MECHANICAL PROPERTIES OF EPOXY COMPOSITES REINFORCED WITH NATURAL FIBERS

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MAY 2024

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A Graduation Exercise Submitted to the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science in Mechanical Engineering

DEPARTMENT OF MECHANICAL ENGINEERING

SONARGAON UNIVERSITY (SU) DHAKA, BANGLADESH

MAY 2024

CERTIFICATION OF APPROVAL

The thesis title **"Mechanical Properties Of Epoxy Composites Reinforced With Natural Fibers"** submitted by Md. Roman Babu, Md. Arman Bhuiyan, Md. Al-Mehedi, Syed Irtiza Hossain, Md. Salim Hossain, Jakia Sultana and Farid Ahmed has been accepted as partial fulfillment of the requirement for the degree of bachelor of science in mechanical engineering on May 2024.

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DECLARATION

We hereby declare that this thesis is our own work and to the best of our knowledge it contains no materials previously published or written by another person, or have been accepted for the award of any other degree or diploma at Sonargaon University or any other educational institution. We also declare that the intellectual content of this thesis is the product of our own work and any contribution made to the research by others, with whom we have worked at Sonargaon University or elsewhere, is explicitly acknowledged.

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ACKNOWLEDGEMENT

First and above all, we praise the Almighty Allah for providing us the opportunity, patience and allocating us the capability of completing the thesis for the degree of Bachelor of Science in Mechanical Engineering.

It is a great pleasure to acknowledge our profound gratitude and respect to our supervisor Prof. Md Mostofa Hossain, Head in Mechanical Engineering and all respected teachers in Sonargaon University for their continuous help and support in all stages of this thesis for their consistent guidance, encouragement, helpful suggestion, constructive criticism and endless patience through the progress of this work. The successful completion of this thesis would not have been possible without their persistent motivation and continuous guidance.

We would like to expresses cordial thanks to our loving parents, friends and well- wishers for their cooperation, during the course of this study cheerfulness and inspiration.

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ABSTRACT

This thesis conducts a comprehensive examination of bio-inspired composite materials, focusing on the integration of jute cloth with epoxy reinforced by microfibers derived from coconut and banana. The study employs tensile, bending, and impact tests to thoroughly analyze the mechanical characteristics of these innovative composites. Additionally, scanning electron microscopy (SEM) is utilized to investigate the microstructure of the materials. The primary constituent, jute fabric, is chosen for its sustainability and environmentally friendly attributes, while epoxy serves as the matrix for heightened structural stability. The primary goals of this research are to assess the tensile strength, flexural properties, and impact resistance of the bio-inspired composite material. Through SEM analysis, the microstructure of the composite will be explored to gain insights into the distribution and interaction of fibers within the matrix. The study aims to contribute valuable insights to the evolving field of bio-inspired materials. The results hold promise for various industries seeking environmentally friendly alternatives. Understanding the intricate interactions among jute, epoxy, and natural fibers may pave the way for the development of eco-friendly composite materials with enhanced mechanical attributes. It is crucial to acknowledge the limitations of this study, such as the specific conditions under which tests were conducted and the inherent variability in natural fibers. Additionally, the findings may be influenced by the manufacturing process and variations in fiber composition.

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CHAPTER 1: INTRODUCTION

1.1 Research Background

The creation of eco-friendly and sustainable materials for a variety of uses has recently attracted increasing attention. Natural fibers have drawn a lot of interest because of their availability, affordability, and possible mechanical qualities [1]. Examples include banana, jute, and coconut fibers. These fibers may be mixed with epoxy glue to create composite materials that have better mechanical properties than the sum of their parts [2].These composites' mechanical properties, particularly their tensile, bending, and impact characteristics, offer important information about their functionality and possible uses.

In this study, the tensile, bending, impact and microstructure properties of natural fiber reinforced epoxy laminas with the incorporation of jute fabric, micro banana fibers (10%), and coconut fibers (10%). The initial goal entails creating laminas out of these composite materials. The combination of banana, jute, and coconut fibers with epoxy resin resulted in enhanced tensile strength and modulus due to the reinforcing effect of the fibers. In terms of bending behavior, the presence of natural fibers in the epoxy matrix increased resistance to bending and improved stiffness. The combination of the three natural fibers created a hybrid reinforcement system with a synergistic effect on the bending properties. Additionally the interfacial bonding, leading to improved load transfer and resistance to bending deformation. For impact resistance, the natural fiber- reinforced laminas enhanced toughness and energy absorption capacity. The combination of natural fibers and the interlocking structure of the Rubik's layer allowed for effective energy dissipation during impact events, reducing the risk of failure and damage.

The mechanical characterization of banana, jute, and coconut natural fiber-reinforced epoxy lamina demonstrates their potential as high-performance composite materials. Tensile testing reveals improved strength and stiffness, bending tests showcase enhanced flexural properties, and impact testing demonstrates increased resistance to dynamic loads. These findings open up new avenues for the application of these composites in various industries, including automotive, aerospace, and construction, where sustainable and lightweight materials with excellent mechanical properties are highly desirable [3].

1.2 Problem statement and significance

This research aims to investigate the mechanical properties of epoxy-based laminas reinforced with natural fibers such as jute, banana, and coconut. Additionally, the study seeks to evaluate the potential of these composites as eco-friendly alternatives to conventional materials. The assessment will focus on the tensile, flexural, and impact behaviors of the lamina samples, fabricated using a hand lay-up technique and varying fiber volume fractions. Furthermore, the research will explore the effects of introducing a thin interlayer material between the fibers and epoxy matrix. This interlayer aims to enhance interfacial adhesion and the overall mechanical performance of the composite structure. By concluding these investigations, the study aims to contribute valuable insights into the characteristics of these natural fiber composites and their suitability for diverse technical applications.

1.3 Objective

i. To know the fabrication process of jute, banana, and coconut fiber reinforced epoxy laminas.
ii. To determine the tensile, flexural strength, impact resistant and microstructures of the jute, banana, coconut fiber-reinforced epoxy lamina.
iii. To compare the properties of two composite materials.

CHAPTER 2: LITERATURE REVIEW

Naik et al (2021) studied natural fiber composite materials that have become increasingly popular as a sustainable substitute for synthetic fibers. Scientists have been investigating the potential of utilizing organic fibers like jute, banana, and coconut fibers along with epoxy resin to fabricate composite substances that offer better physical and ecological characteristics [4]. The goal of this article is to present a summary of the studies carried out on natural fiber composites and their possible uses.

Allafi et al (2022) found the engineering industry is increasingly recognizing the value of natural fibers, owing to their abundant supply, lightweight nature, and superior thermal and acoustic insulation properties [5].

