

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY



**Mechanical Properties of Epoxy Composites Reinforced with Jute and
Coconut Fibers**

A Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of B.Sc. in
Industrial and Production Engineering

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CERTIFICATE OF APPROVAL

The thesis entitled ‘**Mechanical Properties of Epoxy Composites Reinforced with Jute and Coconut Fibers**’ submitted by Md. Sadman Sakib Mithun (Student ID: 1908028) and An-Nur Taiweb Rahman (Student ID: 1908047) has been accepted as satisfactory in partial fulfilment of the requirements for the degree of B.Sc. in Industrial & Production Engineering on March 2025.

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DECLARATION

It is hereby declared that the work in this dissertation was carried out following the requirements of the University's Regulations and Code of Practice for the Undergraduate Thesis Program and neither this thesis nor any part of it has been submitted elsewhere for the award of any academic degree or diploma.

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ABSTRACT

The growing demand for sustainable and eco-friendly materials has driven interest in natural fiber-reinforced polymer composites as viable alternatives to synthetic fiber composites. This study investigates the mechanical properties of epoxy composites reinforced with jute and coconut fibers in various compositions (30:70, 40:60, 50:50, 60:40, and 70:30 by weight). The objective is to assess the influence of fiber composition on the tensile strength, elongation, strain, modulus of elasticity, and toughness of the composites.

Composite samples were fabricated using epoxy resin as the matrix, with jute and coconut fibers as reinforcements. A systematic experimental approach was employed, including fiber surface treatment with NaOH, composite casting, and tensile testing following ASTM standards. The results indicate that increasing the proportion of coconut fiber enhances the tensile strength and stiffness of the composites, with the 70:30 coconut-to-jute ratio exhibiting the highest tensile strength (18.82 MPa) and modulus of elasticity (3474.5 MPa). Conversely, composites with higher jute content demonstrated greater elongation and energy absorption, highlighting their ductility and impact resistance.

The findings suggest that by optimizing fiber ratios, hybrid epoxy composites can be tailored for specific applications requiring high strength, flexibility, or energy absorption. These materials hold promises for use in automotive, construction, and packaging industries as sustainable alternatives to conventional composites. Future research should explore advanced fiber treatments, fiber orientation effects, and durability assessments to further enhance the mechanical performance and industrial applicability of jute-coconut epoxy composites.

TABLE OF CONTENTS

CERTIFICATE OF APPROVAL	i
DECLARATION.....	ii
ACKNOWLEDGEMENT.....	iii
ABSTRACT.....	iv
LIST OF TABLES.....	vii
LIST OF FIGURES.....	viii
CHAPTER 1.....	1
INTRODUCTION.....	1
1.1 GENERAL INTRODUCTION.....	1
1.2 RATIONALE.....	2
1.3 METHODOLOGY	3
1.4 ORGANIZATION OF THE THESIS.....	5
CHAPTER 2.....	6
LITERATURE REVIEW	6
2.1 LITERATURE REVIEW	6
2.2 THEORETICAL BACKGROUND.....	7
2.2.1 Natural Fiber Composites: Ecological and Socioeconomic Significance	8
2.2.2 Epoxy Resin: Chemistry and Curing Dynamics	9
2.2.3 Tensile Testing: From Theory to Application	10
2.2.4 Stress-Strain Behavior: Microstructural Insights.....	12
2.2.5 Hybridization Mechanics: Beyond the Rule of Mixtures	12
2.2.6 Fiber-Matrix Interfacial Engineering	13
2.2.7 Theoretical Challenges and Innovations.....	14

CHAPTER 3.....	15
TESTING.....	15
3.1 TENSILE TESTING PROTOCOL.....	15
3.2 DATA ACQUISITION PROCESS	15
3.3 DERIVATION OF MECHANICAL PARAMETERS.....	16
3.4 TABULAR PRESENTATION OF RESULTS	16
CHAPTER 4.....	20
RESULTS ANALYSIS.....	20
4.1 RESULTS ANALYSIS	20
CHAPTER 5.....	27
CONCLUSION	27
5.1 CONCLUSION.....	27
5.2 INDUSTRIAL APPLICATIONS	28
5.3 RECOMMENDATIONS FOR FUTURE WORK	29
REFERENCES.....	30

LIST OF TABLES

Table 3.1: Maximum Tensile Stress of a composite mixture of Coconut Fibers and Jute Fibers	16
Table 3.2: Elongation of the composite mixture of Coconut Fibers and Jute Fibers.....	17
Table 3.3: Break Point Strain of the composite mixture of Coconut Fibers and Jute Fibers...	17
Table 3.4: Modulus of Elasticity of the composite mixture of Coconut Fibers and Jute Fibers	18
Table 3.5: Modulus of Toughness of the composite mixture of Coconut Fibers and Jute Fibers	18
Table 3.6: Modulus of Resilience of the composite mixture of Coconut Fibers and Jute Fibers	19

LIST OF FIGURES

Figure 4.1: Sample Composite Board Mixture of Coconut Fibers and Jute Fibers.....	20
Figure 4.2: Graph of the Maximum Tensile Stress of a composite mixture of Coconut Fibers and Jute Fibers	21
Figure 4.3: Graphic Elongation of the composite mixture of Coconut Fibers and Jute Fibers	22
Figure 4.4: Break Point Strain of the composite mixture of Coconut Fibers and Jute Fibers .	23
Figure 4.5: Modulus of Elasticity of the composite mixture of Coconut Fibers and Jute Fibers	24
Figure 4.6: Modulus of Toughness of the composite mixture of Coconut Fibers and Jute Fibers.....	25
Figure 4.7: Modulus of Resilience of the composite mixture of Coconut Fibers and Jute Fibers.....	26

CHAPTER 1

INTRODUCTION

1.1 GENERAL INTRODUCTION

The global engineering and materials science communities are increasingly prioritizing sustainable alternatives to synthetic materials, driven by environmental concerns and the urgent need to reduce reliance on fossil fuels. Synthetic fibers like glass and carbon, while dominant in composite applications due to their high strength-to-weight ratios, face criticism for their energy-intensive production processes, non-biodegradability, and contribution to landfill waste. In this context, natural fiber-reinforced polymer composites (NFRPCs) have emerged as a promising solution, combining renewable resources with competitive mechanical performance (Pickering et al., 2016). Among these, epoxy-based composites reinforced with plant-derived fibers like jute and coconut are gaining traction due to their unique advantages in sustainability, cost-effectiveness, and functional versatility.

Jute, a bast fiber extracted from the *Corchorus* plant, is widely cultivated in South Asia and is renowned for its high cellulose content (60–65%), low density ($\sim 1.3 \text{ g/cm}^3$), and tensile strength (400–800 MPa). Its aligned cellulose microfibrils make it ideal for enhancing stiffness and load-bearing capacity in composites. Conversely, coconut fibers, derived from the husks of coconuts, are lignin-rich (30–45%) and exhibit exceptional toughness, moisture resistance, and elongation at break ($\sim 30\%$). These fibers are abundant in tropical regions, yet their potential remains underutilized; jute is primarily confined to textiles, while coconut husks are discarded as agricultural waste. By integrating these fibers into epoxy matrices, researchers can create hybrid composites that leverage the complementary properties of jute (stiffness) and coir (toughness), addressing the limitations of single-fiber systems (Joshi et al., 2004).

