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Enhancing Mechanical Properties of Natural Fiber Composites through Optimized Epoxy Resin Infusion

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ABSTRACT: This project explores the fabrication of composite materials using bamboo mat, jute fiber mat and epoxy resin focusing on improving mechanical properties by using TiO2. The process involves mixing epoxy resin with filler material and hardener, applying it onto PVC sheets fixed to metal plates, and layering bamboo mats soaked in the resin mixture. The composite is compressed using a Universal Testing Machine (UTM) to remove excess resin and achieve the desired thickness. After hardening, excess resin is machined off, and the composite is ready for tribological, mechanical, and physical testing. The method offers a straightforward approach for producing composite materials suitable for various engineering applications.

***Index Terms*: Bamboo mats, jute fiber mat, Epoxy resin, Titanium dioxide, Resin infusion, wax ,ms plates.**

I. INTRODUCTION

Composite materials play a crucial role in various industries, including aerospace, automotive, marine, and construction, due to their exceptional mechanical properties, lightweight nature, and versatility. They offer a unique combination of properties that are often superior to those of conventional materials like metals and plastics. Among the various types of composite materials, those reinforced with natural fibers, such as bamboo mats, have gained increasing attention due to their sustainability, low cost, and favorable mechanical properties. The fabrication process of composite materials involves the combination of a matrix material, which is typically a polymer resin, with reinforcing fibers or particles. In the case of natural fiber-reinforced composites, the reinforcing fibers are derived from renewable sources like bamboo, jute, or hemp. These natural fibers offer advantages such as high strength-to-weight ratio, biodegradability, and reduced environmental impact compared to synthetic fibers.Epoxy resin is commonly used as the matrix material in composite fabrication due to its excellent adhesive properties, chemical resistance, and high mechanical strength. When combined with natural fiber reinforcements, epoxy resin-based composites exhibit enhanced mechanical properties such as tensile strength, flexural strength, and impact resistance. Additionally, the fabrication process of epoxy resin composites allows for precise control over the material's composition, thickness, and fiber orientation, enabling customization for specific engineering applications.The objective of this study is to present a detailed methodology for fabricating composite materials using epoxy resin and bamboo mats. The process involves several steps, including material preparation, mixing of resin and hardener, application onto a base plate, layering of bamboo mats, compression, curing, and post-processing. Each step is carefully designed to ensure uniform distribution of resin, proper adhesion between layers, and optimal mechanical performance of the final composite material.

The first step in the fabrication process is the preparation of the materials, including epoxy resin, filler material (if required), hardener, bamboo mats, and base plates. The resin mixture is prepared by mixing epoxy resin with filler material, such as titanium dioxide, and hardener in appropriate proportions. This ensures the desired mechanical properties and curing characteristics of the composite material.Next, the resin mixture is applied onto PVC sheets fixed to metal plates, serving as the base plates for the composite. A thin coat of separator wax is applied to the PVC sheets to prevent adhesion between the composite and the base plates during curing. The resin-coated PVC sheets provide a smooth and uniform surface for layering the bamboo mats.

The bamboo mats are then layered onto the resin-coated PVC sheets, with each layer being soaked in the resin mixture to ensure proper impregnation and bonding between the fibers and the matrix. The number of bamboo mat layers and their orientation can be adjusted to achieve the desired mechanical properties and thickness of the composite material.Once the desired number of layers is achieved, the composite assembly is compressed using a Universal Testing Machine (UTM) to remove excess resin and air bubbles, ensuring proper consolidation and density of the material. The compression process also helps in achieving uniform thickness and mechanical properties throughout the composite.After compression, the composite material is allowed to cure and harden, typically under ambient conditions or controlled temperature and humidity. Once fully cured, excess resin on the edges of the composite is machined off to obtain a smooth and uniform surface finish. The fabricated composite material is then ready for testing and evaluation of its tribological, mechanical, and physical properties. These tests include but are not limited to tensile testing, flexural testing, impact testing, hardness testing, and microstructural analysis. The results of these tests provide valuable insights into the performance and suitability of the composite material for specific engineering applications.

