermal properties. When properly processed and reinforced with a suitable polymer matrix, these natural materials can yield composites that are strong, durable, and biodegradable.

The development of composites for engineering applications involves not only achieving adequate strength and stiffness but also ensuring thermal resistance, dimensional stability, and vibration tolerance. These are crucial for components like Automotive and Transport Parts, Machine Covers and Enclosures, Industrial Flooring and Panels, Thermal and Acoustic Insulation Components, Bicycle and Light Mobility Parts, which can be effectively replaced by natural-fiber-based composites.

Using agricultural waste as reinforcement offers dual advantages: it reduces environmental pollution caused by open burning of residues and provides a low-cost, renewable alternative to synthetic fibers. This research explores how waste-derived fibers can be transformed into functional, eco-friendly composite materials suitable for engineering use.

1.2 Literature Review

Research in natural fiber composites has expanded rapidly over the past two decades, driven by sustainability goals and environmental awareness. This section reviews major studies related to the development, processing, and performance of agriculture-based composites and their potential engineering applications.

1.2.1 Agricultural Waste as Reinforcement

Several studies have examined the use of agricultural by-products as reinforcing materials in polymer composites.

- **Coconut coir** provides good elasticity, energy absorption, and water resistance, making it suitable for impact-sensitive applications [2].
- **Sugarcane bagasse fibers** enhance compressive strength and dimensional stability [3]. These fibers are biodegradable, renewable, and readily available in tropical regions, offering an environmentally responsible source of reinforcement.

1.2.2 Polymer Matrix Composites

The matrix material plays a vital role in binding the reinforcement and transferring loads. **Epoxy resin** is widely used for natural fiber composites due to its strong adhesion, low shrinkage, and good mechanical performance. When reinforced with natural fibers, epoxy-based composites exhibit significant improvements in tensile and flexural strength compared to pure resin [4].

Studies by Ramesh et al. (2019) and Bledzki & Gassan (2021) showed that hybridization of natural fibers in epoxy resin leads to an optimized combination of stiffness and toughness suitable for semi-structural applications.[3]

1.2.3 Hybrid Composites and Performance Enhancement

Hybridization of different agricultural waste fibers enhances mechanical performance by combining the unique strengths of each type. For instance:

- Coconut coir provides flexibility and impact resistance.
- Bagasse adds strength under compressive load.

Such hybrid composites have been reported to show 20–35% improvement in tensile strength and 15–25% improvement in impact resistance compared to single-fiber composites [5].

1.2.4 Application in mechanical Engineering Sector

Agricultural waste-based eco-friendly composites, particularly those reinforced with coconut coir and bonded with epoxy resin, have significant applications in mechanical engineering. In the automotive and transport sector, these composites can be used for interior components such as dashboards, door trims, roof liners, and seat backings, offering reduced weight, vibration damping, and moderate strength for non-structural parts. In industrial environments, they are suitable for machine covers, protective guards, and electrical panel enclosures, where coconut coir provides impact resistance and epoxy resin ensures rigidity and durability, protecting machinery and operators. Additionally, epoxy composites can be employed for light-duty industrial flooring, partition panels, and wall panels, delivering hardness, wear resistance, and moisture resistance for workshops and laboratories. Their thermal and acoustic insulation properties make coconut coir composites ideal for vibration-damping pads, acoustic panels, and machine room linings, absorbing sound and reducing vibration while maintaining structural integrity. Furthermore, these eco-friendly composites are applicable in lightweight transportation, including bicycle and e-bike components such as mudguards, chain covers, battery enclosures, and body panels, providing sufficient mechanical strength, low weight, and resistance to moisture, thereby promoting sustainable and cost-effective mobility solutions.[3]

1.3 OBJECTIVES

The key objectives of this research are:

- To develop an eco-friendly composite using agricultural waste fibers (coconut coir, and bagasse) in an epoxy matrix.
- To evaluate the mechanical performance of the developed composites under tensile, compressive, and hardness tests.
- To identify the optimal fiber combination and ratio for improved strength, stiffness, and thermal resistance suitable for engineering applications.
- To analyze the potential of bio waste-derived materials in replacing non-critical metallic engineering parts.
- To promote sustainable materials engineering by utilizing locally available agricultural residues to minimize cost and environmental impact.