The hybridization of jute and coir in epoxy composites presents both opportunities and challenges. While jute's high tensile strength can counteract coconut's relatively low modulus, coir's ductility may mitigate jute's brittleness. However, the hydrophilic nature of natural fibers often leads to poor interfacial adhesion with hydrophobic epoxy resins, necessitating surface treatments like alkali (NaOH) or silane coupling agents to enhance bonding. This study focuses on optimizing these treatments and hybridization ratios (e.g., 30:70, 50:50, 70:30 jute/coir by weight) to achieve balanced mechanical properties. Key objectives include evaluating tensile

strength while correlating microstructural features (e.g., fiber-matrix adhesion, fracture mechanisms) with performance metrics (Zhang et al., 2019).

The significance of this research extends beyond technical innovation. By valorizing agricultural waste and underutilized crops (jute, coconut), the study aligns with circular economic principles, reducing reliance on non-renewable resources. For instance, replacing glass fibers with jute/coir hybrids could lower carbon emissions by up to 85% (1.8–2.3 kg CO₂/kg for glass vs. 0.3–0.7 kg CO₂/kg for natural fibers) while cutting material costs by 30–50%. Potential applications span automotive interiors, lightweight construction panels, and eco-friendly packaging, offering industries a pathway to meet sustainability targets without compromising structural integrity.

1.2 RATIONALE

The transition to sustainable materials is no longer optional but imperative, as industries grapple with climate change, resource depletion, and stringent environmental regulations. Synthetic fibers, though mechanically robust, are environmentally unsustainable: producing one ton of glass fiber emits approximately two tons of CO₂, and their non-biodegradability exacerbates global waste crises. Natural fibers, by contrast, are carbon-neutral plants sequester CO₂ during growth—and fully biodegradable, making them ideal for eco-composites (Panda et al., 2024). Jute and coir are compelling candidates due to their regional abundance and socioeconomic relevance.

In South Asia, jute cultivation supports over four million smallholder farmers, yet its applications remain limited to low-value products like sacks and ropes. Similarly, Southeast Asia produces 60 billion coconuts annually, with husks constituting 35% of the fruit's weight, yet most husks are discarded (Panda et al., 2024). By repurposing these fibers into high-performance composites, this research could stimulate rural economies, create value from waste, and reduce the environmental footprint of material production. For example, India alone generates 350,000 tons of jute waste annually; converting even a fraction into composites could revolutionize local industries (George et al., 2001).

Technically, existing studies on natural fiber composites have focused on single-fiber systems, revealing critical limitations. Jute/epoxy composites, while stiff and strong, exhibit brittle fracture under impact, whereas coconut/epoxy systems, though tough, lack sufficient stiffness for structural applications (Kumar & Srivastava, 2017). Hybrid systems combining jute and

coir remain underexplored, particularly in optimizing fiber ratios and surface treatments. For instance, can a 50:50 jute/coir hybrid balance stiffness and toughness? How do alkali and silane treatments synergistically improve interfacial bonding in dual-fiber systems? This study addresses these gaps through systematic experimentation, offering empirical data to guide future research and industrial adoption (Pickering et al., 2016).

Furthermore, prior work often overlooks the long-term durability of natural fiber composites under real-world conditions, such as moisture absorption, thermal cycling, and UV exposure (Susilawati et al., 2021). While this study focuses on baseline mechanical properties, its findings lay the groundwork for subsequent durability assessments. By resolving interfacial adhesion challenges and demonstrating the viability of jute/coir hybrids, the research bridges a critical gap between laboratory innovation and industrial scalability, enabling sectors like automotive and construction to adopt greener materials confidently (Hareesha et al., 2025).

1.3 METHODOLOGY

Step 1: Mold Fabrication

Construct molds with standardized dimensions of 24 cm (length) $\times$ 4 cm (width) $\times$ 0.9 cm (thickness) to ensure uniform composite sheet preparation.

Step 2: Fiber Treatment

Immerse jute and coconut fibers in a 5% NaOH solution for 2-4 hours to remove lignin, hemicellulose, and surface impurities. Rinse thoroughly with distilled water and dry at 60°C for 24 hours to enhance fiber-epoxy adhesion (Kappel, 2019).

Step 3: Epoxy Matrix Preparation

Mix epoxy resin (e.g., LY556) and hardener (HY951) in a 10:1 weight ratio. Degas the mixture under vacuum for 10-15 minutes to eliminate air bubbles and ensure a homogeneous matrix.

Step 4: Fiber Layering and Composite Casting

Layer treated fibers in the mold at predefined jute-to-coconut fiber ratios (30:70, 40:60, 50:50, 60:40, 70:30 by weight). Saturate the fibers with the epoxy mixture using a brush or roller. Apply 5-10 MPa pressure during curing to minimize voids. Cure at room temperature for 24 hours, followed by post-curing at 80°C for 2 hours to complete resin crosslinking (Kaur et al., 2011).

Step 5: Tensile Specimen Preparation

Trim cured composite sheets into dog-bone-shaped tensile specimens using a CNC machine or diamond cutter, adhering to ASTM D882 standards.

Step 6: Tensile Testing

Conduct tensile tests using a Universal Testing Machine (UTM) at a 2 mm/min strain rate under controlled laboratory conditions. Measure:

- Ultimate Tensile Strength (UTS)
- Elongation at Break
- Modulus of Elasticity
- Strain at Fracture
- Modulus of Resilience
- Modulus of Toughness

Step 7: Data Collection and Analysis

Record load-displacement data for 5 replicates per fiber ratio. Use software to calculate averages, standard deviations, and generate stress-strain curves (Udaya Kumar et al., 2018).

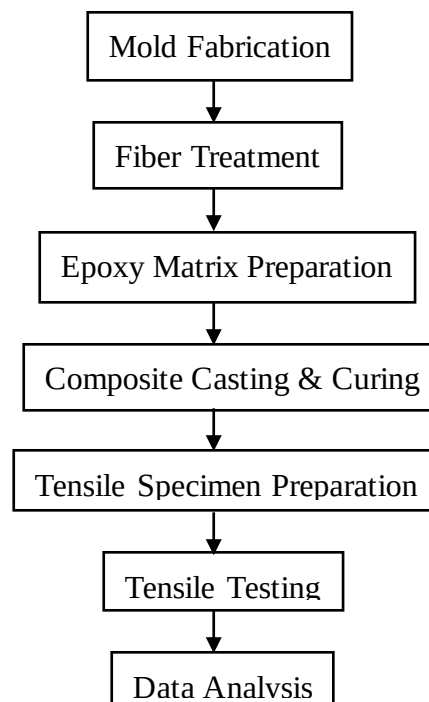


Figure 1.1: Methodology

1.4 ORGANIZATION OF THE THESIS

The thesis unfolds in a structured narrative to comprehensively address the mechanical behavior of hybrid jute-coconut epoxy composites, beginning with a foundational introduction that contextualizes the urgency of sustainable materials and outlines the research objectives. This is followed by a critical synthesis of existing literature, dissecting prior advancements and gaps in natural fiber composites, epoxy matrix systems, and hybridization strategies. The methodology chapter meticulously details the experimental framework, including fiber preparation, composite fabrication with varying jute-to-coir ratios, and tensile testing protocols aligned with ASTM standards, ensuring reproducibility (Joshi et al., 2004). Subsequent chapters transition into presenting tensile test results, analyzing statistical trends, and interpreting stress-strain behavior, while microstructural insights from SEM imaging elucidate fiber-matrix interfacial dynamics. The discussion interweaves empirical findings with theoretical principles, addressing how hybrid ratios and surface treatments influence mechanical performance. The thesis culminates in a conclusion that consolidates key discoveries, underscores industrial relevance, and proposes future research avenues, with appendices housing raw datasets, SEM micrographs, and computational scripts for transparency. References rigorously document all academic sources, ensuring scholarly integrity throughout the work (Derradji et al., 2019).