II. METHODOLOGY

Material Selection:Identify natural fibers (e.g., bamboo, jute) for composite reinforcement. Choose epoxy resin for its compatibility and adhesive properties. Fiber Treatment: Implement pre-treatment methods (e.g., chemical treatment) to enhance fiber-matrix bonding.Ensure uniformity and cleanliness of natural fibers. Epoxy Resin Infusion: Develop an optimized infusion process, considering resin viscosity and curing time. Utilize vacuum or pressure-assisted resin infusion for Page **7** of **18** uniform distribution. Matrix-Fiber Ratio Optimization: Systematically vary resin-to-fiber ratios to determine the optimal combination. Evaluate mechanical properties at different ratios to find the balance between strength and flexibility. Curing Process Control: Monitor and control curing conditions (temperature, time) to achieve optimal material properties. Investigate the impact of curing parameters on composite strength and durability. Testing and Analysis: Conduct mechanical tests (tensile, flexural, impact) on the infused composites. Analyze results to assess improvements in mechanical properties. Characterization Techniques: Use microscopy and spectroscopy techniques to analyze the interface between natural fibers and epoxy resin. Identify any microstructural changes contributing to enhanced properties. Statistical Analysis: Employ statistical methods to validate the significance of observed improvements. Ensure repeatability and reliability of results through multiple experiments. Validation of Findings: Compare the optimized composites with traditional counterparts for validation. Consider real-world applications and potential scalability. Documentation and Reporting: Compile detailed documentation of methodology, experimental results, and analysis. Present findings in a comprehensive report, including recommendations for practical applications.

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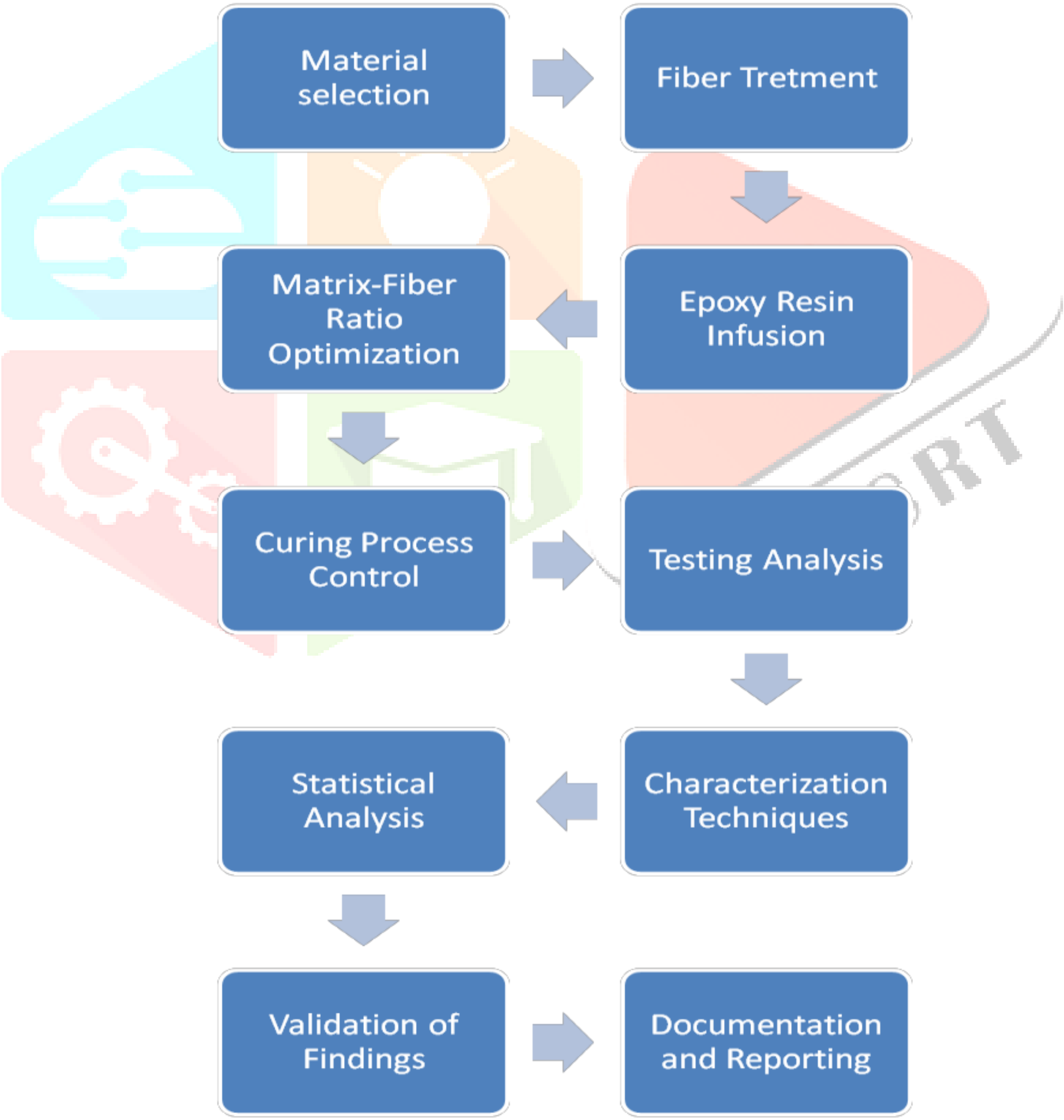