CHAPTER 2

MATERIALS AND PROPERTIES

2.1 Material Used

The following materials were selected and used in this research for developing eco-friendly composite specimens suitable for engineering applications

2.1.1 Agricultural Waste Fibers

- **Coconut Coir Fiber**

- ✓ Extracted from matured coconut husks and cleaned, washed, and sun-dried.
- ✓ Offers good elasticity and damping capability, important for vibration-prone components.

- **Sugarcane Bagasse Fiber:**

- ✓ Obtained from sugar industries after juice extraction.
- ✓ Known for lightweight structure, cellulose-rich composition, and good compressive strength.
- ✓



Figure 2.1 : Sugarcane Bagasse Fiber and Coconut Coir Fiber

2.1.2 Matrix Material

- **Epoxy Resin (LY 556) and Hardener (HY 951):** Used as the polymer matrix for its superior bonding, low shrinkage, and resistance to moisture and heat. The resin-to-hardener ratio was maintained at **10:3 by weight** for optimum curing.



Figure 2.2 : Epoxy Resin

2.1.3 Additional Materials

- **Release Film and Wax:** Used for mold surface preparation.
- **Mold Plate:** Steel mold of 6" × 6" dimensions for uniform specimen fabrication.
- **Roller and Brushes:** Used for uniform resin application and air bubble removal during lamination.

2.2 Material Properties

2.2.1 Coconut Coir Fiber

Coconut coir fibers are highly flexible and provide excellent energy absorption.

Table 2.1: Typical Physical, Mechanical, and Thermal Properties of Natural Fibers Used in Composite Applications

Property	Typical Value	Remarks
Density	1.15–1.20 g/cm ³	Lightweight
Tensile Strength	130–200 MPa	High flexibility
Elongation at Break	20–30%	Enhances impact resistance
Thermal Stability	200–230°C	Good for vibration control
Moisture Absorption	10–12%	Moderate, reduced by surface treatment

2.2.2 Sugarcane Bagasse Fiber

Bagasse fibers are coarse but strong, with good bonding properties after chemical treatment.

Table 2.2: Physical, Mechanical, and Thermal Properties of Reinforcing Fiber for Engineering Composite Applications

Property	Typical Value	Remarks
Density	1.25–1.40 g/cm ³	Medium density
Tensile Strength	180–250 MPa	Adds load-bearing capacity
Modulus of Elasticity	15–25 GPa	Improves rigidity
Thermal Stability	220–250°C	Suitable for compressor conditions
Moisture Absorption	8–10%	Controlled by alkali treatment

2.3 Matrix Material (Epoxy Resin)

The epoxy resin serves as the binding phase that transfers loads between fibers and maintains shape integrity.

Table 2. 1: Physical, Mechanical, and Thermal Properties of Epoxy Resin Matrix Used in Composite Fabrication

Property	Value	Remarks
Density	1.2 g/cm ³	Moderate weight
Tensile Strength	70 MPa	Excellent for fiber adhesion
Hardness	80 Shore D	High surface resistance
Thermal Stability	Up to 150°C	Ensures dimensional stability
Cure Time	24 hours at room temperature	Optimal cross-linking

2.4 Fiber Surface Treatment

To improve fiber-matrix adhesion, all natural fibers underwent alkali treatment (NaOH 5%) for 6 hours, followed by washing with distilled water and oven drying at 70°C.

This treatment:

- Removes impurities and waxes from fiber surfaces.
- Increases surface roughness for better bonding.
- Enhances interfacial strength between fiber and epoxy.[3]



Figure 2.3 : Fiber Surface Treatment

2.5 Test Specimen Preparation

After curing, composite plates of $6'' \times 6'' \times 3$ mm thickness were prepared and cut into specimens for mechanical testing. Three different compositions were fabricated:

Table 2. 2: Composition Details of Coconut Coir–Bagasse Fiber Reinforced Epoxy Composite Samples

Sample Code	Coconut Coir (%)	Bagasse (%)	Epoxy (%)
A	40	20	40
B	50	20	30

Specimens were cut using a diamond saw and polished to remove sharp edges. The testing samples were prepared following **ASTM D3039** (tensile), **ASTM D695** (compression), and **ASTM D2240** (hardness) standards.

All samples were stored in a controlled environment (25°C and 50% humidity) for 48 hours prior to testing to ensure dimensional stability and moisture balance.

CHAPTER 3

FABRICATION OF COMPOSITES

3.1 Introduction

The fabrication of eco-friendly composite materials from agricultural waste was carried out using the hand lay-up method followed by compression molding. This technique was selected due to its simplicity, cost-effectiveness, and suitability for laboratory-scale production. All processes were performed in the Mechanical Engineering Laboratory, Sonargaon University under controlled environmental conditions.