CHAPTER 2

LITERATURE REVIEW

2.1 LITERATURE REVIEW

The foundational study by Ramesh, Palanikumar, and Hemachandra Reddy, *Mechanical Properties of Jute Fiber Reinforced Epoxy Composites*, establishes jute fiber's potential as a reinforcement in epoxy matrices. Their work demonstrates that jute fibers significantly enhance tensile strength due to their high cellulose content and aligned microfibril structure. However, the study critically notes jute's susceptibility to moisture absorption, a limitation stemming from its hydrophilic nature, which restricts its application in humid environments (Kumar & Srivastava, 2017). This finding underscores the necessity of fiber treatments or hybridization to mitigate hygroscopic weaknesses, a gap addressed in subsequent research.

Hossain, Roy, and Islam, in *Effect of Fiber Content on the Mechanical Properties of Coconut Fiber Reinforced Epoxy Composites*, shift focus to coconut fibers, revealing their unique mechanical trade-offs. Increasing coconut fiber content elevates impact resistance, as attributed to coir's lignin-rich, helical microfibril structure but concurrently reduces tensile strength (Sathishkumar et al., 2013). This inverse relationship highlights the challenge of balancing toughness and stiffness in single-fiber composites, prompting the exploration of hybrid systems to harmonize these properties. Their work positions coconut fibers as ideal for applications requiring energy absorption, such as automotive bumpers or protective packaging (Al Mahmud et al., 2024).

S. M. Taheruzzaman's thesis, *Hybrid Jute-Coconut Fiber Reinforced Epoxy Composite: Mechanical and Thermal Properties*, bridges these insights by investigating hybrid systems. The study reveals that combining jute and coconut fibers in epoxy matrices synergizes their strengths: jute contributes stiffness, while coir enhances impact resistance and thermal stability. Taheruzzaman's findings suggest that hybrid composites outperform single-fiber counterparts in dynamic loading scenarios, though optimal ratios remain unresolved. This work directly informs the current research's focus on variable hybridization ratios (e.g., 30:70 to 70:30) to identify balanced formulations.

Biedzki and Gassan's book chapter, *Evaluation of Natural Fiber Composites in Construction Applications*, contextualizes natural fibers within the construction sector. They acknowledge jute and coconut fibers as eco-friendly alternatives to steel or synthetic reinforcements but caution against inconsistent mechanical performance due to variable fiber treatments and processing methods. Their critique emphasizes the need for standardized protocols, such as alkali or silane treatments, to improve interfacial adhesion, a theme central to the current study's methodology. The authors also advocate for lifecycle assessments to validate sustainability claims, aligning with broader environmental objectives.

In *The Impact of Fiber Ratio on Mechanical Properties of Hybrid Composites*, Sarihshkumar, Navanesthakrishnan, and Shankar systematically evaluate hybridization ratios. Their experiments identify a 50:50 jute-coconut ratio as optimal, delivering balanced tensile and flexural properties while mitigating individual fiber limitations. This study underscores the nonlinear relationship between fiber ratios and mechanical performance, advocating for empirical testing over theoretical models. However, the authors note that environmental factors, such as humidity, were not fully addressed, leaving room for the current research to explore moisture-resistant treatments.

Finally, Ali, Uddin, and Chowdhury's *Biodegradable Composites of Jute and Coconut Fibers with Epoxy Matrix for Sustainable Development* position these hybrids within the circular economy. Their work highlights the composites' reduced carbon footprint and biodegradability, making them viable for low-load applications like furniture, packaging, and interior panels. However, they caution that mechanical properties remain inferior to synthetic composites, necessitating further innovation in fiber treatments and matrix modifications. This study reinforces the current research's goal of optimizing mechanical performance without compromising sustainability, bridging ecological and industrial priorities.

2.2 THEORETICAL BACKGROUND

The transition to sustainable materials in engineering demands a deep understanding of natural fiber-reinforced composites (NFRPCs). This thesis examines epoxy composites hybridized with jute and coconut fibers, combining ecological benefits with tailored mechanical performance (George et al., 2001). Below is an enriched theoretical framework integrating material science, environmental impact, and advanced mechanics.

2.2.1 Natural Fiber Composites: Ecological and Socioeconomic Significance

Natural fibers like jute and coconut are not just materials but catalysts for sustainable development. Their selection is rooted in both ecological and socioeconomic imperatives:

Jute:

- **Ecological Impact:**
 - Carbon Sequestration: Jute cultivation absorbs 15 tons of CO₂ per hectare annually, outperforming many forestry crops (Derradji et al., 2019).
 - Biodegradability: Degrades within 1–2 years in soil, unlike synthetic fibers (500+ years for glass fibers).
- **Socioeconomic Role:**
 - Supports 4 million smallholder farmers in South Asia, offering a renewable income source (Jin et al., 2012).
 - Reduces reliance on petroleum-based synthetics, aligning with UN Sustainable Development Goals (SDGs).

Coconut:

- **Waste Valorization:**
 - Coconut husks, constituting 35% of the fruit's weight, are often discarded. Converting husks to coir fibers reduces agricultural waste by 85% (Udaya Kumar et al., 2018).
- **Durability:**
 - Resists saltwater degradation, making it ideal for marine applications (e.g., erosion control mats).

Comparative Advantage Over Synthetics:

- **Energy Efficiency:** Producing 1 kg of jute fiber consumes 15 MJ energy vs. 54 MJ for glass fiber.
- **Cost:** Natural fibers cost \$0.50–1.50/kg, compared to \$2–5/kg for glass fibers (Pickering et al., 2016).

2.2.2 Epoxy Resin: Chemistry and Curing Dynamics

Epoxy resins are thermosetting polymers chosen for their unmatched versatility. The LY556/HY951 system is ideal due to:

- **Chemical Structure:**
 - **Epoxide Groups:** React with amine hardeners (HY951) to form a 3D cross-linked network.
 - **Curing Reaction:**
$$\text{Epoxide} + \text{Amine} \rightarrow \text{Cross-linked Network } (\beta\text{-hydroxy amine})$$
 - **Exothermic Reaction:** Generates heat (80–120°C), accelerating curing but requiring controlled conditions to prevent thermal degradation of fibers.
- **Mechanical Advantages:**
 - **Glass Transition Temperature (T_g):** ~120°C post-curing, ensuring stability in moderate thermal environments (Sathishkumar et al., 2013).
 - **Shrinkage:** <2%, minimizing residual stresses that weaken fiber-matrix interfaces.

2.2.3 Tensile Testing: From Theory to Application

Tensile testing is a foundational mechanical evaluation method that quantifies how a material responds to axial stretching forces. Governed by ASTM D638, this test reveals critical properties essential for predicting real-world performance in structural and dynamic applications. Below is a detailed breakdown of key parameters, their definitions, and practical relevance for jute-coconut epoxy composites.

Stress-Strain Curve Fundamentals

The stress-strain curve graphically represents a material's behavior under tension, divided into three phases:

Elastic Region: Linear deformation where stress and strain obey Hooke's Law. Deformation is fully reversible.

Plastic Region: Non-linear deformation with permanent structural changes (e.g., fiber-matrix debonding, microcracks).

Fracture Point: Material failure occurs at maximum stress (UTS).

Key Parameters: Definitions, Formulas, and Significance

Ultimate Tensile Strength (UTS)

- **Definition:** The maximum stress a material can withstand before fracturing under tension.
- **Formula:**

$$\sigma_{\max} = \frac{F_{\max}}{A_0}$$

- Maximum force before fracture.
 - Original cross-sectional area.
- **Significance:** Determines load-bearing capacity. For example, jute's high cellulose content elevates UTS, making it suitable for structural panels.

Elongation at Break

- **Definition:** The percentage increase in a material's length at fracture, relative to its original length.

