Fabrication and Mechanical Characterization of Carbon Fiber Reinforced PLA Composites

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Abstract —

As the demand for sustainable and high-performance materials increases, composite materials reinforced with natural and synthetic fibers have emerged as a promising solution. In this study, the fabrication and mechanical analysis of a composite material developed using carbon fiber and polylactic acid are presented. The objective of this work is to evaluate the mechanical properties of the composite, including its strength, stiffness, and behavior under loading conditions.

The fabrication process is carried out using suitable manufacturing techniques to ensure proper fiber alignment and uniform distribution within the matrix. The mechanical performance of the developed composite is analyzed through experimental testing and supporting analysis methods. The results indicate that the incorporation of carbon fiber significantly improves the strength and load-carrying capacity of the base material.

Furthermore, the composite exhibits a favorable strength-to-weight ratio, making it suitable for lightweight structural applications. Overall, this study demonstrates the potential of carbon fiber reinforced PLA composites for use in engineering fields such as automotive and aerospace industries, where lightweight and durable materials are essential.

Keywords: Carbon Fiber, PLA Composite, Composite Material, Tensile Properties, Lightweight Structures

Introduction

Composites have transformed industries like aerospace and automotive by offering a unique combination of strength, lightweight properties, and corrosion resistance that traditional materials cannot match. These materials are made by combining a matrix (e.g., resin) with a reinforcement (e.g., fibers), creating structures with excellent performance and design flexibility. Natural fiber composites, such as those made from bamboo or pineapple leaf fibers, are gaining attention due to their sustainability and biodegradability, offering a renewable alternative to synthetic fibers.

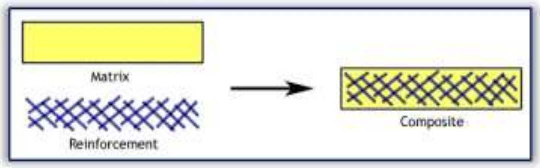

Figure 1: Composition of Composites

Hybrid bio-composites, which combine natural and synthetic fibers, provide an exciting opportunity for creating eco-friendly materials with enhanced mechanical properties. These composites can be applied in industries like construction, automotive, and aerospace, where high strength and low weight are critical. This study focuses on the fabrication and static stress analysis of a bio-composite made from carbon fiber and pineapple leaf fiber, using epoxy resin. The goal is to assess its mechanical properties and explore its potential applications. By incorporating natural fibers, this research contributes to the shift towards more sustainable, high-performance materials in modern manufacturing.

I. OBJECTIVE

This study aims to develop a hybrid bio-composite material that combines natural and synthetic fibers to enhance mechanical properties while reducing environmental impact. The primary objective is to create a lightweight, high-performance material suitable for aerospace applications. We aim to improve the material's strength, durability, and cost-effectiveness, making it a practical, eco-friendly alternative to traditional materials in industries like aerospace and automotive.

II. METHODOLOGY

Extraction of Pineapple leaf Fiber: The extraction of Pineapple Leaf Fiber (PALF) involves several key steps to separate the fibers from the leaves and prepare them for use in applications like composite materials. First, mature pineapple leaves are harvested, as they are long and fibrous. Next, the leaves are cleaned to remove dirt and pollutants. The process of retting follows, where the leaves are submerged in water to break down the lignin and hemicellulose that bind the fibers. After retting, the fibers are thoroughly cleaned, dried (usually through air or sun-drying), and then combed or sorted to remove any remaining impurities. This ensures the fibers are ready for use in high-quality applications such as composites.

Mould Preparation: For tensile property testing of plastics, ASTM D638-14 specifies three specimen types (Type I, II, III), with Type I having a total length of 165 mm, a gauge length of 115 mm, a width of 13 mm ±0.4 mm, and a thickness of 3.2 mm
±0.1 mm. These specimens are designed with square cross-sections to distribute loads evenly, though some may include notches or tapers based on the test type. The specimens must be precisely cut and treated.