Kuriakose et al (2022), composite materials use natural fibers for added reinforcement and predicting the vibration characteristics and damping features of natural fibers holds significant importance. Hemp, jute, banana, and coconut coir fibers have been recognized for their exceptional mechanical qualities and can serve as reinforcing materials in composite materials such as epoxy [6].

Sastra et al (2006) et al investigated that the composites were formulated by integrating epoxy resin with cross-plied jute fibers as well as fibers sourced from bananas and coconuts. The creation of natural fiber composites requires multiple stages in the manufacturing process. Initially, the natural fibers are obtained from their respective sources and then undergo cleansing and dehydration procedures to eliminate any pollutants and dampness [7].

Zimniewska et al (2016) studied the fibers undergo a process where they are exposed to specific chemicals or coupling agents that enhance their capacity to blend well with the epoxy resin matrix. After being treated, the fibers are combined with the epoxy resin and then undergo a curing procedure to solidify the resin Different methods, such as manual placement, compact molding, or air-tight wrapping, are available to create composites in specific forms and dimensions [8].

Crini et al (2010) studied the desired end-product requirements, various finishing techniques including cutting, polishing, and smoothing may be applied during postproduction stages. Jute, banana, and coconut fiber composites mixed with epoxy resin

have a wide range of uses in numerous industries. Due to their lightweight properties and strength, these composites have become popular in the automotive industry for creating interior components like seat backs, dashboards, and door panels [9].

Gholampour et al (20) studied about Sustainable building materials like boards, panels, and roofing tiles are produced using them extensively in the construction sector when it comes to packaging, natural fiber composites offer a sustainable substitute for materials derived from plastic, constituting an eco-conscious solution. These composite materials serve a variety of purposes in industries such as furniture, consumer products, and various other industrial sectors where achieving a balance between cost and environmental concerns is crucial. Using natural fibers in combination with epoxy resin presents several benefits compared to traditional synthetic fiber composites [10].

Fan et al (2017), Natural fibers instead of synthetic ones can decrease the environmental impact because they are renewable and biodegradable. In addition, these products display a minimal usage of energy during their manufacturing process and can be effortlessly discarded without any environmental harm. In addition, the use of natural fibers helps to foster agricultural practices in developing nations, offering revenue to farmers and encouraging sustainable means of living. The combination of jute, banana, and coconut fiber with epoxy resin has displayed potential in creating natural fiber composites that possess better mechanical capabilities and sustainable features. These mixtures possess the capability of taking over synthetic fiber mixtures in diverse uses, leading to a manufacturing industry that is both environmentally and socially aware. Additional investment in research and development is necessary to surmount the obstacles linked to natural fiber composites and broaden their scope of usage [11].

CHAPTER 3: METHODOLOGY

3.1 Introduction

In this thesis paper, we delve into the fascinating realm of new materials, harnessing the inherent qualities of natural fibers that abound in our surroundings. With their effortless collection, ease of fabrication, biodegradability, and eco-friendliness, these fibers present a valuable resource that should not be squandered. By employing a straightforward fabrication method, we can fashion an innovative material imbued with a multitude of unique properties.

At its core, this material represents a novel composition derived from natural fibers, which can be tailored for diverse purposes in our daily lives. Within the realm of composite materials, we encounter a rich tapestry of applications, each serving a distinct function. However, our primary objective lies in the creation of a new material that not only possesses distinctive mechanical properties but also ensures a simple manufacturing process, thus preventing the wastage of these precious fibers.

Composite materials utilizing natural fibers are engineered marvels that amalgamate the advantages offered by both natural fibers and synthetic matrices. Through a synergistic integration of two components, a material is born, boasting augmented properties and superior performance characteristics. This amalgamation offers a promising gateway to an entirely new market of materials, fostering a multitude of applications and generating fresh demand in addition to existing options.

By exploring the concept of new materials harnessed from readily available natural fibers, this paper ventures into a realm where sustainability meets innovation. Through the convergence of nature's bountiful offerings and human ingenuity, we stand at the precipice of unlocking a wealth of possibilities, ultimately leading us toward a future that champions both environmental stewardship and technological advancement.

3.2 Materials and Method

- Banana fiber
- Jute fiber
- Coconut fiver

- Resin and Hardener
- Mold (for casting)
- Pressure weight (for curing)

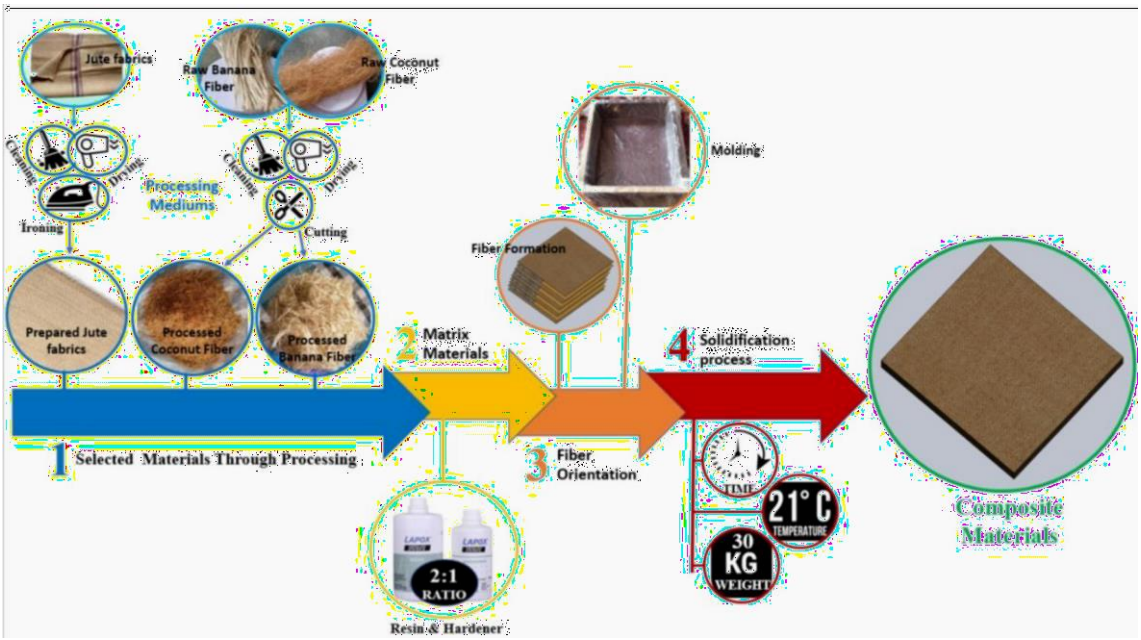


Figure 3.1 Block diagram of composite materials with sequence.