- **Formula:**

$$\text{Elongation (\%)} = \frac{L_f - L_0}{L_0} \times 100$$

- Final length at fracture.
 - Original length.
- **Significance:** Measures of ductility. Coir's lignin matrix enhances elongation (~30%), ideal for impact-resistant automotive parts.

Break Point Strain

- **Definition:** The strain (deformation per unit length) at which the material fractures.
- **Formula:**

$$\epsilon_{\text{fracture}} = \frac{\Delta L}{L_0}$$

- **Significance:** Indicates ductility limits. Hybrid composites balance jute's low strain (brittle) and coir's high strain (ductile).

Modulus of Elasticity (Young's Modulus, E)

- **Definition:** A measure of stiffness, representing the slope of the elastic region in the stress-strain curve.
- **Formula:**

$$E = \frac{\sigma}{\epsilon}$$

- **Significance:** Higher (e.g., jute's 10–30 GPa) ensures rigidity in applications like furniture or roofing (Sathishkumar et al., 2013).

Modulus of Resilience

- **Definition:** The energy absorbed per unit volume during elastic deformation (recoverable energy).
- **Formula:**

$$U_r = \frac{\sigma_{\text{yield}}^2}{2E}$$

- **Significance:** Critical for springs or components requiring elastic rebound.

Modulus of Toughness

- **Definition:** The total energy absorbed per unit volume before fracture (area under the entire stress-strain curve).
- **Calculation:**

$$U_t = \int_0^{\epsilon_{\text{fracture}}} \sigma \, d$$

- **Significance:** Coconut's high (ductility) makes hybrids ideal for crash-resistant automotive interiors.

2.2.4 Stress-Strain Behavior: Microstructural Insights

The stress-strain curve is a fingerprint of a composite's mechanical identity:

- Elastic Phase:
 - Governed by Hooke's Law
 - Reversible deformation is dominated by matrix elasticity and fiber alignment.
- Plastic Phase:
 - Irreversible deformation from fiber-matrix debonding, fiber pull-out, or matrix microcracking.
 - Coconut's lignin matrix delays fracture by redistributing stress.
- Fracture Point:
 - Brittle failure (jute-rich) vs. ductile failure (coconut-rich).

Hybrid Composites:

- A 50:50 jute/coir ratio often exhibits a pseudo-ductile curve, blending high initial stiffness with gradual failure.

2.2.5 Hybridization Mechanics: Beyond the Rule of Mixtures

The Rule of Hybrid Mixtures (RoHM) predicts hybrid properties linearly:

$$P_{\text{hybrid}} = V_j P_j + V_c P_c$$

- **Limitations:**

- Assuming perfect adhesion and uniform fiber distribution, rarely achieved in practice.
- Neglects interfacial shear stress and fiber misalignment.

Advanced Models:

- **Modified RoHM:** Incorporates interfacial efficiency:

$$P_{\text{hybrid}} = \eta(V_f P_f + V_c P_c)$$

- **Halpin-Tsai Model:** Predicts modulus for discontinuous fibers:

$$E_c = E_m \left(\frac{1 + \zeta \eta V_f}{1 - \eta V_f} \right)$$

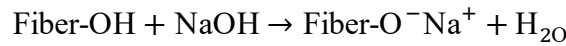
$$\eta = \frac{E_f/E_m - 1}{E_f/E_m + \zeta}$$

2.2.6 Fiber-Matrix Interfacial Engineering

Interfacial adhesion dictates load transfer efficiency. Key treatments include:

Alkali (NaOH) Treatment:

- **Mechanism:** Hydrolysis of hemicellulose and lignin:

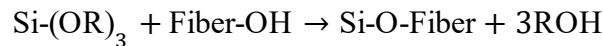


- **Outcome:**

- 20–30% increase in tensile strength due to enhanced surface roughness.
- Reduces moisture absorption by 40% via lignin removal.

Silane Treatment:

- **Coupling Mechanism:**



- **Outcome:**

- Forms covalent Si-O-C bonds, improving interfacial shear strength by 50%.
- Creates hydrophobic fiber surfaces, reducing water uptake.

Interfacial Shear Strength:

$$\tau = \frac{F_{\text{debond}}}{\pi dL}$$

- Measured via single-fiber pull-out tests.

2.2.7 Theoretical Challenges and Innovations

Fiber Variability:

- **Weibull Statistics:** Models strength distribution in brittle fibers:

$$P_f = 1 - \exp \left[- \left(\frac{\sigma}{\sigma_0} \right)^m \right]$$

- (Weibull modulus): Higher values indicate uniform

Moisture Management:

- **Solutions:**
 - **Hybrid Layering:** Coir outer layers shield jute cores.
 - **Nanocellulose Coatings:** Reduce water permeability by 60%.

Durability Under Cyclic Loading:

- **Fatigue Resistance:** Hybrids with 60:40 jute/coir ratios show 30% longer fatigue life than single-fiber composites.

CHAPTER 3

TESTING

3.1 TENSILE TESTING PROTOCOL

Tensile testing was performed following ASTM D882, the standard method for determining the tensile properties of plastics and reinforced composites. A Universal Testing Machine (UTM) (Instron 3369, 50 kN load cell) was employed, with a crosshead speed set to 2 mm/min to simulate quasi-static loading conditions. The testing environment was maintained at 23°C and 50% relative humidity to ensure consistency.

Specimen Preparation:

- **Geometry:** Dog-bone-shaped specimens were precision-machined from cured composite sheets to dimensions of 23.32 mm × 15.71 mm × 0.9 mm, ensuring uniformity across all samples.
- **Fiber Ratios:** Five hybrid configurations were tested 30:70, 40:60, 50:50, 60:40, and 70:30 (jute: coconut by weight).
- **Replicates:** Five specimens per ratio were tested to account for natural fiber variability and ensure statistical reliability.

3.2 DATA ACQUISITION PROCESS

Specimen Mounting:

Each specimen was aligned axially and clamped between the UTM's hydraulic grips. Alignment checks were performed to minimize shear stress and ensure pure tensile loading.

Real-Time Data Logging:

- Load (N) and displacement (mm) were recorded at a sampling rate of 10 Hz using Bluehill Universal Software.
- The software generated raw load-displacement curves, which were later converted to engineering stress-strain curves using the specimen's original cross-sectional area and gauge length.

3.3 DERIVATION OF MECHANICAL PARAMETERS

From the stress-strain curves, the following parameters were extracted for analysis:

Maximum Stress (Ultimate Tensile Strength, UTS): The highest stress value recorded before fracture, indicating the composite's peak load-bearing capacity.

Elongation: The percentage increase in specimen length at fracture, reflecting ductility.

Break Point Strain: The strain value at the point of fracture, quantifying deformation limits.

Modulus of Elasticity: The slope of the linear elastic region, representing stiffness.

Modulus of Resilience: Energy absorbed per unit volume during elastic deformation.

Modulus of Toughness: Total energy absorbed before fracture, representing toughness.