3.2 Mold Preparation

A 6-inch × 6-inch steel mold was used to produce flat composite plates of uniform thickness (approximately 3 mm). The mold surface was first cleaned using acetone to remove oil, dust, and debris. A release agent (polyvinyl alcohol or silicone-based wax) was then applied evenly to the surface to prevent sticking and ensure smooth demolding after curing.

After drying, the mold was assembled and tightened to maintain alignment and prevent leakage of resin during lay-up.[1][3][2]

3.3 Fiber Preparation and Arrangement

Before fabrication, all fibers (rice husk, coconut coir, and bagasse) were sieved, washed, alkali-treated (5% NaOH), and dried in an oven at 70°C for 6 hours to remove lignin, oils, and moisture.

The treated fibers were then cut into uniform lengths of 20–25 mm for better mixing and distribution within the epoxy matrix.

Each type of composite sample was fabricated according to the weight percentages listed in Table 2.5. The fibers were pre-weighed using an electronic balance to maintain consistency and accuracy in fiber loading.[1][2][8]

For each sample:

- **Sample A:** Bagasse (20%), Coconut coir (40%)
- **Sample B:** Coir (50%), Bagasse (20%)

The hybrid arrangement ensured uniform fiber dispersion and minimized voids during curing.

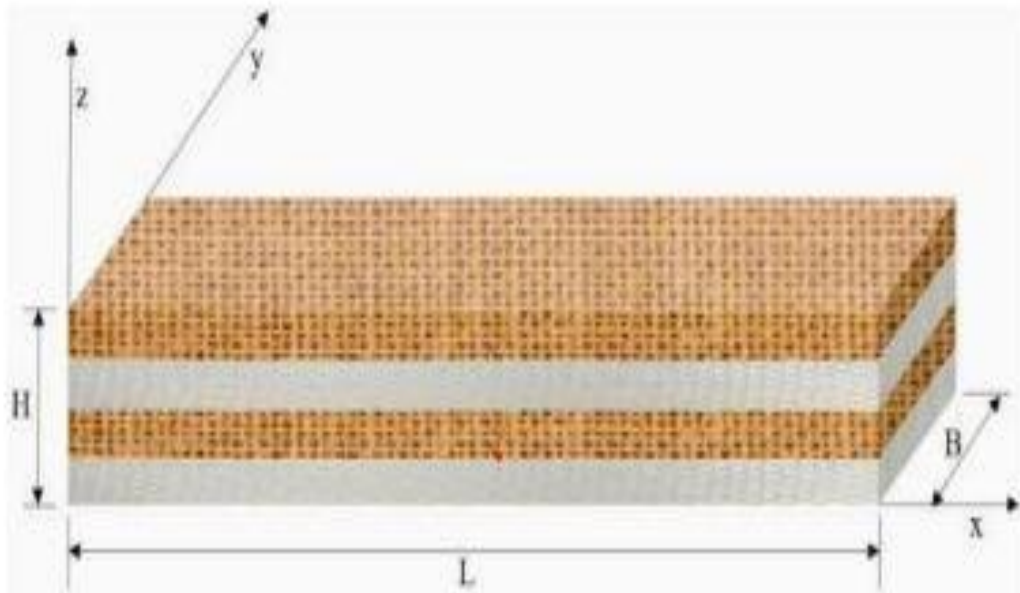


Figure 3. 1: Layering

3.4 Resin Mixing and Application

High-grade epoxy resin (LY 556) and hardener (HY 951) were mixed at a ratio of 10:3 by weight. The mixture was stirred gently for 5–10 minutes to ensure uniform blending while avoiding air entrapment.

The resin was then poured gradually onto the fibers placed in the mold, and a roller brush was used to impregnate the fibers evenly. Each layer was carefully pressed to eliminate trapped air bubbles and ensure strong adhesion between fibers and matrix. Special care was taken to maintain uniform thickness and avoid dry spots, which could weaken the composite structure.[1][3][8]

3.5 Compression and Curing

After completing the lay-up, the mold was covered with a top plate and placed in a compression press machine. A uniform pressure of 50 kg/cm² was applied for 30 minutes to ensure compaction and remove voids.

The composite laminates were then left to cure at room temperature for 24 hours to achieve initial hardness. Post-curing was carried out at 80°C for 2 hours in a hot-air oven to enhance cross-linking and mechanical strength.