Table: 3.1: Composition of materials.

Name	Percentage
Banana fiber	10%
Jute fiber	70%
Coconut fiver	10%
Resin and Hardener	10%

3.3 Basic materials details:

Some of the basic equipment's are described below:

3.3.1. Banana fiber

Banana fiber is a captivating and renewable gem derived from the stem of the banana plant. With its mesmerizing blend of eco-friendliness and natural allure, it presents itself as a remarkable choice for reinforcing materials in the realm of composites. Possessing inherent strength and a lightweight essence, it adds a touch of enchantment to sustainable applications. These fibers are typically derived from plants and offer advantages like low cost, renewability, low density, and biodegradability.



Figure 3.2. From raw banana trunks to dry banana fiber.

Select mature banana plants with fully grown leaves as the first stage. The outer layers of the pseudo stem are then chopped off close to the ground. The remaining internal fibers are soaked in water for a predetermined period to soften them. After soaking, the fibers are gently separated into long, thin strands and the pulp is scraped away with a knife or a motorized decorticator. When the fibers have dried, they are combed or brushed to separate them and enhance their quality after being cleansed to eliminate any impurities before being dried in the sun or using mechanical drying procedures.

3.3.2. Jute fiber

Jute fiber is a captivating natural gift, known for its sustainable charm, exceptional durability, and remarkable versatility. Cultivated in an eco-friendly manner, possessing high tensile strength, and finding applications across various industries, it elegantly contributes to a wide range of creations while promoting sustainability and innovation.



Figure 3.3 From jute tree's skin to dry jute fiber.

A series of procedures must be followed to extract the jute plant's natural bast fiber. Retting is the first step in the process, which entails soaking harvested jute plants in water to let microorganisms decompose the non-fibrous material around the fiber. After retting, the jute stems are smashed to separate the fibers from the woody core. The last step is stripping, which involves manually removing the fibers from the jute stems. After being stripped, the fibers are thoroughly cleansed to remove impurities before being sun-dried. The process of carding involves straightening, washing, and aligning the fibers with carding machinery after they have dried.

3.3.3. Coconut fiber

Derived from the husk of the majestic coconut fruit, coconut fiber, also known as coir, is a resplendent treasure. With its innate beauty and exceptional characteristics, it emerges as a captivating resource that combines strength, versatility, and ecological harmony. From resilient ropes and mats to sustainable gardening solutions, coconut fiber elegantly weaves its enchanting presence into a multitude of applications, embodying the seamless integration of nature's wonders with human ingenuity.



Figure 3.4 From rip coconut shell to dry coconut fiber.

Harvesting ripe coconuts marks the start of the coconut fiber production process. The coconuts are then physically stripped of their husks before being immersed in water to soften them for a while. The husks are pounded mechanically or manually to remove the fibers from the pith once they have softened. The pith and fibers are freed by the pounding movement. The fibers are then extensively cleaned to get rid of any leftover contaminants. The fibers are dried after washing, either by sun drying or by employing mechanical drying techniques. After drying, the fibers are separated and evaluated according to their length and quality.

3.3.4. Resin and Hardener

The fusion of resin and hardener results in a mesmerizing chemical reaction, yielding a remarkable substance that boasts great resilience and durability. This captivating collaboration combines to create a sturdy and long-lasting connection that can endure over time. The irresistible features of the resin, combined with the energizing effect of the hardener, create a perfect blend that opens up endless opportunities, spanning from creative ventures to industrial uses.



Figure 3.5 Resin and Hardener (Ratio 2:1).

3.3.5. Mold (for casting)

A casting mold is a beautifully crafted tool that shapes and contains molten material during the casting process. With precision and artistry, it enables the transformation of liquid into solid, bringing artistic visions and industrial creations to life.



Fig 3.6. Wooden Mold.

3.3.6 Pressure weight (for curing)

A pressure weight for casting is a device used to apply pressure or weight onto a mold during the casting process. This ingenious tool exerts force to ensure proper compaction and even distribution of the casting material within the mold cavity. By applying controlled pressure, it enhances the quality and integrity of the casted object, resulting in improved surface finish, reduced porosity, and enhanced dimensional accuracy. The pressure weight plays a pivotal role in achieving optimal casting results, ensuring that the material fills the mold and creates a flawless final product. We use here 30 kg weight for pressure purposes.

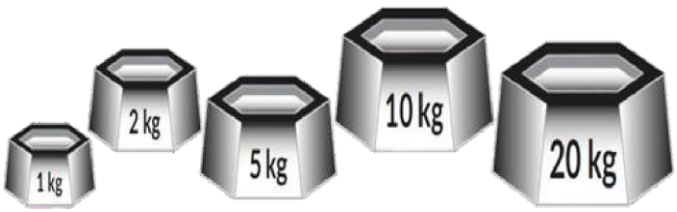


Figure 3.7. Weight (for cured).

3.4 Fabrication process

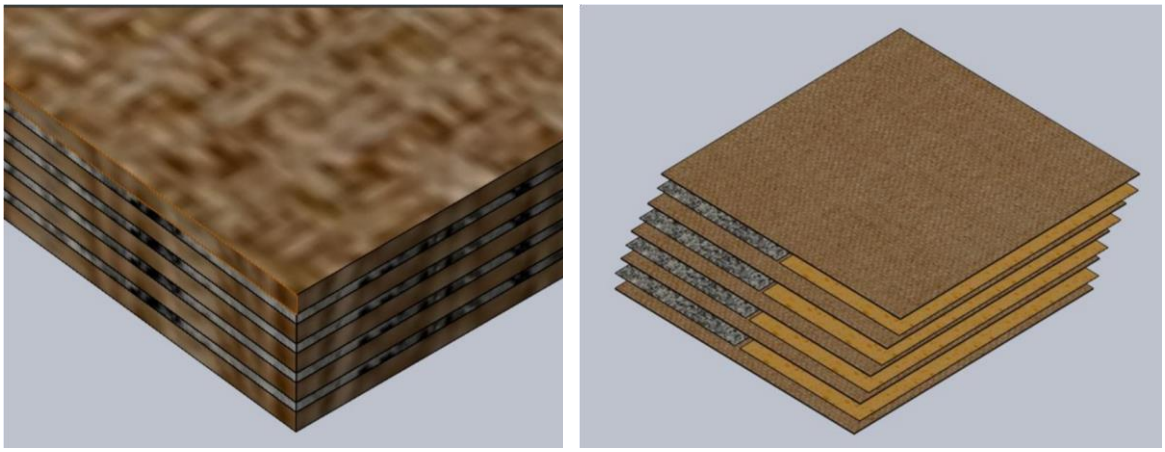
- At first, we select natural fibers such as banana, jute, and coconut fiber as the primary reinforcing materials.
- Then prepare a matrix material consisting of resin and hardener, which will act as a binding agent for the natural fibers. Clean and dry the natural fibers to remove impurities and enhance their mechanical properties. This treatment also improves the compatibility of the fibers with the matrix material.
- After that integrate the treated fibers into the matrix material in a controlled manner, typically using injection molding. Arrange the fibers in specific orientations to achieve desired mechanical properties in the final composite.
- Now, apply pressure and time to the composite material, allowing the matrix material to cure and harden. This process creates a rigid structure and ensures proper bonding between the fibers and matrix.
- Perform testing and quality control measures to assess the mechanical properties, durability, and other characteristics of the composite material. This step ensures that the material meets the required standards and specifications.