For 3D printing the mold for these specimens, the process involves designing the model using CAD software (SolidWorks or AutoCAD), selecting suitable materials like PLA or carbon fiber-reinforced polymers, and choosing a 3D printing technology based on accuracy and material requirements. Key printing parameters, including layer height, infill density, and print orientation, are set to ensure consistency and minimize issues like anisotropic properties. After printing, post- processing steps such as support removal and surface smoothing are done to meet ASTM specifications for accurate dimensions.

*Composite Fabrication:*The fabrication process begins with the lay-up method, where fiber layers are arranged within a mold. The fibers alternate between carbon fiber and pineapple leaf fibers (PALF) as per the design requirements.

The matrix resin is then applied using a brush or spray to ensure thorough impregnation of the fibers. This step is critical for achieving proper bonding and uniform material distribution.In some cases, the fiber-matrix system is placed in a mold and subjected to heat and pressure. This technique enhances the material's strength by ensuring better compaction and curing of the composite.

To eliminate voids and improve resin distribution, the setup is sealed in a vacuum bag. Applying vacuum pressure ensures uniformity in the composite structure and enhances its mechanical properties.

We have made three tensile test specimens in varying proportions of carbon fiber and PALF in 70:30, 60:40 and 50:50 ratios. We have made the specimens in the standard ASTM tensile test specimen dimens by Hand layup process.

The testing of the composite material has been carried out in the **Geological & Metallurgical Laboratories (GLM)** which is located at No.105/X, 3rd Cross, 3rd Main, 2nd Stage, Industrial Suburb, Yeshwanthpur, Bangalore - 560022.

We have achieved good Tensile strength in 60:40 Ratio of our Bio-CompositeMaterial. We have achieved High Young's Modulus in 70:30 ratio.

III. NUMERICAL ANALYSIS

In this study, we aim to simulate the tensile behavior of a 70-30 Carbon Fiber and PALF bio-composite material using ANSYS.

The material's impressive mechanical properties, demonstrated through experimental testing, make it ideal for this simulation. Key properties include a tensile strength of 76.8 MPa, a
Young's Modulus of 8697.7 MPa, and a reasonable elongation at break of 2.0%. These characteristics make it suitable for structural applications, providing a balance of strength, stiffness, and ductility.

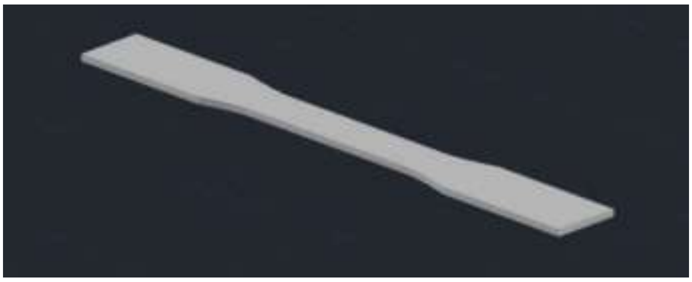

Figure 2: 3-D geometry of ASTM-D638-14

The tensile test simulation in ANSYS is based on experimental data, with a focus on analyzing the material's response to tensile loads. The problem is defined by simulating the behavior of the composite material, considering parameters like width, thickness, tensile strength, Young's Modulus, and elongation. The standard ASTM-D638-14 specimen dimensions are used to create the 3D model and perform simulations.In the simulation, a static structural analysis is conducted in ANSYS Workbench, where the tensile specimen geometry is modeled based on ASTM-D638-14 standards.

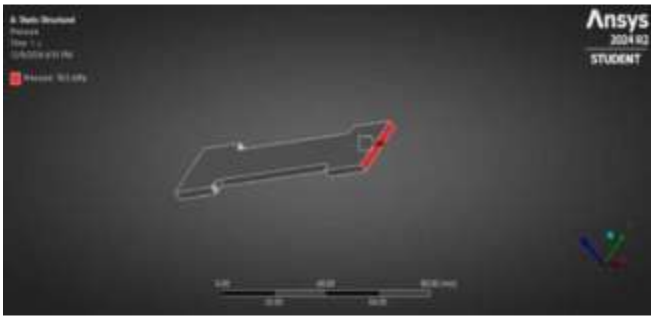

Figure 3: Boundary Condition by applying a tensile load on the other end.