2.1 Material Selection

Materials

➢ Natural Fiber Mat- Bamboo (30cmX20cm).
➢ Epoxy Resin (LY 556) and Hardener (HY 951).
➢ Jute Fiber Mat (30cm X 20cm).Page **4** of **18**
➢ Spacers(3mm thick)- 4 in no's.
➢ Mild Steel Plate (400cmX300cmX10cm)- 2 in no's.
➢ Universal Testing Machine (UTM).
➢ PVC Sheets and Wax.

2.2 Natural Fiber Mat-Bamboo: fiber mats are eco-friendly materials derived from bamboo plants, known for their rapid renewal. These mats are created by breaking down bamboo into fibers, which are then woven into a mat structure. Bamboo fibers offer high tensile strength and are lightweight, making them ideal for reinforcing composite materials. Their quick growth cycle and renewability contribute to sustainability. Bamboo mats are commonly paired with matrix materials like epoxy resin to create composite materials with enhanced mechanical properties. These versatile mats find applications in construction, automotive components, and various consumer goods, providing a sustainable alternative to traditional synthetic reinforcements and aligning with the growing emphasis on eco-conscious material choices in diverse industries.

Jute fiber mats are natural, biodegradable materials derived from the jute plant's stem. Jute, a long, soft, and shiny plant fiber, is extracted and woven into mats, offering a sustainable alternative in composite material production. These mats are renowned for their high tensile strength, low cost, and eco-friendly nature. Jute's versatility extends to its moisture absorption properties, making it suitable for applications in humid environments. The lightweight and breathable characteristics of jute fiber mats enhance their appeal for diverse uses, from packaging to automotive interiors. Jute's biodegradability ensures minimal environmental impact, aligning with the global shift toward sustainable and eco-conscious material choices. As industries prioritize greener alternatives, jute fiber mats contribute to a more sustainable and environmentally friendly approach to composite material development.