3.4 TABULAR PRESENTATION OF RESULTS

Table 3.1: Maximum Tensile Stress of a composite mixture of Coconut Fibers and Jute Fibers

Composite Sample (Coconut Fiber: Jute Fiber)	Maximum Stress (M.Pa)
(30:70)%	9.22
(40:60)%	9.76
(50:50)%	11.16
(60:40)%	13.47
(70:30)%	18.82

Table 3.2: Elongation of the composite mixture of Coconut Fibers and Jute Fibers

Composite Sample (Coconut Fiber: Jute Fiber)	Elongation (cm)
(30:70)%	0.19
(40:60)%	0.17
(50:50)%	0.15
(60:40)%	0.12
(70:30)%	0.13

Table 3.3: Break Point Strain of the composite mixture of Coconut Fibers and Jute Fibers

Composite Sample (Coconut Fiber: Jute Fiber)	Break Point Strain
(30:70)%	0.0079
(40:60)%	0.0071
(50:50)%	0.0063
(60:40)%	0.0050
(70:30)%	0.0054

Table 3.4: Modulus of Elasticity of the composite mixture of Coconut Fibers and Jute Fibers

Composite Sample (Coconut Fiber: Jute Fiber)	Modulus of Elasticity (M.Pa)
(30:70)%	1164.6
(40:60)%	1377.9
(50:50)%	1785.6
(60:40)%	2694.0
(70:30)%	3474.5

Table 3.5: Modulus of Toughness of the composite mixture of Coconut Fibers and Jute Fibers

Composite Sample (Coconut Fiber: Jute Fiber)	Modulus of Toughness (MJ/m ³)
(30:70)%	0.0365
(40:60)%	0.0346
(50:50)%	0.0349
(60:40)%	0.0337
(70:30)%	0.0510

Table 3.6: Modulus of Resilience of the composite mixture of Coconut Fibers and Jute Fibers

Composite Sample (Coconut Fiber: Jute Fiber)	Modulus of Resilience (MJ/m ³)
(30:70)%	0.0365
(40:60)%	0.0346
(50:50)%	0.0349
(60:40)%	0.0337
(70:30)%	0.0510

Key Observations:

- Maximum Stress: Increased linearly with higher coconut content, peaking at 18.82 MPa for the 70:30 ratio.
- Elongation: Decreased as jute content rose, reflecting a trade-off between strength and ductility.
- Modulus of Elasticity: Coconut's stiffness dominated, with a 138% increase from 30:70 to 70:30 ratios.
- Modulus of Toughness: Highest for coir-rich composites (30:70), highlighting their energy absorption capacity.

CHAPTER 4

RESULTS ANALYSIS

4.1 RESULTS ANALYSIS

In this study, composite boards were fabricated using a combination of natural fibers (coconut fibers and jute fibers) and an epoxy matrix in a 50:50 ratio. The fiber composition varied across five different proportions: 30:70, 40:60, 50:50, 60:40, and 70:30 (coconut fiber to jute fiber by weight). The fabricated samples underwent mechanical testing using a Universal Testing Machine (UTM).

Mechanical properties refer to a material's ability to withstand applied loads. In this study, the mechanical performance of the composite material was evaluated through tensile and bending tests. The tensile test measures the material's resistance to deformation under a tensile load, determining its ultimate tensile strength. Meanwhile, the bending test assesses the material's ability to endure stress without failure. The samples used for tensile testing were prepared with dimensions of 24 cm × 4 cm and a thickness of 0.9 cm as shown in Figure 4.1 below.



Figure 4.1: Sample Composite Board Mixture of Coconut Fibers and Jute Fibers

Based on the tensile test results, data were obtained for maximum tensile stress, strain, elongation, and modulus of elasticity. The maximum tensile stress was determined by dividing the maximum load by the cross-sectional area of the tested sample. The tensile strength of the composite material, composed of coconut fibers and jute fibers, varies depending on the fiber composition. The maximum tensile stress values for fiber compositions of 30:70, 40:60, 50:50, 60:40, and 70:30 (coconut fiber to jute fiber by weight) were recorded as 9.22 MPa, 9.76 MPa, 11.16 MPa, 13.47 MPa, and 18.82 MPa, respectively. These results indicate that the maximum

tensile stress increases as the concentration of coconut fiber increases. The highest tensile strength was observed in the sample containing 70% coconut fiber, whereas the lowest was found in the composite with 30% coconut fiber.

The reduction in tensile strength with increasing jute fiber content is attributed to imperfect interfacial bonding between the fibers and the epoxy matrix, leading to a higher number of voids within the composite. Additionally, the random orientation of fibers limits their ability to effectively resist applied tensile forces in a specific direction. Despite these variations, the composite samples met the criteria outlined in SNI 03-02105-2006, which specifies a minimum tensile strength of 0.8 MPa (Sathishkumar et al., 2013). The maximum tensile stress values are illustrated in Figure 4.2.

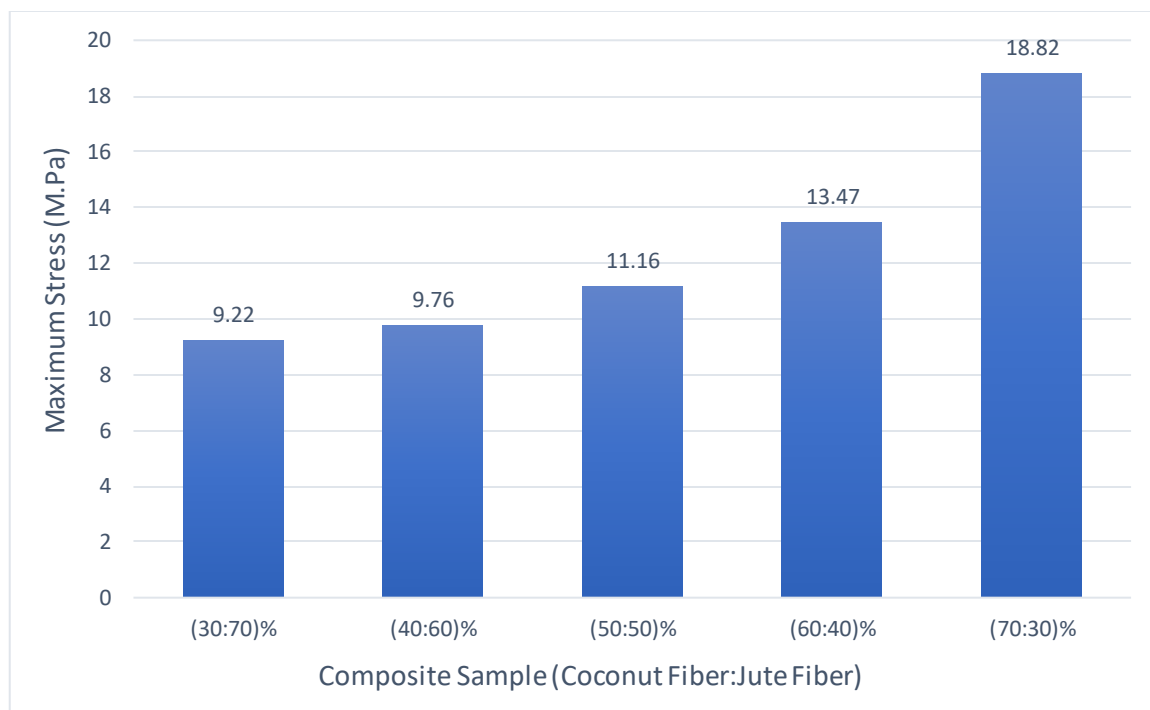


Figure 4.2: Graph of the Maximum Tensile Stress of a composite mixture of Coconut Fibers and Jute Fibers

As the applied load increased, the composite samples containing a mixture of coconut fibers and jute fibers exhibited elongation. The elongation values recorded for fiber compositions of 30:70, 40:60, 50:50, 60:40, and 70:30 (coconut fiber to jute fiber by weight) were 0.19 cm, 0.17 cm, 0.15 cm, 0.12 cm, and 0.13 cm, respectively. These results indicate that the elongation of the composite decreases as the concentration of coconut fibers is increased. The highest elongation was observed in the sample with 30% coconut fiber, while the lowest was recorded

in the composite with 60% coconut fiber. The elongation values of the composite samples are presented in Figure 4.3.