The material properties for the 70-30 Carbon Fiber and PALF bio-composite are defined in ANSYS, and a mesh is applied for higher accuracy in critical regions. Boundary conditions are applied by fixing one end of the specimen and applying a cyclic point load to the free end.

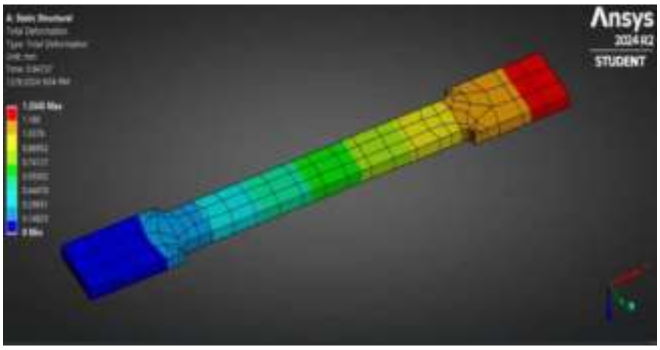

Figure 4: Total deformation

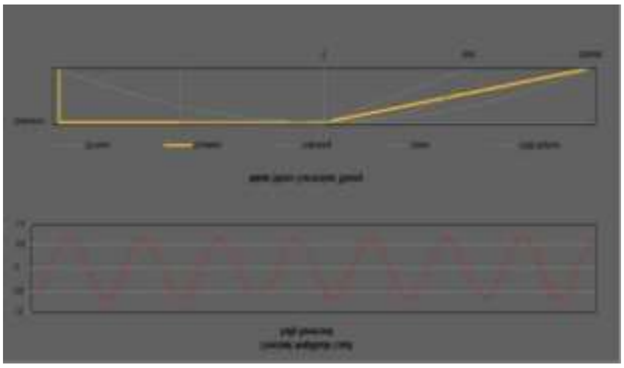

Figure 5: Goodman-Soderberg Curve

The simulation results are analyzed through post-processing, where the stress-strain curve, total deformation, and equivalent stress (von Mises) are plotted. The Goodman-Soderberg curve is also used for fatigue analysis, incorporating both the Goodman and Soderberg criteria to ensure safe design considerations.

This simulation will help validate the experimental results and further analyze the material's performance under various loading conditions, supporting its potential for structural applications,

IV. RESULTS

We investigated a bio-composite material made from varying blends of carbon fiber and pineapple fiber (70:30, 60:40, and 50:50 ratios) to assess its strength, durability, and suitability for aerospace applications. The material was fabricated using hand lay-up and vacuum bagging methods, followed by curing under controlled conditions.

Tensile testing revealed that the 60:40 blend showed the highest tensile strength, while the 70:30 blend performed well in stiffness. The 50:50 blend didn't meet performance expectations.

The bio-composite offers a strong strength-to-weight ratio, making it ideal for non-primary aircraft structures, UAV components, and interior panels. Compared to conventional carbon fiber composites, it's lighter, more cost-effective (40- 50% cheaper), and only 10-12% weaker in mechanical properties.

Sustainably, the material is made from renewable pineapple fiber, reducing reliance on synthetic materials and lowering production costs and waste. Future research could optimize resin formulations and expand its use in lightweight structures for aerospace and automotive applications.

V. CONCLUSION

This study explores a bio-composite made of 60% carbon fiber and 40% pineapple fiber, offering a lightweight, cost-effective, and eco-friendly alternative to traditional composites. It performs well in strength-to-weight ratio, making it suitable for non-critical aerospace parts and interiors.

The material reduces production costs by 40-45% and has environmental benefits, such as lower carbon emissions and energy consumption. While slightly weaker than pure carbon fiber, it remains strong enough for various applications. This research paves the way for further improvements and broader use of bio-composites in industries like aerospace and automotive.

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