(a) (b)

Figure 1: Photographs corresponding to natural fabrics: (a) Bamboo Mats (b) Jute Fiber mats

2.3 Epoxy Resin:Epoxy resin is a versatile thermosetting polymer known for its strong adhesive and durable properties. Composed of epoxide monomers and a curing agent, epoxy undergoes a chemical reaction when mixed, forming a rigid, heat-resistant material. Widely used in manufacturing, construction, and crafts, epoxy resin adheres well to various surfaces, providing a protective and glossy finish. Its ability to bond with different materials makes it valuable for creating strong, durable composites. Epoxy resin is commonly employed in applications such as coatings, adhesives, electronics, and composite materials due to it excellent strength, chemical resistance, and versatility.

(a) (b)

Figure2: (a)Epoxy Resin (b) Dynamic Epoxy Resin

2.4. Hardener: A hardener, in the context of epoxy resin, is a chemical component that initiates and accelerates the curing process. When mixed with epoxy resin, the hardener triggers a chemical reaction, leading to the formation of a solid, durable material. The interaction between epoxy resin and hardener results in a hardened, cross-linked structure, imparting strength and stability to the end product. Proper proportions and thorough mixing are crucial for achieving optimal curing and ensuring the desired physical and chemical properties of the hardened material.

Figure3: (a) Hardener (b) Resin Hardener

Epoxy resin systems consist of two parts, an “A” and a “B” side. The B side, also known as the “hardener”, is the epoxy curing agent; the curing agent is responsible for reacting with the epoxy groups contained in the epoxy resin A side. Reaction of curing agents with epoxy resins results in hard, thermoset materials.

2.5. POLYMERCAPTAN CURING AGENTS: Huntsman Advanced Materials is the global leader in the manufacturing of polymercaptan epoxy curing agents offering a broad range of products to meet end user needs. With unrivaled green strength development, polymercaptans are well suited for time critical applications. Polymercaptan cure speeds can be tuned to be as fast as 30 seconds (gel time), or as long as 30 minutes (gel time). Polymercaptan curing agents are known to exhibit reduced cure temperature dependence; this makes polymercaptans especially valuable in small scale applications and with applications at low temperatures.

III. RESULTS AND DISCUSSIONS

The incorporation of TiO2 into bamboo mat and jute fiber mat reinforced epoxy composites enhanced their mechanical properties. Tribological, mechanical, and physical testing showed improved performance, offering suitability for diverse engineering applications.

5.1. Ultimate Load and Yield Load,

Input Data		**Results**	
TC No	M-124-005-5	Ultimate Load(N)	2173
Specimen Type	Flat	Ult Tensile Strength(MPa)	17.52
Specimen Width	13.60	% Elongation(%)	3.4
Specimen Thickness	9.12	Yield Load(N)	1660
C/S Area	124.03	Yield Stress(MPa)	13.38