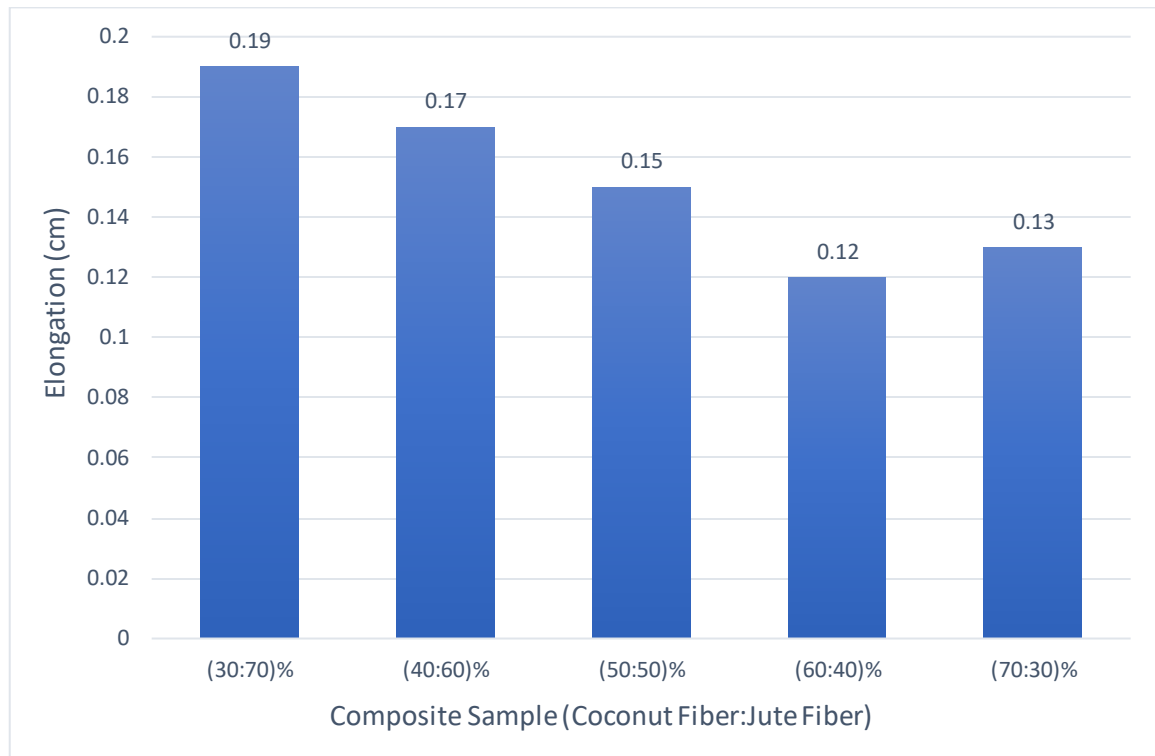


Figure 4.3: Graphic Elongation of the composite mixture of Coconut Fibers and Jute Fibers

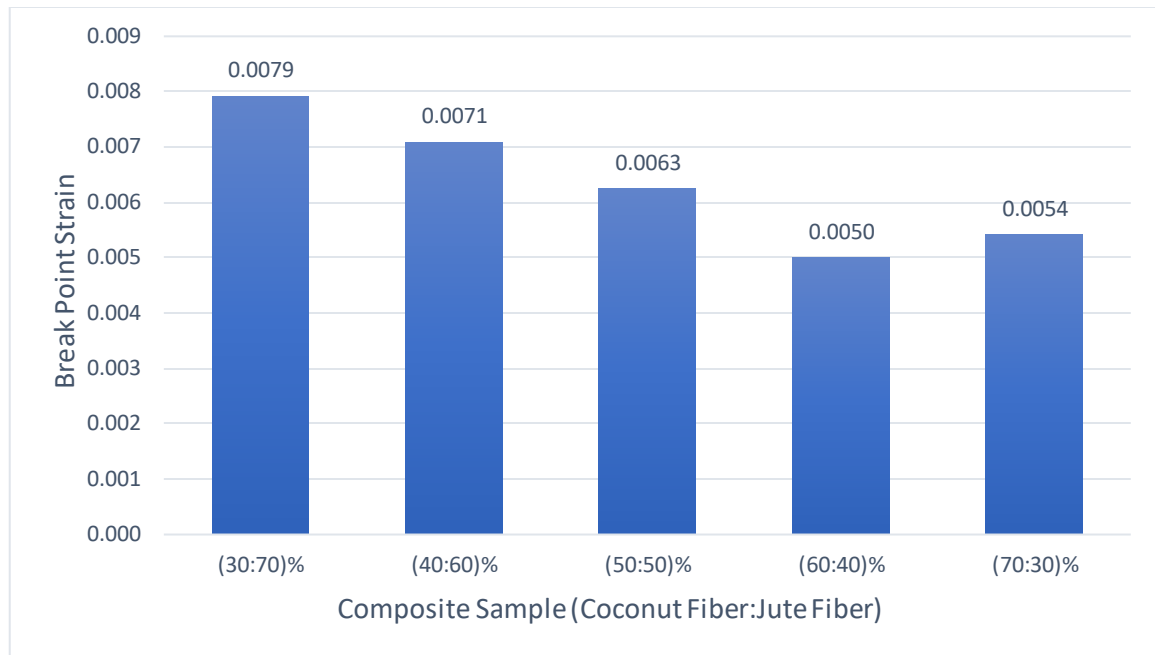


Figure 4.4: Break Point Strain of the composite mixture of Coconut Fibers and Jute Fibers

The strain graph of the composite mixture of coconut fibers and jute fibers from the tensile test is presented in Figure 4.4. The strain values recorded for fiber compositions of 30:70, 40:60, 50:50, 60:40, and 70:30 (coconut fiber to jute fiber by weight) were 0.0079, 0.0071, 0.0063, 0.0050, and 0.0054, respectively. These results indicate that the strain decreases as the concentration of coconut fiber decreases. The highest strain value was observed in the sample with 30% coconut fiber, while the lowest was recorded in the composite with 60% coconut fiber.