3.5 Fiber Orientations

To improve overall characteristics, a deliberate combination of materials has been used in the manufacture of composite materials. The foundation is made up of five layers of jute fabric, which is renowned for being durable and environmentally beneficial. Ten percent of the weight of the inner layers is made up of microscopic banana and coconut fibers, which combine to improve the mechanical and reinforcing characteristics. Jute fabric itself adds 250gm to the entire weight, which creates a strong base. These microscopic fibers are added to the composite to give it more strength and flexibility. Resin is added to the components to bind them together and create a cohesive matrix. By utilizing the distinctive qualities of each component material to create a synergistic impact in the finished result, this novel approach seeks to maximize the strength, durability, and overall performance of the composite material.



(a) A section of the composite substance



(b) Complete side view displaying the fiber orientations in the composite material

Figure 3.8 Different view of the composite materials

3.6 Fabricated composite materials

The analysis of composite materials involves a multifaceted approach, with distinct cross sectional views providing comprehensive insights. Section 8(a) focuses on localized composition, emphasizing a targeted analysis of specific areas. Another section reveals layering and internal structure, offering a thorough summary. A critical perspective illustrates fiber orientations, enhancing understanding of overall structural integrity. Notably, banana fibers are combined on the right, and coconut fibers on the left, contributing to the material's complexity. The composite, manufactured in a hardwood mold, utilizes epoxy resin, jute fabric, banana, and coconut fibers, undergoing compression and temperature exposure. A precise 2:1 ratio of epoxy resin to hardener is crucial for optimal curing and bonding. Balanced fiber distribution, with 10% banana and coconut fibers, enhances mechanical qualities. The resulting composite, under a compressive force, attains a pressure of 0.00327 Nmm2 across a 90,000 mm2 area, ensuring a robust and well-structured material.



Figure 3.9 Final Composite material

3.7. Characterization

Mechanical characterization is a branch of materials science and engineering that focuses on studying and understanding the mechanical properties and behavior of materials. It involves the measurement and analysis of various mechanical parameters to evaluate how materials respond to external forces and loads. By characterizing the mechanical properties of materials, engineers, and scientists gain valuable insights into their strength, stiffness, toughness, durability, and other important attributes. Mechanical characterization is of utmost importance in materials science and engineering. It enables engineers and scientists to understand the mechanical properties and behavior of materials, make informed decisions in design and optimization, ensure quality control in manufacturing, analyze failures, advance research and development, and comply with regulatory standards. It plays a critical role in improving product performance, enhancing safety, and driving innovation in various industries.

The following test has done:

(I) Tensile test
(II) Bending test
(III) Impact test
(IV) SEM test



Figure 3.10 Composite bar sample for testing impact, tensile, bending and SEM.

3.7.1. Tensile Test

Tensile testing is a widely used method for characterizing the mechanical properties of composite materials. It involves applying a gradually increasing axial force to a specimen until it fractures, allowing researchers to measure various parameters and draw conclusions about the material's performance. During a tensile test, a composite specimen is typically prepared in the form of a thin, rectangular strip. The specimen is securely clamped onto a testing machine, and a controlled force is applied along its length. As the force is increased, the specimen experiences stress and strain, which are measured simultaneously. The

stress-strain curve obtained from the tensile test provides valuable information about the material's behavior. The elastic modulus, or Young's modulus, is determined from the initial linear portion of the curve and represents the material's stiffness. The ultimate tensile strength indicates the maximum stress the material can withstand before failure, while the elongation at break measures its ductility. Composite materials often exhibit anisotropic behavior due to the alignment of reinforcing fibers. Tensile testing can help assess the material's strength in different directions, providing valuable insights into its structural integrity. Additionally, fracture analysis of the tested specimen can reveal the failure mode, such as fiber pull-out, fiber breakage, or matrix cracking. This information aids in understanding the composite's failure mechanisms and guides improvements in material design and manufacturing processes. Tensile testing is a vital tool for characterizing composite materials, enabling the determination of key mechanical properties and offering insights into their structural performance and failure behavior.



Figure 3.11 Universal Testing Machines for Tensile Test.

3.7.2. Bending test

Bending tests are commonly employed to characterize the mechanical behavior of composite materials. In this type of test, a specimen of the composite material is subjected to a bending moment or force, which induces flexural stress and strain within the specimen. During a bending test, a composite specimen is typically prepared as a beam or a rectangular plate. The specimen is supported at its ends and subjected to a load at its center

or through a three-point or four-point loading configuration. As the load is applied, the specimen bends, and its deflection is measured. The bending test provides valuable information about the material's stiffness, strength, and ductility. The modulus of elasticity, or flexural modulus, is determined from the initial linear portion of the load deflection curve and represents the material's resistance to bending deformation. The maximum bending stress indicates the material's strength in bending, while the deflection at failure measures its ductility. Bending tests also allow the assessment of the composite material's resistance to delimitation, inter-laminar shear, and other failure modes specific to bending. Fracture analysis of the tested specimen can provide insights into the failure mechanisms and help optimize the composite's design and manufacturing processes. Bending tests are valuable for characterizing composite materials by providing information about their stiffness, strength, ductility, and resistance to specific failure modes associated with bending.