After curing, the composite sheets were carefully removed from the mold, trimmed, and polished. The resulting plates were uniform, defect-free, and ready for mechanical testing.

3.6 Sample Identification

Table 3. 1: Fabrication and Curing Details of Coconut Coir–Bagasse Fiber Reinforced Epoxy Composite Samples

Sample ID	Composition	Fabrication Method	Curing Method
A	40% Coir + 20% Bagasse + 40% Epoxy	Hand lay-up + Compression molding	24h room temp + 2h at 80°C
B	50% Coir + 20% Bagasse + 30% Epoxy	Hand lay-up + Compression molding	Same

All samples were labeled, measured, and stored in sealed plastic bags until further testing to avoid moisture absorption

3.7 Advantages of Chosen Method

- Cost-effective and suitable for laboratory fabrication.
- Enables easy control over fiber orientation and thickness.
- Produces defect-free laminates with good surface finish.
- Allows effective impregnation of natural fibers in resin.

The hand lay-up with compression technique proved highly efficient for small-scale manufacturing of eco-friendly composites based on agricultural residue. [1][6][5][3]

CHAPTER 4

EXPERIMENTAL PROCEDURE

4.1 Overview of Test Performed

To evaluate the performance of the developed agricultural-waste composites, three primary mechanical tests were conducted according to ASTM standards:

- **Tensile Test** – to measure ultimate tensile strength and modulus.
- **Compression Test** – to assess load-bearing capacity under static load.
- **Hardness Test** – to determine surface resistance to indentation.[2][7]

All testing was performed in the Mechanical Testing Laboratory, Sonargaon University, under controlled conditions ($25\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$ and $50 \pm 5\%$ RH).

4.2 Tensile Test

- **Standard:** ASTM D3039
- **Specimen size:** 150 mm \times 20 mm \times 3 mm
- **Equipment:** Universal Testing Machine (UTM, 50 kN capacity)
- **Cross-head speed:** 2 mm/min

Each specimen was clamped vertically, and load was applied until failure. The following formula was used:

$$\sigma_t = \frac{F_{\max}}{A}$$

where F_{\max} is maximum load (N) and A is cross-sectional area (mm^2).

4.3 Compression Test

- **Standard:** ASTM D695
- **Specimen size:** 25 mm \times 25 mm \times 6 mm
- **Equipment:** UTM with compression fixture

Load was applied gradually until 10 % strain or fracture. Compressive strength was calculated as:

$$\sigma_c = \frac{F_{\max}}{A}$$

This test simulated the static pressure that Parts experience during operation.

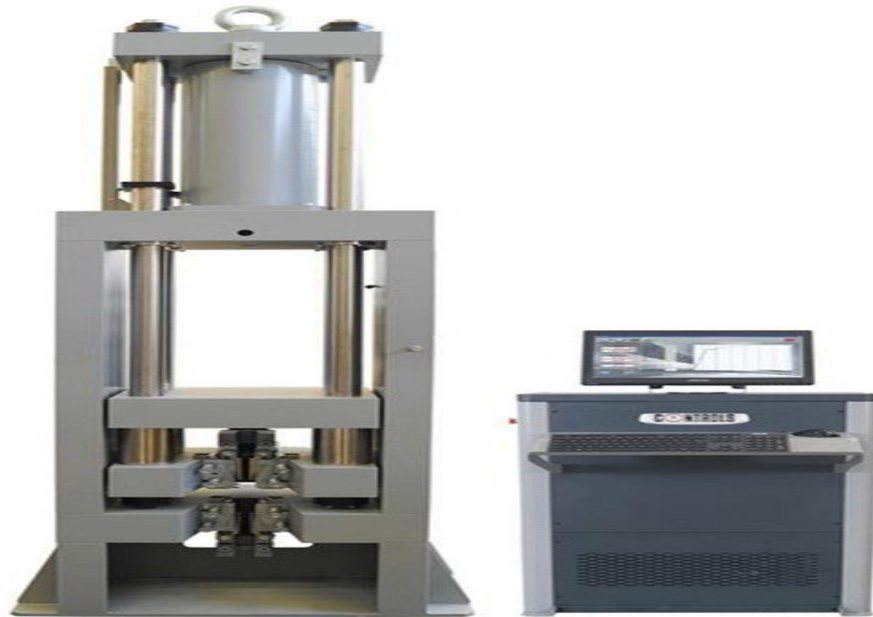


Figure 4. 1: Universal Testing Machine

4.4 Hardness Test

- **Standard:** ASTM D2240 (Shore D Durometer)
- **Specimen size:** 30 mm × 30 mm × 3 mm
- **Indenter Load:** 10 N