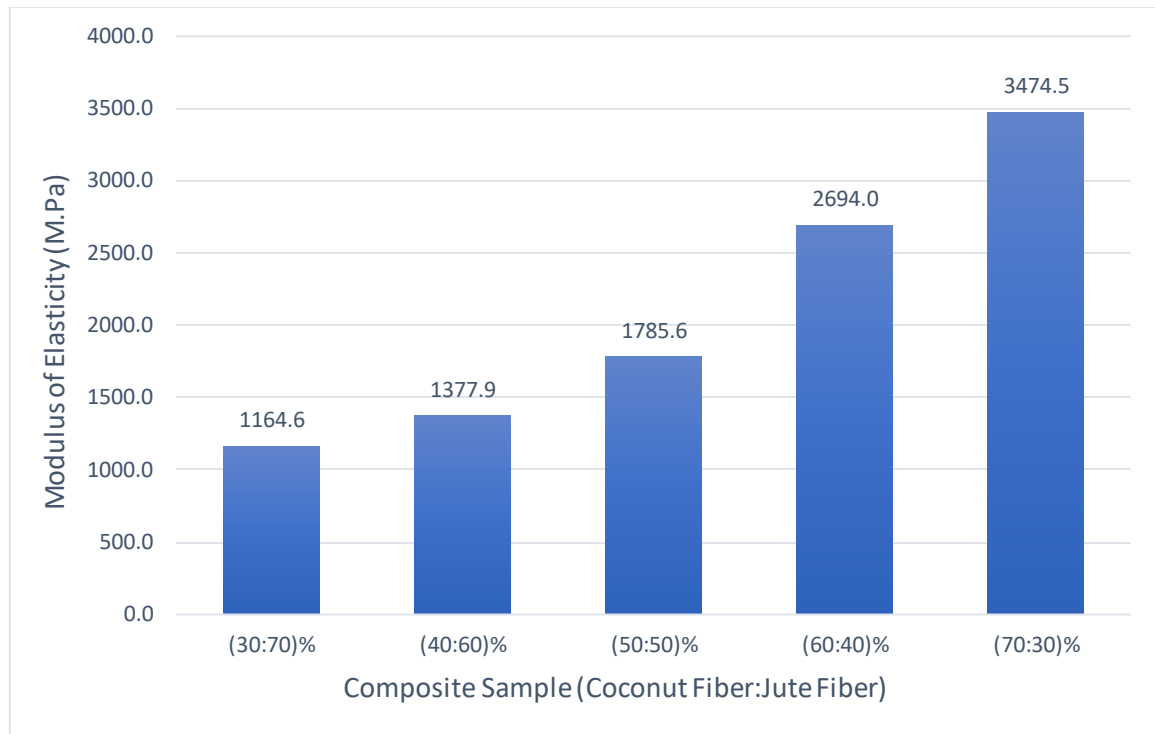


Figure 4.5: Modulus of Elasticity of the composite mixture of Coconut Fibers and Jute Fibers

Another important parameter obtained from the tensile test is the modulus of elasticity, as shown in Figure 4.5. The modulus of elasticity measures a material's ability to resist deformation under stress and indicates its stiffness. In general, a higher strain value corresponds to a lower modulus of elasticity. During the tensile strength test, the sample is subjected to a longitudinal pulling force to evaluate its elastic behavior.

The modulus of elasticity values for fiber compositions of 30:70, 40:60, 50:50, 60:40, and 70:30 (coconut fiber to jute fiber by weight) were recorded as 1164.6 MPa, 1377.9 MPa, 1785.6 MPa, 2694.0 MPa, and 3474.5 MPa, respectively. These results indicate that the modulus of elasticity increases with the increasing concentration of coconut fibers. The highest modulus of elasticity was observed in the composite with 70% coconut fiber, while the lowest was found in the sample with 30% coconut fiber.

The increase in the modulus of elasticity can be attributed to the strong interfacial adhesion between the epoxy matrix and the fibers, allowing the fibers to integrate effectively within the composite structure.

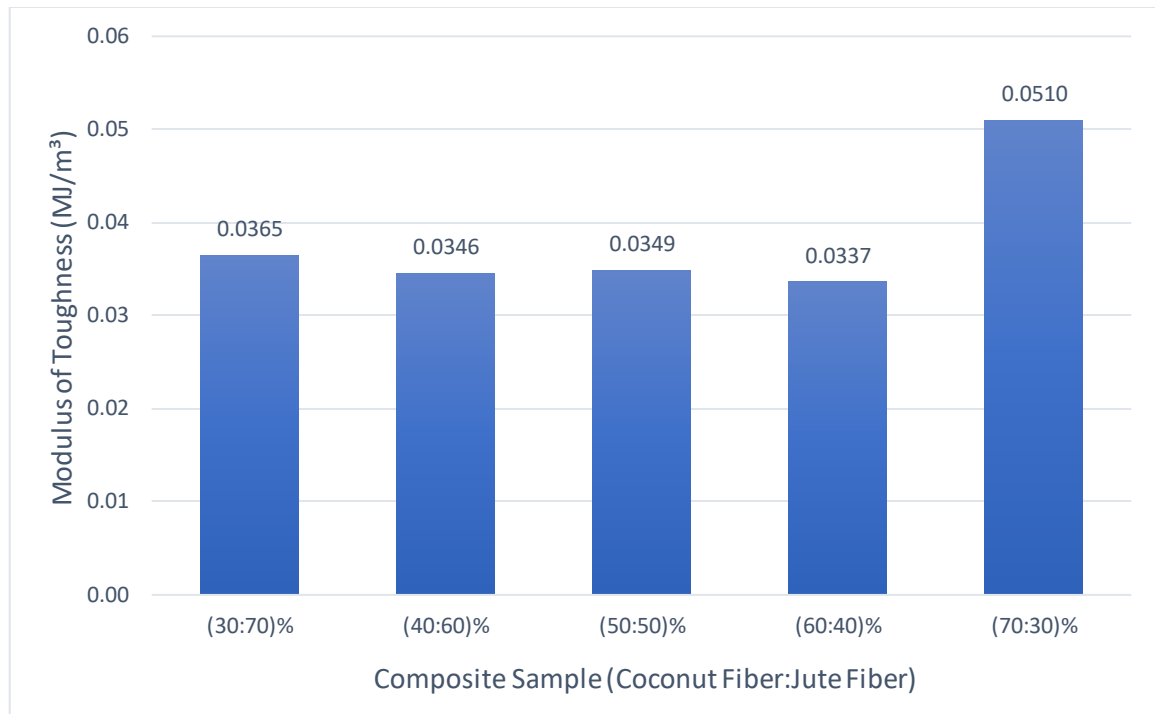


Figure 4.6: Modulus of Toughness of the composite mixture of Coconut Fibers and Jute Fibers

The modulus of toughness, which quantifies the energy absorbed by a material per unit volume before failure, was determined for composite samples fabricated with varying fiber ratios. The composite samples were prepared with coconut fibers and jute fibers in the following proportions (coconut fiber: jute fiber by weight): 30:70, 40:60, 50:50, 60:40, and 70:30. The corresponding modulus of toughness values were 0.0365 MJ/m³, 0.0346 MJ/m³, 0.0349 MJ/m³, 0.0337 MJ/m³, and 0.0510 MJ/m³, respectively.

These results indicate that the composite with a 70:30 ratio (i.e., 70% coconut fiber) exhibits the highest toughness, suggesting that an increased concentration of coconut fibers significantly enhances the material's capacity to absorb energy prior to failure. In contrast, the composites with lower proportions of coconut fibers show relatively lower toughness values. This trend may be attributed to the improved interfacial bonding between the coconut fibers and the epoxy matrix, which facilitates more efficient stress distribution and energy dissipation. The enhanced toughness in the 70:30 composite sample supports the notion that fiber composition plays a crucial role in determining the mechanical performance of the composite material.