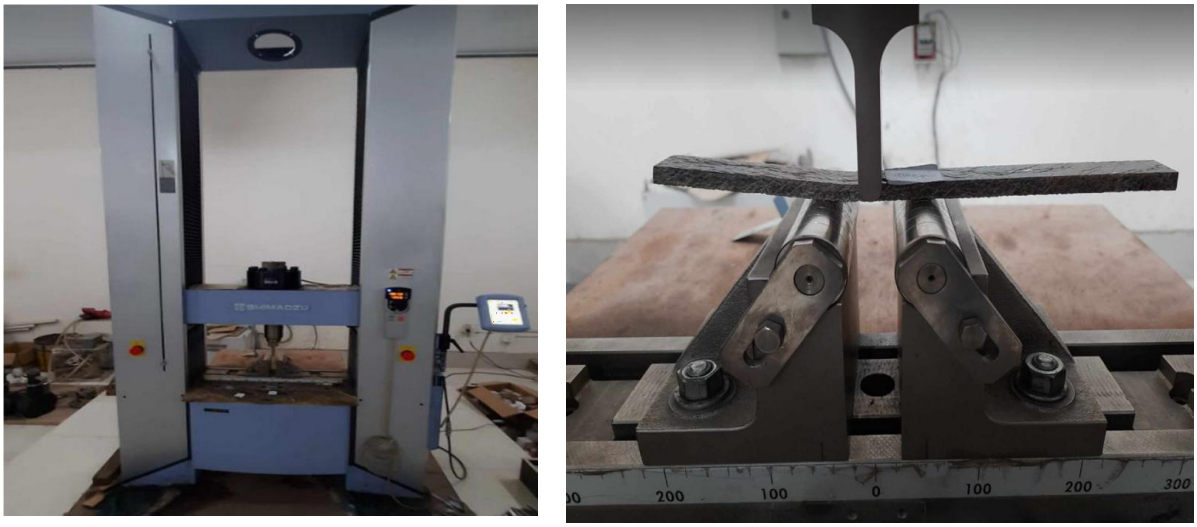


Figure 3.12 Bending test of composite materials.

3.7.3. Impact test

Impact testing is a crucial method for characterizing the behavior of composite materials under dynamic loading conditions. This test simulates the response of a material when subjected to sudden, high-energy impacts or collisions, such as those encountered in real-world scenarios. In an impact test, a composite specimen is typically prepared as a notched or unmatched rectangular or cylindrical shape. The specimen is mounted in an impact testing machine, and a pendulum or a falling weight is released to strike the specimen. The

impact generates a rapid deformation and applies a high force or energy to the material. The impact test provides valuable information about the composite material's resistance to sudden loading, its toughness, and its ability to absorb energy. The total energy absorbed by the specimen during impact, as well as the maximum force or stress experienced, are measured and analyzed. The impact test also helps in assessing the composite material's behavior under various failure modes, such as cracking, delimitation, or fiber breakage. Fracture analysis of the tested specimen can provide insights into the specific failure mechanisms and guide improvements in material design and manufacturing processes to enhance impact resistance. Impact testing is a significant method for characterizing composite materials, allowing the evaluation of their response to sudden, high-energy loading. It provides information about toughness, energy absorption, and failure modes, aiding in the optimization of composite materials for impact-resistant applications.



Figure 3.13 Chirpy Impact test of composite materials in pendulum impact testers.

3.7.4 SEM analysis

The bio-inspired composite material offers an intriguing blend of natural fibers and synthetic resin. It is made of jute fabric reinforced with micro fibers from bananas and coconuts in an epoxy matrix. A thorough analysis of this composite’s microstructure using a Scanning Electron Microscope (SEM) can provide important details about its mechanical and structural qualities.

CHAPTER 4: RESULT AND DISCUSSION

Natural fibers, such as tiny coconut, banana fibers, and jute fabrics, are mechanically characterized by putting them through a battery of tests to determine their mechanical characteristics. Tensile testing measures the strength and elongation qualities of fibers by stretching them until they break. Impact testing determines a fiber's toughness and ability to withstand unexpected loads by measuring the energy needed to fracture it. Bending tests use controlled bending forces to examine the fibers' stiffness and flexibility. Understanding the microstructure of natural fiber composites, spotting flaws, evaluating interfacial bonding, and learning more about the variables affecting their mechanical and physical characteristics all depend on SEM testing.

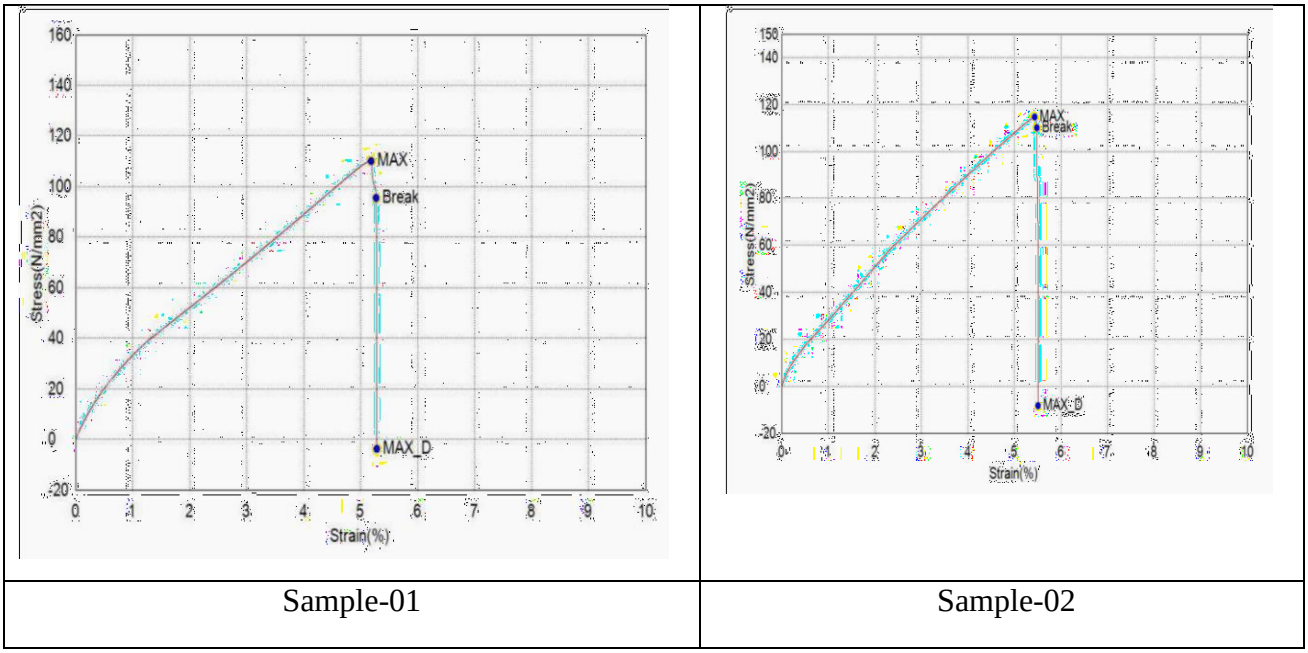
The first group consists of jute fabric containing 10% tiny banana fibers, whereas the second group consists of jute fabric containing 10% coconut fibers. The materials have been divided into these two groups to make testing easier in areas like impact resistance, bending characteristics, tensile strength, and scanning electron microscopy (SEM).