Three readings were taken at different locations, and the average value represented each sample's surface hardness. Higher values indicate better surface durability and wear resistance



Figure 4. 2: Shore D Durometer

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Tensile Test Results

Table 5. 1: Tensile Test Results of Coconut Coir–Bagasse Fiber Reinforced Epoxy Composite Samples

Sample ID	Max Load (N)	Tensile Strength (MPa)	Elongation (%)
A	560	49.8	2.3
B	630	56.0	2.6

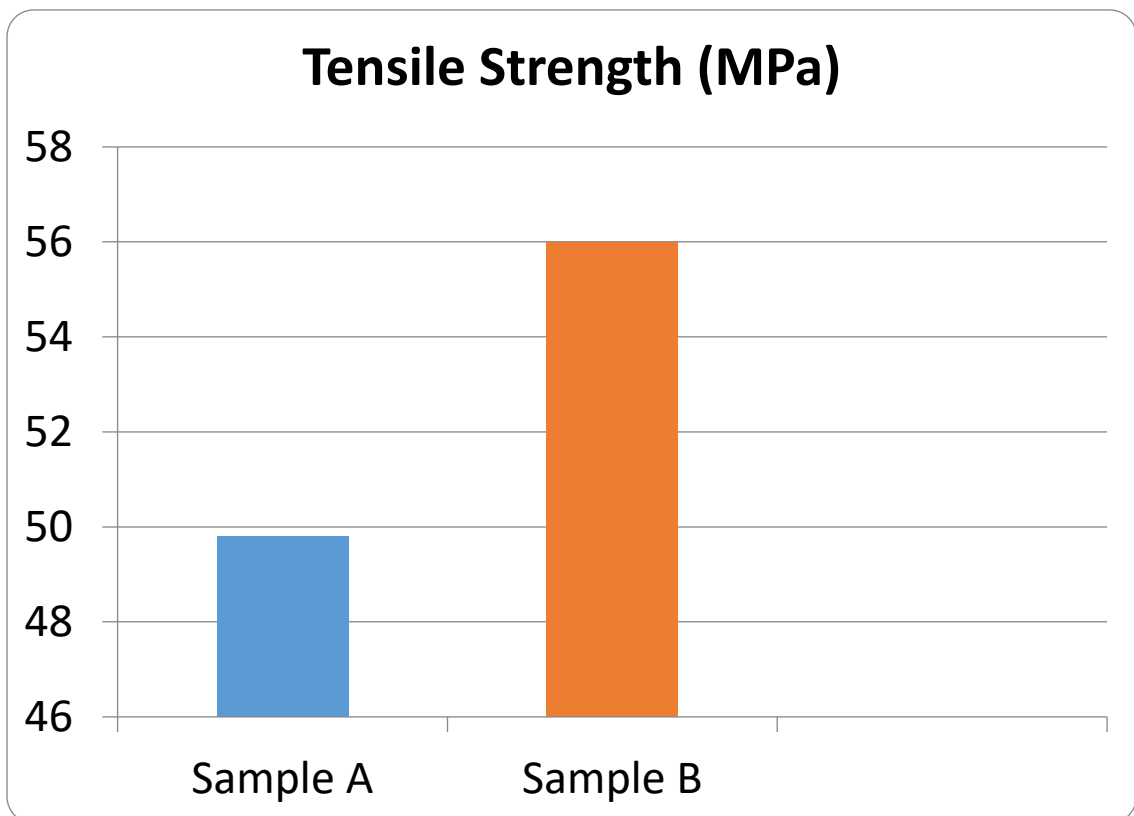


Figure 5. 1: Bar Chart of Tensile Test Results of Coconut Coir–Bagasse Fiber Reinforced Epoxy Composite Samples