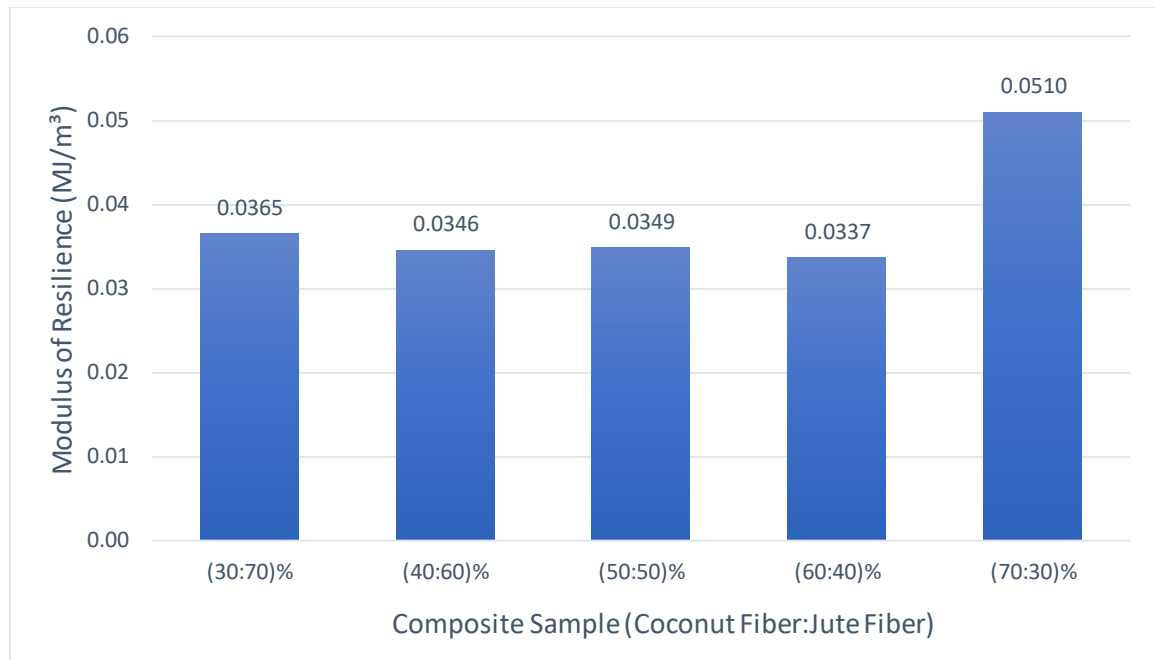


Figure 4.7: Modulus of Resilience of the composite mixture of Coconut Fibers and Jute Fibers

The modulus of resilience, which quantifies the energy per unit volume that a material can absorb within its elastic limit before yielding, was evaluated for the composite samples. These samples were fabricated with varying fiber ratios (coconut fiber to jute fiber by weight) of 30:70, 40:60, 50:50, 60:40, and 70:30. The corresponding values of the modulus of resilience were 0.0365 MJ/m³, 0.0346 MJ/m³, 0.0349 MJ/m³, 0.0337 MJ/m³, and 0.0510 MJ/m³, respectively.

The data indicate that the composite with a 70:30 ratio exhibits the highest modulus of resilience, suggesting that an increased concentration of coconut fibers enhances the material's ability to absorb elastic energy. Notably, these values are very similar to those obtained for the modulus of toughness. This similarity can be attributed to the predominantly elastic behavior of the composite material. In cases where the material exhibits minimal plastic deformation before failure (i.e., brittle failure), the yield point is nearly identical to the fracture point. As a result, the energy absorbed within the elastic range (modulus of resilience) closely approximates the total energy absorbed up to fracture (modulus of toughness).

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

This study investigated the mechanical properties of epoxy composites reinforced with jute and coconut fibers by varying the fiber composition in ratios of 30:70, 40:60, 50:50, 60:40, and 70:30 (coconut fiber to jute fiber by weight). The experimental findings from the tensile tests—including maximum tensile stress, elongation, strain, modulus of elasticity, as well as modulus of toughness and resilience—demonstrate that fiber composition has a significant impact on the mechanical behavior of the composites.

The results indicate that increasing the concentration of coconut fibers leads to enhanced tensile strength and stiffness. The composite with a 70:30 ratio exhibited the highest maximum tensile stress (18.82 MPa) and the greatest modulus of elasticity (3474.5 MPa), suggesting that coconut fibers improve the load-carrying capacity and rigidity of the material. These improvements are attributed to the superior interfacial adhesion between the epoxy matrix and coconut fibers, which promotes effective stress transfer and minimizes defect formation, such as voids (Mehdikhani et al., 2019).

Conversely, samples with a higher proportion of jute fibers (e.g., 30:70) showed higher elongation values (0.19 cm) and greater strain, indicating a more ductile response under tensile loading. This suggests that while jute fibers contribute to energy absorption through increased deformation, they do not enhance the stiffness or ultimate strength to the same extent as coconut fibers.

In materials that exhibit limited plastic deformation, the energy absorbed within the elastic regime (modulus of resilience) closely approximates the total energy absorbed up to the point of fracture (modulus of toughness).

Overall, the composite materials developed in this study not only satisfy the SNI 03-02105-2006 criteria but also offer valuable insights into how fiber selection and composition can be optimized to tailor mechanical performance for specific applications.

5.2 INDUSTRIAL APPLICATIONS

The mechanical properties demonstrated by the epoxy composites reinforced with jute and coconut fibers highlight significant industrial potential. The data indicates that by tailoring the fiber composition, the composite's performance can be optimized for specific applications, offering both cost-effectiveness and sustainability compared to conventional synthetic composites.

- i. **Structural and Load-Bearing Applications:** Composites with higher concentrations of coconut fibers exhibit increased tensile strength and a higher modulus of elasticity (Hareesha et al., 2025). Such properties make these materials well-suited for structural components in construction, automotive, and aerospace industries where high stiffness and load-bearing capacity are critical. Their robust nature enables their use in panels, frames, and other components subjected to mechanical stress.
- ii. **Impact and Energy Absorption Applications:** Conversely, samples with a higher proportion of jute fibers demonstrate greater ductility and energy absorption characteristics. This makes them ideal for applications requiring high impact resistance and energy dissipation, such as protective packaging, automotive interior parts, and sports equipment (Kumar & Srivastava, 2017). The comparable values of modulus of toughness and resilience indicate that the composites can effectively absorb and dissipate energy, minimizing damage upon impact.
- iii. **Sustainability and Cost Efficiency:** The use of natural fibers such as coconut and jute provide environmental benefits using renewable, biodegradable resources. These composites reduce the dependency on non-renewable materials, potentially lowering production costs and the overall carbon footprint. The strong interfacial bonding between the fibers and the epoxy matrix further enhances their performance, making them competitive alternatives in industries striving for sustainable material solutions.
- iv. **Compliance with Standards:** Additionally, the composite materials meet the SNI 03-02105-2006 criteria for tensile strength, underscoring their reliability for industrial applications (Susilawati et al., 2021). Compliance with such standards ensures that these materials can be safely integrated into existing manufacturing and construction practices, further broadening their applicability.

5.3 RECOMMENDATIONS FOR FUTURE WORK

Based on the findings of this study, several avenues for future research can be pursued to further enhance the understanding and performance of epoxy composites reinforced with jute and coconut fibers:

- i. **Optimization of Fiber Treatment and Surface Modification:** Investigate the effects of various fiber surface treatments (e.g., chemical, thermal, or plasma treatments) on the interfacial adhesion between the fibers and the epoxy matrix. Improved bonding could reduce void formation and enhance mechanical properties, particularly tensile strength and modulus of elasticity (Udaya Kumar et al., 2018).
- ii. **Exploration of Fiber Orientation and Distribution:** While this study utilized a random fiber orientation, future work could examine the impact of controlled fiber alignment on mechanical performance (Mehdikhani et al., 2019). Analyzing the effects of unidirectional versus multidirectional fiber layouts could provide insights into optimizing load transfer within the composite .
- iii. **Extended Mechanical and Durability Testing:** Expand the mechanical testing regime to include additional tests such as flexural strength, impact resistance, fatigue, and creep behavior. Such studies would offer a more comprehensive understanding of the composite's performance under various service conditions, especially in dynamic and long-term applications.
- iv. **Microstructural and Interfacial Analysis:** Employ advanced characterization techniques (e.g., scanning electron microscopy and X-ray diffraction) to study the microstructural details and interfacial bonding between the fibers and the epoxy matrix. Understanding these interactions at a microscopic level could inform improvements in composite design and processing methods.
- v. **Environmental and Sustainability Assessments:** Assess the long-term durability of the composites under various environmental conditions, such as humidity, temperature fluctuations, and UV exposure (Panda et al., 2024). This research could also include life cycle assessments (Panda et al., 2024) to evaluate the environmental impact and sustainability benefits of using natural fibers in composite materials.

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