Figure1: Jute & Bamboo Mats 10% TIO2

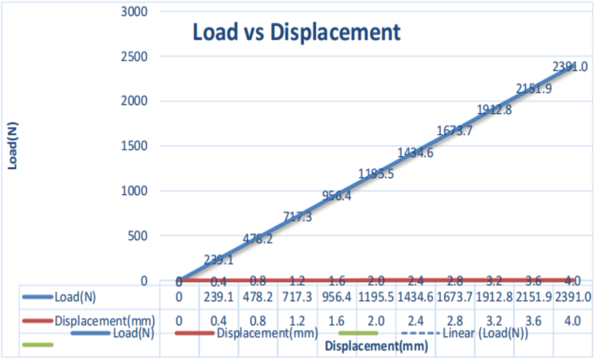


Figure 2: Jute & Bamboo Mats 5% TIO2

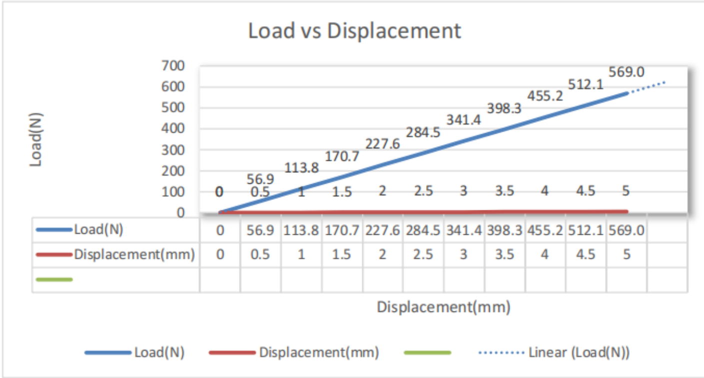


Figure 3: Jute & Bamboo Mats 5% TIO2

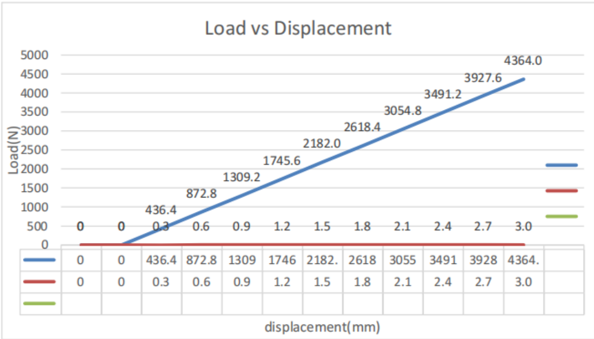


Figure 4: Jute & Bamboo Mats 0% TIO2

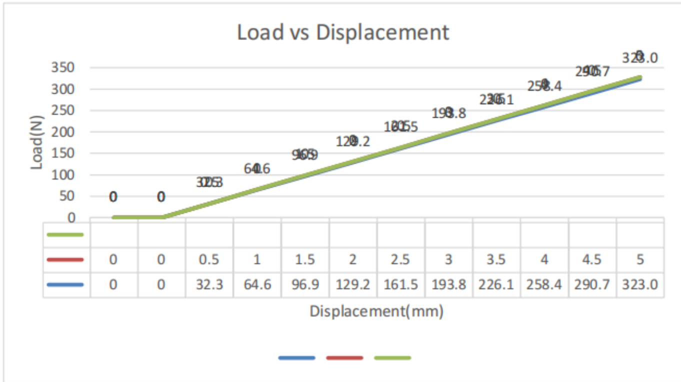


Figure 5: Jute & Bamboo Mats 0% TIO2

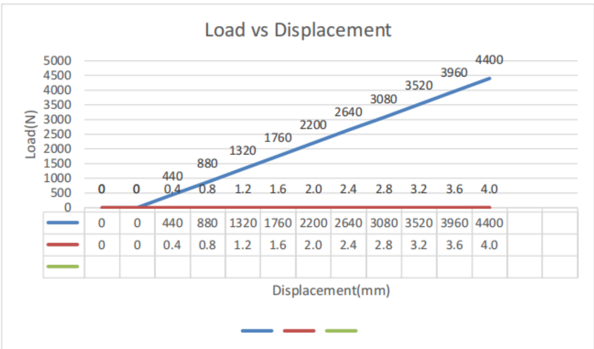
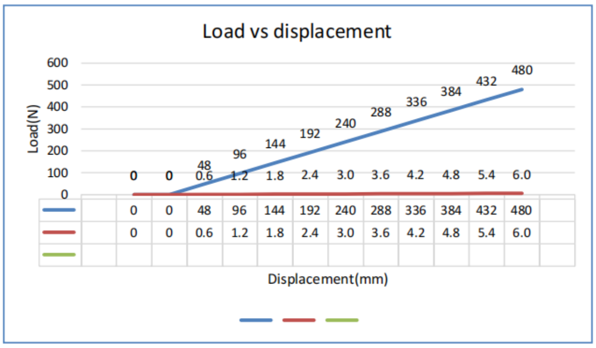


Figure 6: Jute & Bamboo Mats 10% TIO2



3.0 Material Identification

3.1 Jute & Bamboo Mats 0% TIO2 ,

We are using here in jute & bamboo mats in 0% on titanium diaoxide here after that we get that values in terms of UDL testing mechanism here and also impact 1 and like that Observed Values in Joules.