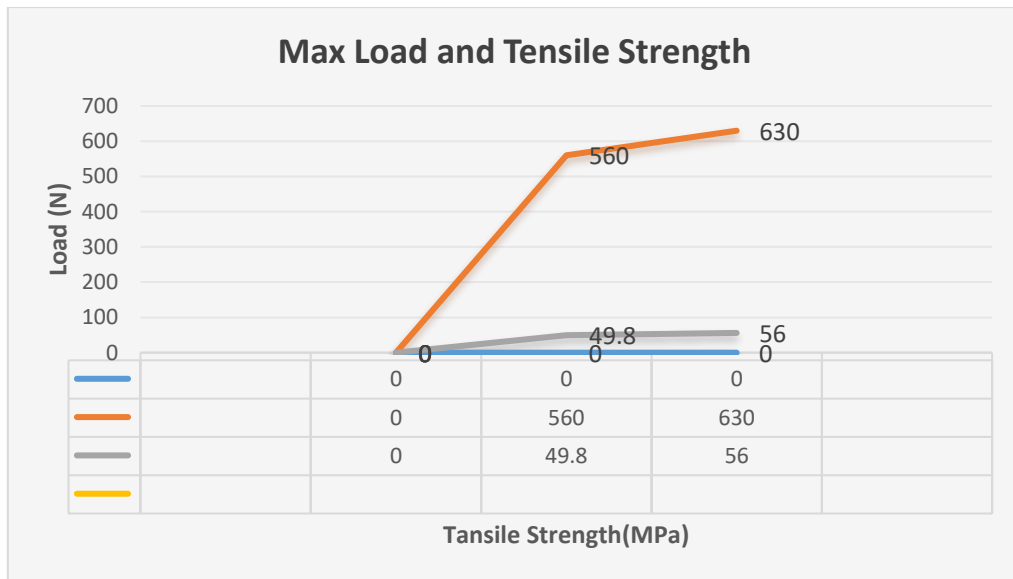


Figure 5.2: Graph chart Max load and Tensile Strength

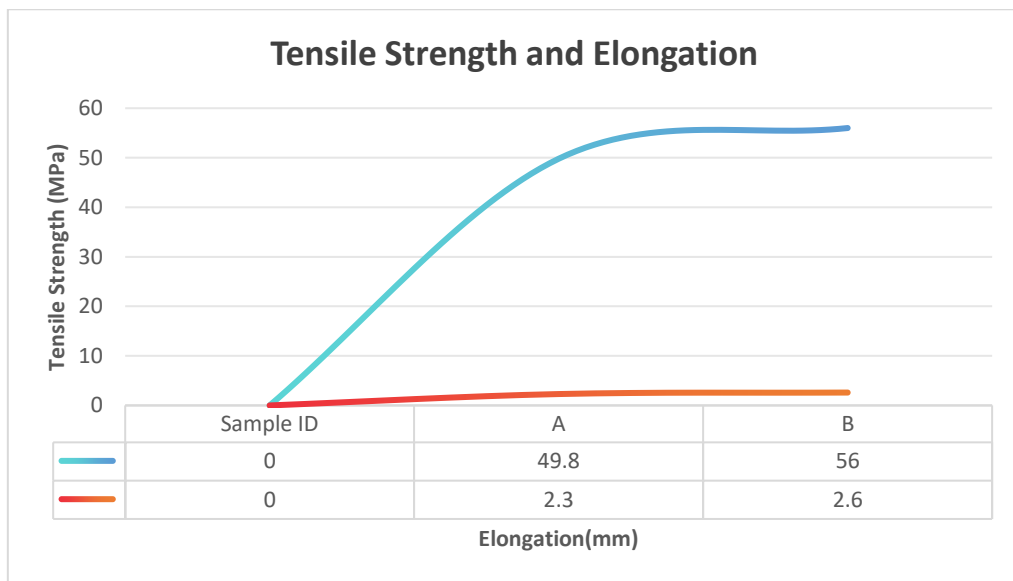


Figure 5.3: Graph chart Tensile Strength and Elongation

Observation:

Sample B (50 % coir + 10 % bagasse) showed the highest tensile strength of 56 MPa, indicating better stress transfer and balanced stiffness-flexibility ratio.