4.1 Tensile tests

The mechanical properties of samples 1 and 2 are shown in detail in Table 4.1. Tensile testing epoxy-reinforced specimens are an important stage in the manufacturing of natural fiber composite materials. This test evaluates the mechanical qualities of the material under tension, exposing its elasticity, strength, and deformation patterns. To create a composite with improved structural integrity, epoxy resin is mixed with natural fibers like hemp or jute. Researchers can ascertain the specimen's ultimate tensile strength and elongation at break by gradually stretching it till failure throughout the test. The findings direct the optimization of resin content and fiber orientation, guaranteeing the creation of long-lasting and environmentally friendly natural fiber composites for a range of uses. Tensile testing was performed on two different fabric samples to assess their mechanical characteristics. Sample 1 was made of 10.0% banana fiber-infused jute cloth that measured 4.25 mm in thickness, 16.02 mm in width, and 50.00 mm in gauge length. The ASTM D638 standard was used for the tensile test, which was carried out at a speed of 5 mm/min in a single test mode. Conversely, Sample 2 had a gauge length of 50.00 mm, a thickness of 4.48 mm, a breadth of 17.31 mm, and was made of jute fabric mixed with 10% coconut fiber. To evaluate the materials' tensile strength, these metrics were measured.

Table 4.1. Mechanical properties of composite material (Tensile test)

Name	Max Force	Max Stress	Max Strain	Max Time	Break Force	Break Stress	Break Strain
Unit	**N**	**N/mm^2**	**%**	**sec**	**N**	**N/mm^2**	**%**
Sample-1	7494.31	110.07	5.181	31.120	6503.01	95.513	5.272
Sample-2	8884.05	114.561	5.4344	32.64	8545.11	110.190	5.48271



Sample-01 | Sample-02

Figure 4.1 Stress and strain curve of two samples of tensile tests.

A series of mechanical testing yielded the stress-strain curves for Samples 1 and 2 as shown in Figure 12, and the data revealed significant material qualities. Sample 1 saw a maximum strain of 5.181% and a peak stress of 110.07 N/mm2 due to the maximum force applied of 7494.31 N. A break stress of 95.513 N/mm2 and a break strain of 5.272% resulted from the matching break force of 6503.01 N. It took 31.120 seconds to complete the process. Likewise, Sample-2 experienced a maximum strain of 5.4344% and a peak stress of 114.561 N/mm2 due to the application of a higher maximum force of 8884.05 N. For Sample-2, the break strain was 5.48271%, and the break force and stress were 8545.11 N and 110.190 N/mm2, respectively. The test took 32.64 seconds to complete for Sample 2. These stress-strain curves illustrate the materials' ultimate breakdown sites and their response to external pressures, offering important insights into the mechanical behavior of the materials.

4.2 Bending tests

The epoxy reinforcing in natural fiber composite materials is essential for improving strength and flexibility in the bending test. To make a strong and adaptable composite, natural fibers like flax or jute are impregnated with epoxy resin. The material's ability to withstand bending forces is assessed during the test, demonstrating the effectiveness of the epoxy-reinforced natural fibers. This combination advances the development of high-performance, environmentally friendly composite materials by offering a lightweight, strong solution with exceptional mechanical qualities. It may be used for everything from sustainable building materials to automobile components.

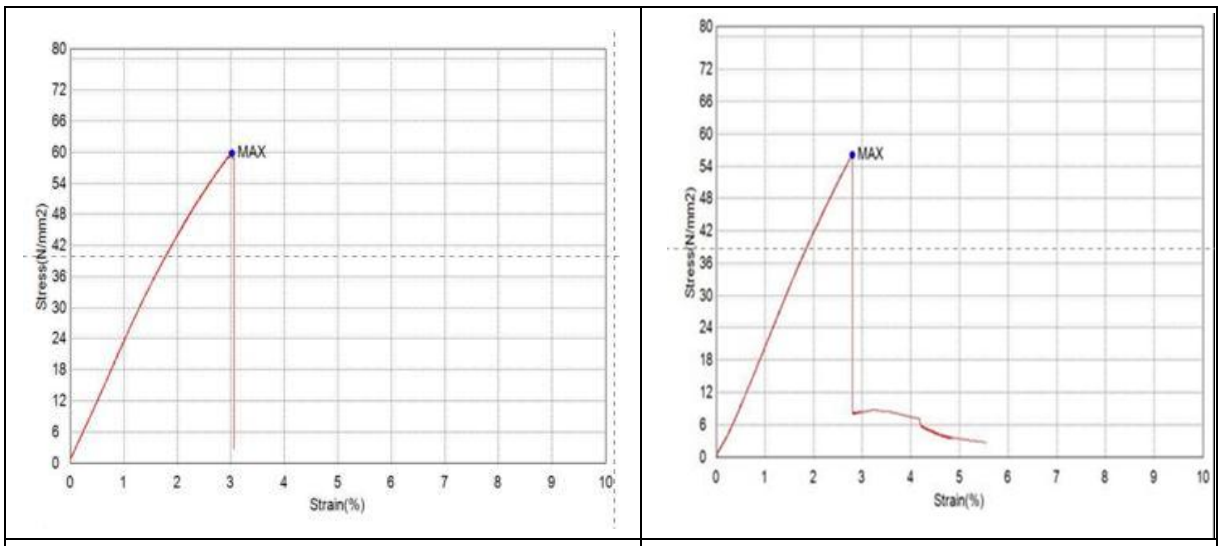
Two distinct fabric samples were bent in order to evaluate their mechanical properties. Sample 1 had dimensions of 7.69 mm in thickness, 24.43 mm in width, and 50.00 mm in gauge length. It was constructed from 10.0% banana fiber-infused jute fabric. The tensile test was performed in a single test mode at a speed of 5 mm/min using the ASTM D638 standard. On the other hand, Sample 2 measured 50.00 mm in gauge length, 7.9600 mm in thickness, and 26.050 mm in width. It was composed of 10% coconut fiber blended with jute cloth. These parameters were tested in order to assess the bending strength of the materials.