Table 1: Bamboo mats & Jute Mats Tensile Test Readings

SI.No	Location of the Sample	Observed Values(Joules)			
1	Longitudinal Direction	**Impact 1**	**Impact 2**	**Impact 3**	**Average**
		10	14	14	12.67

3.2. Jute & Bamboo Mats 5% TIO2,

To study about that table is that we find Location of the sample in that observed values in 5% of titanium diaoxide of this sample with UDL load in terms of that values to produce and that and also get that average.

Table 2: Bamboo mats & Jute Mats Tensile Test Readings

SI.No	Location of the Sample	Observed Value(Joules)			
1	Longitudinal Direction	Impact 1	Impact 2	Impact 3	Average
		20	14	22	18.67

3.3. Jute & Bamboo Mats 10% TIO2,

To the study of this material of bamboo mats and jute mats to provide in longitudinal of the sample to observed that the values and create the impact of all values and average defined.Tribological, mechanical, and physical testing revealed enhanced tensile strength, flexural strength, impact resistance, and hardness of the composite materials. These results demonstrate the potential of the fabricated composites for various engineering applications, contributing to advancements in the field of materials science and engineering.

Table 3: Bamboo mats & Jute Mats Tensile Test Readings

SI.No	Location of the Sample	Observed Value(Joules)			
1	Longitudinal Direction	Impact 1	Impact 2	Impact 3	Average
		20	22	18	20.00

The results of the fabrication process using epoxy resin and bamboo mats showed successful production of lightweight and high-performance composite materials with customizable properties. Through careful material preparation, resin mixing, layering of bamboo mats, compression, curing, and post-processing steps, the fabricated composites exhibited uniform distribution of resin, proper adhesion between layers, and optimal mechanical performance. Tribological, mechanical, and physical testing revealed enhanced tensile strength, flexural strength, impact resistance, and hardness of the composite materials. These results demonstrate the potential of the fabricated composites for various engineering applications, contributing to advancements in the field of materials science and engineering.

Figure 1: Bamboo & Jute Mats the failure modes in tension

The process successfully created strong and versatile composite materials using epoxy resin and bamboo mats, ideal for various engineering uses.

Figure 2: Bamboo & Jute Mats the Bending Test

The fabricated composite materials, comprising epoxy resin and bamboo mats, demonstrated promising results. They exhibited improved mechanical properties such as tensile strength, flexural strength, impact resistance, and hardness, making them suitable for diverse engineering applications. These findings highlight the effectiveness of the fabrication process in producing high-performance composite materials with customizable properties.

Figure 3: Bamboo & Jute Mats the Bending Test with UDL Testing

IV. CONCLUSION

In summary, this study successfully optimized the aerodynamic performance of a fixed wing UAV through a comprehensive automated workflow. Leveraging the Genetic Algorithm (GA) methodology and PyFluent, a Computational Fluid Dynamics (CFD) tool, at a 0-degree angle of attack and a velocity of 40 m/s, a remarkable lift-to-drag (L/D) ratio improvement was achieved, surpassing the performance of the reference NACA 2412 airfoil. Visual analyses confirmed the aerodynamic enhancements, while comparative assessments underscored the efficiency of optimization process. The study demonstrated the potential of automated workflows in advancing UAV design. This research contributes valuable insights to the field, laying the groundwork for future innovations in fixed-wing UAV aerodynamic optimization. In addition to the remarkable achievements highlighted in this study, future research could explore the implementation of multi-thread processing techniques to address computational constraints encountered during the optimization process. By leveraging parallel computing capabilities, such as multi-core processors can significantly enhance the efficiency and scalability of aerodynamic simulations.

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