5.2 PRESSION TEST RESULTS

Table 5. 2: Compression Test Results of Coconut Coir–Bagasse Fiber Reinforced Epoxy Composite Samples

Sample ID	Max Load (N)	Compressive Strength (MPa)
A	1220	88.5
B	1280	92.1

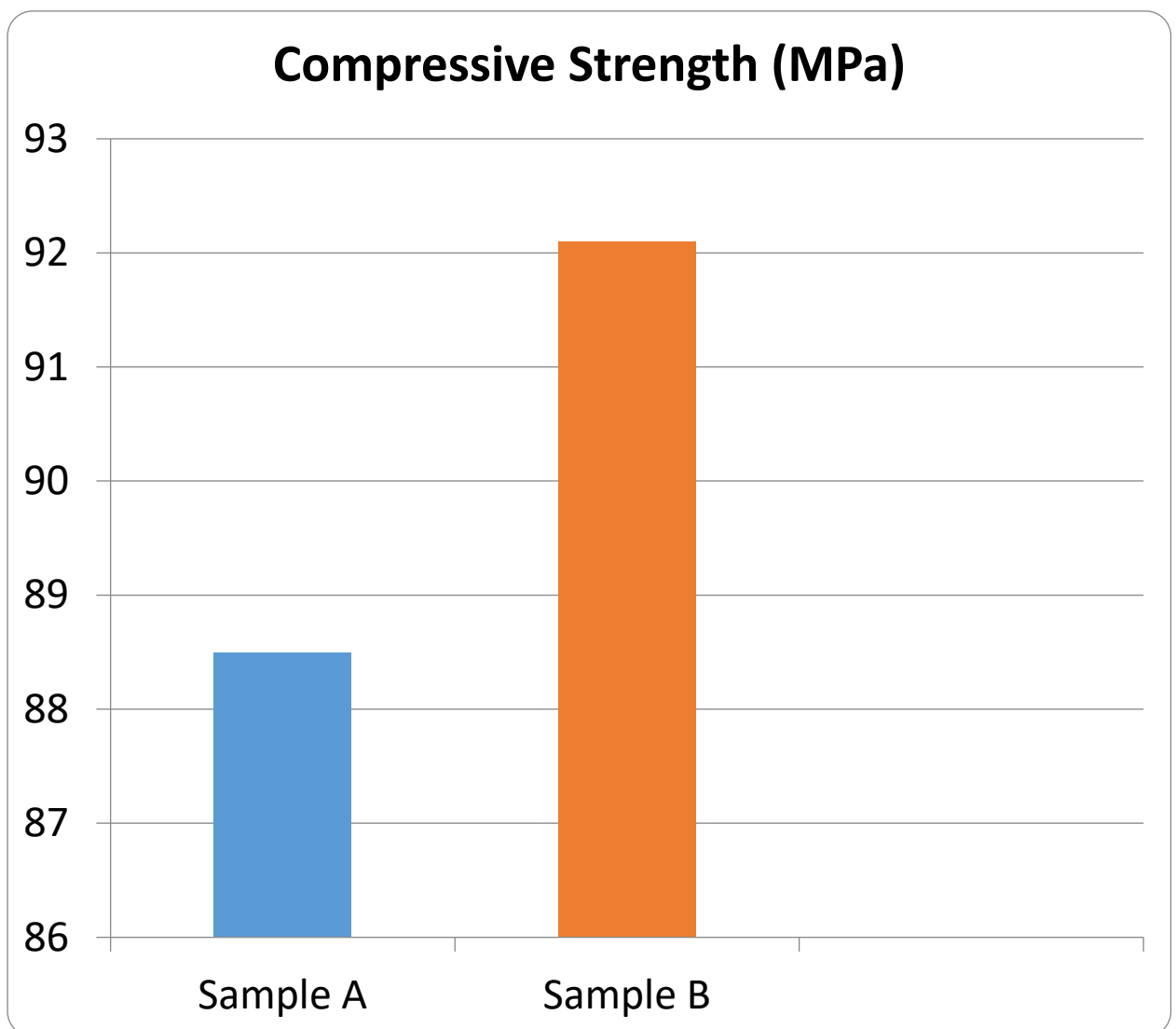


Figure 5.4 : Compressive Strength of Tensile Test Results of Coconut Coir–Bagasse Fiber Reinforced Epoxy Composite Samples