Table 4.2. Mechanical properties of composite material (Bending test)

Name	Max Force	Max Stress	Max Strain	Max Time	Break Force	Break Stress	Break Strain
Unit	**N**	**N/mm^2**	**%**	**sec**	**N**	**N/mm^2**	**%**
Sample-1	1152.09	59.8095	3.01790	70.0800	1029.02	48.3056	3.1963
Sample-2	1235.15	56.1239	2.79541	62.710	1006.96	42.0178	2.9487

Table 4.2 provides a detailed summary of the different mechanical properties for the two samples, Samples 1 and 2. Maximum force (Max Force), maximum stress (Max Stress) expressed as a percentage, maximum time before failure (Max Time) in seconds, break force (Break Force), break stress (Break Stress), and break strain (Break Strain) are among the mechanical properties. The highest force applied to Sample-1 is 1029.02N, which translates to a maximum strain of 3.01790% and a maximum stress of 48.3056 N/mm2.

The breaking strain for sample-1 is 3.1963 and sample-2 2.9487. Before breaking, the sample lasted for 70.08 seconds, and its break force, break stress, and break strain were all equal to their maximum values. In contrast, Sample-2 displayed a marginally lower maximum strain of 2.9487% and a slightly higher maximum force of 1235.15 N, which were correlated with a maximum stress of 56.1239 N/mm2. For Sample- 2, the failure time was 62.710 seconds. Consistent values were observed in both samples between the maximum and break measurements, offering important information about their mechanical behavior under stress. The stress and strain curves of two samples in tensile tests are depicted in Figure 4.2.



Sample-01	Sample-02

Figure 4.2 Stress and strain curve of two samples in bending tests.

Samples 1 and 2's stress-strain graphs show how the materials behave mechanically when subjected to tensile force. Plotting the stress (force per unit area) against strain (deformation) provides information about the elasticity, plasticity, and eventual failure of the material. At a strain of 3.01790%, Sample-1's maximum force was 1152.09 N, which translates to a maximum stress of 59.8095 N/mm². The substance responded steadily for seventy-eight seconds until it reached its maximum strength. A brittle failure is suggested by the break force and break stress being equal to the maximum values. The maximum force, stress, and strain for Sample-2 were likewise 1235.15 N, 56.1239 N/mm2, and 2.79541%, respectively. Before failing, the material was loaded for 62.710 seconds, and both the break force and break stress matched the maximum values. For the purposes of materials engineering and design, these stress-strain curves help characterize the mechanical characteristics and performance limits of the corresponding samples.

4.3 Impact tests

In an impact testing arrangement, the Chirpy impact testing device was specifically used with an 18 kg hammer. 390 mm was the approximate height at which the hammer was discharged. The Chirpy impact testing technique is frequently used to assess a material's ability to tolerate sudden impacts. In order to cause fracture, the hammer was released in this posture, swung down, and struck a material specimen with a notch. Measurement of the energy absorbed by the specimen during this fracture event provides important information on the resilience and shock- or impact-bearing capacity of the material. Table 3 displays the test results, which provide important information regarding how well the material performed in these circumstances.

Table 4.3. Chirpy impact test results.

Name	Trail 01	Trail 02	Trail 03	Average
Unit	Joule	Joule	Joule	Joule
Jute fabrics + 10% tiny banana fibers (Sample-1)	4	5	5	4.67
Jute fabrics + 10% tiny coconut fibers (Sample-2)	5	5	6	5.33

To evaluate their toughness and resilience, the bio-inspired composite materials—more especially, the jute cloth epoxy reinforced with microscopic banana and coconut fibers—went through Chirpy impact testing. The energy absorption capacity of the samples during trials 01, 02, and 03 is shown in Table 4.3 along with the corresponding values in joules. The Chirpy impact test results for trials 01, 02, and 03 in Sample-1, which is made up of jute fabrics reinforced with 10% tiny banana fibers, were 4, 5, and 5 joules, respectively. This means that the average impact resistance of Sample-1 is 4.67 joules. However, Sample 2, which was made up of jute fabrics reinforced with 10% microscopic coconut fibers, showed 5, 5, and 6 joules in impact test values for the different trials. This means that Sample 2's average impact resistance was 5.33 joules. These results imply that the jute fabric epoxy composite may have a marginally higher impact resistance than banana fibers due to the addition of little coconut fibers. The study emphasizes how bioinspired composite materials can improve conventional materials' mechanical qualities for a range of uses.

4.4 Scanning Electron Microscope (SEM) analysis

The bio-inspired composite material offers an intriguing blend of natural fibers and synthetic resin. It is made of jute fabric reinforced with micro fibers from bananas and coconuts in an epoxy matrix. A thorough analysis of this composite's microstructure using a Scanning Electron Microscope (SEM) can provide important details about its mechanical and structural qualities.

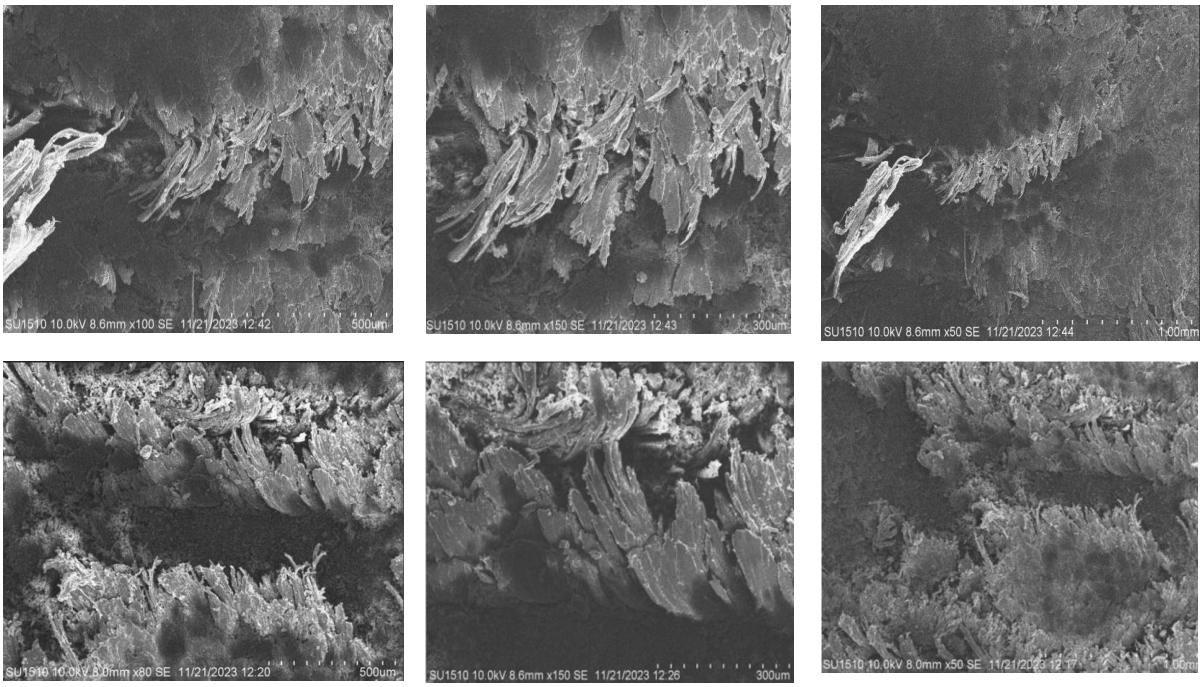


Figure 4.3 SEM test images

The microstructural properties of the bio-inspired composite materials, namely Jute Fabric reinforced with 10% small banana fibers (Sample-1) and 10% tiny coconut fibers (Sample-2), are profoundly shown by the Scanning Electron Microscopy (SEM) results. SEM pictures of Sample-1 taken at 10.0 kV and at various magnifications (8.6 mm x 100, 8.6 mm x 150, and 8.6 mm x 50) show that the banana fibers are evenly dispersed inside the Jute fabric matrix. Strong interfacial bonding between Jute fibers and small banana fibers is clearly seen in the micrographs, which greatly improves the material's tensile, bending, and impact qualities. The SEM analysis of Sample 2 shows that the little coconut fibers are distributed more uniformly throughout the Jute matrix. A cohesive interface between the coconut fibers and the Jute fabric is highlighted in images taken at 10.0 kV and at different magnifications (80mm x 80, 8.6mm x 150, and 8.0mm x 50), which may indicate improvements in mechanical performance. All things considered, the SEM analysis highlights the effectiveness of these bio-inspired composite materials, highlighting the

potential microstructural properties attained by adding microscopic banana and coconut fibers to epoxy-reinforced jute fabric.

4.4 Discussion on Results

The bio-inspired composite material, which included microscopic fibers from coconut and banana embedded in jute fabric bonded with epoxy, was thoroughly inspected. The mechanical properties of the material were assessed by evaluating its tensile, bending, and impact strengths. Furthermore, the microstructure was examined using scanning electron microscopy (SEM). The results show that adding coconut and banana fibers together improves mechanical performance in a synergistic way. This research highlights the possibility for high-performance, environmentally friendly composite materials by examining the feasibility of sustainable reinforcements and offering insights into the complex interactions between these natural elements.

Samples 1 and 2's tensile test results highlight important mechanical characteristics. With a break force of 6503.01 N and a break stress of 95.513 N/mm², Sample-1 displayed a maximum force of 7494.31 N, a maximum stress of 110.07 N/mm², and a maximum strain of 5.181%. Sample-2, on the other hand, showed greater values: break force of 8545.11 N and break stress of 110.190 N/mm², coupled with max force of 8884.05 N, max stress of 114.561 N/mm², and max strain of 5.4344%.

Important mechanical characteristics are revealed by the bending test results for Samples 1 and 2. With a break force and break stress that matched the maximum values, Sample 1 showed a maximum force of 1152.09 N, a maximum stress of 59.8095 N/mm2, and a maximum strain of 3.0179%. 70.0800 seconds was the matching maximum time. With a break force and break stress that mirrored the peak values, Sample 2 showed somewhat higher maximum forces (1235.15 N, 56.1239 N/mm2, and maximum strains 2.79541%). Based on these findings, Sample-2 may be more resilient in bending applications than Sample-1 because of its slightly higher strength and resilience.

Sample-1 demonstrated impact values of 4, 5, and 5 Joules in the corresponding trials during the impact test, resulting in an average of 4.67 Joules. Sample-2, on the other hand, measured impact values of 5, 5, and 6 Joules, averaging 5.33 Joules. The results indicate that Sample-1 with banana fibers showed slightly lower impact resistance than Sample2, which included microscopic coconut fibers. These results suggest that adding coconut

fibers could improve the material's overall toughness and durability. Comparison of sample 1, sample 2, and sample 3 impact test results.

The microstructural characteristics of bio-inspired composite materials, specifically Jute Fabric reinforced with 10% small banana fibers (Sample-1) and 10% tiny coconut fibers (Sample-2), are revealed by the results of scanning electron microscopy (SEM). Sample 1 exhibit strong interfacial bonding that improves tensile, bending, and impact characteristics. SEM images taken at different magnifications reveal the uniform distribution of banana fibers within the Jute matrix. Sample 2 highlights a coherent contact between the coconut fibers and the fabric with a more consistent dispersion of coconut fibers throughout the Jute matrix. These results validate the effectiveness of adding tiny coconut and banana fibers to epoxy-reinforced jute cloth and point to possible gains in mechanical performance.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Sample-2 illustrates how adding 10% small coconut fibers to Jute Fabric epoxy reinforcement produces a bio-inspired composite material with notably improved mechanical properties. Sample-2 was shown to have better strength and elasticity in tensile tests when compared to Sample-1. This indicates that Sample-2 is a good option for applications requiring high mechanical performance. Furthermore, Sample-2 demonstrated enhanced tensile strength and resilience while bending, highlighting its superiority. The findings of the impact test showed increased resistance to impacts, suggesting increased toughness and durability overall. These results were corroborated by scanning electron microscopy, which demonstrated a more even distribution of coconut fibers in the jute matrix and a consistent fiber-to-fabric interface. The SEM pictures' extensive interfacial bonding highlights how important coconut fiber thickness is for improving mechanical properties. Because of this, adding 10% tiny coconut fibers to the epoxy reinforcement of Jute Fabric results in a bio-inspired composite material with improved mechanical properties that can be used in a variety of real-world applications.

5.2 Recommendations

Based on the investigation into the mechanical properties of epoxy composites reinforced with natural fibers, it is recommended to explore further research avenues for optimizing the composite's performance. Focus on identifying the most suitable natural fibers, their processing methods, and their impact on key mechanical properties such as tensile strength, flexural strength, and impact resistance. Additionally, investigate the influence of varying fiber content and orientation on the overall composite performance. Employ advanced characterization techniques, such as microscopy and spectroscopy, to gain deeper insights into the microstructural aspects. Furthermore, it is crucial to conduct durability studies to assess the long-term stability of the composites under different environmental conditions. These recommendations aim to enhance the understanding of epoxy composites reinforced with natural fibers, paving the way for their application in diverse engineering and industrial sectors.

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