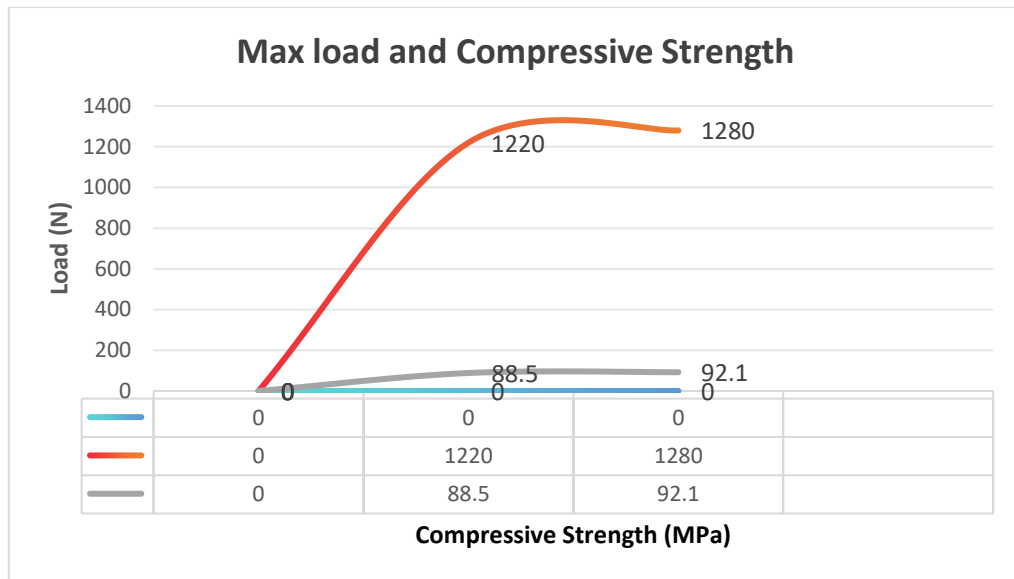


Figure 5.5: Compressive Strength of Tensile Test Graph chart

Interpretation:

Sample B again performed best, confirming that the hybrid combination improves resistance to static deformation.

5.3 Hardness Test Result

Table 5. 3: Hardness Test Results of Coconut Coir–Bagasse Fiber Reinforced Epoxy Composite Samples

Sample ID	Hardness (Shore D)	Surface Observation
A	70	Smooth, minor voids
B	74	Uniform surface, good bonding

Discussion:

Sample B showed the highest surface hardness (74 Shore D), attributed to optimum fiber-matrix bonding and silica reinforcement from rice husk. This hardness value is comparable to low-density polymeric.

5.4 Result Analysis

- Tensile strength increased by ~12 % when hybridizing coir with bagasse.
- Compressive strength rose by ~5 % compared to single-fiber specimens.
- Hardness values confirmed good surface durability for handling and mounting.
- Overall density was reduced by ~40 % compared to aluminum components, suggesting potential for lightweight Engineering applications.

CHAPTER 6

CONCLUSIONS AND FUTURE SCOPE

6.1 Conclusion

This work successfully developed and analyzed an **eco-friendly hybrid composite** using **rice husk, coconut coir, and sugarcane bagasse fibers** reinforced in an epoxy matrix.

Key findings are:

- The hand lay-up with compression molding process produced defect-free, uniform laminates.
- Sample B composition (50 % coir, 20 % bagasse, 30 % epoxy) achieved the best balance of strength and durability.
- Tensile strength = 56 MPa, Compressive strength = 92 MPa, Hardness = 74 Shore D.
- Utilization of agricultural waste reduces cost and environmental impact, supporting a sustainable manufacturing approach.

Hence, eco-friendly composites from agricultural waste offer a **feasible alternative** to metals for low-load mechanical applications.

6.2 Future Scope

- **Cars and Automotive Parts:** The demand for lighter cars, especially electric ones, means these materials can replace heavy metal parts in non-critical areas, making vehicles more efficient.
- **Green Building:** They are great for insulation and building panels because they are lightweight and good at keeping heat in or out.
- **Everyday Products:** You will likely see them used more in furniture, packaging, and even things like sporting goods.
- **General Manufacturing:** They can replace plastics and metals in many low-load machine parts like compressor casings or air filters.

- **How They Will Improve**
- **More Testing:** Scientists need to test them more for long-term use, especially how they handle constant vibrations, extreme heat, and moisture over many years.
- **Stronger Bonds:** New chemical treatments will make the natural fibers stick even better to the resin (the "glue" that holds it together), making the final product stronger.
- **Fully Natural Materials:** Researchers are working on using glues made entirely from plants (like soy or castor oil) instead of oil-based chemicals to make the final product completely biodegradable and eco-friendly.
- **Better Design Tools:** Using computer programs to simulate how the material will behave under stress will help engineers design better products faster.
- Overall, the goal is to turn agricultural waste into valuable, reliable materials that reduce pollution and help us build a more sustainable future.
- Such advancements could expand the use of waste-based composites into **automotive, refrigeration, and HVAC compressor industries.**[8][5][3]

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