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Fabrication and Testing of Biodegradable PLA Composites Reinforced with Natural Fibers

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Abstract: ***Biodegradable hybrid composites are becoming a more environmentally friendly choice for lightweight uses than traditional materials. This study developed a high-performance composite by reinforcing a bio-epoxy matrix modified with PLA with pineapple leaf fiber (PALF) and kenaf fiber. The hybridization combines the stiffness of PALF with the toughness of kenaf, which makes the overall mechanical behavior better. We made laminates by hand-laying them up and then tested them for important mechanical properties. The new composite has better strength-to-weight properties, which makes it good for structural uses like machine panels and industrial parts. These results show that hybrid composites made from natural fibers could be good for the environment and useful in engineering.***

Keywords: Biodegradable composites, Hybrid natural fibers, Pineapple leaf fiber, Kenaf fiber, Bio-epoxy resin, Polylactic acid, Hand lay-up method, Mechanical properties, Lightweight materials, Sustainable engineering materials

I. INTRODUCTION

The environmental problems associated with petroleum-based materials have led to an increased need for environmentally friendly materials in engineering applications. Conventional composites, such as those reinforced with glass and carbon fibers, are not environmentally friendly because of their non-biodegradability, high energy consumption, and negative impact on the environment. On the other hand, pineapple leaf fiber (PALF) and kenaf fibers are environmentally friendly, lightweight, and cost-effective materials with favorable mechanical properties.

In this research, a bio-based composite material is developed by using a bio-epoxy matrix with polylactic acid (PLA) and hybrid pineapple leaf fiber (PALF) and kenaf fibers. Hybridization of the fibers is done with the aim of achieving a balance of stiffness and toughness of the developed composite material. The developed composite material is then tested for its mechanical properties with the aim of evaluating its suitability for engineering applications.

II. MATERIALS & METHODOLOGY

A. Materials

A bio-epoxy resin system (LB2) with a suitable hardener was used as the primary matrix material, while polylactic acid (PLA) was incorporated as a biodegradable modifier to enhance sustainability. Pineapple leaf fiber (PALF) and kenaf fibers were employed as reinforcing materials due to their high tensile strength, low density, and renewable nature. These natural fibers were selected to improve the mechanical performance of the composite while reducing overall weight and environmental impact.



Fig 1: Bio epoxy resin


Fig 2: PLA

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Fig 3: PALF fiber


Fig 4: Kenaf fiber

B. Methodology

The composite laminates were fabricated using the hand lay-up method due to its simplicity and suitability for natural fiber composites. A 30 × 30 cm mould was first prepared and coated with a thin layer of release agent (wax) to prevent adhesion and facilitate easy demoulding. Pineapple leaf fiber (PALF) and kenaf fibers were cleaned, dried, and arranged in the desired orientation within the mould. A bio-epoxy resin system was then prepared and mixed with a small proportion of polylactic acid (PLA) to improve biodegradability. The resin–PLA mixture was uniformly applied over the fiber layers to ensure proper wetting and impregnation. Multiple layers were built to achieve the required thickness, followed by rolling to remove air bubbles and enhance interfacial bonding. The laminate was allowed to cure at ambient conditions, after which it was removed from the mould and cut into standard specimens for mechanical testing.

III. FABRICATION PROCESS

A. Pineapple Leaf Fiber Preparation

Pineapple leaf fiber (PALF), a lignocellulosic fiber extracted from pineapple leaves, was prepared prior to composite fabrication to enhance its interfacial compatibility with the matrix. The fibers were initially cleaned to remove surface impurities and subsequently dried at 60–80 °C to eliminate moisture. An alkali treatment using NaOH solution was performed to remove lignin and hemicellulose, thereby increasing surface roughness and improving fiber–matrix adhesion.


Figure 5: PALF fiber

B. Kenaf Fiber Preparation

Kenaf fibers, obtained from the bast of Hibiscus cannabinus, were pre-treated prior to composite fabrication to enhance their compatibility with the polymer matrix. The fibers were cleaned to remove impurities and dried to eliminate moisture content. An alkali treatment was then applied to remove lignin and surface contaminants, thereby improving surface characteristics and promoting better interfacial bonding with the matrix.


Figure 6: Kenaf fiber

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C. Mould Preparation

The mould surface was cleaned using a clean cloth to remove dust and contaminants, followed by the application of a release agent to prevent adhesion during demoulding. Paste wax was used as the release agent in this study. A mould of dimensions 30 cm × 30 cm was prepared using a glass sheet as the base and secured with masking tape. A polyethylene sheet was applied to obtain a smooth surface finish of the composite. The wax coating ensured easy removal of the cured laminate from the mould.



Fig 7: Mould

D. Mixing PLA in Bio Epoxy Resin

The PLA powder is mixed with bio epoxy resin using a beaker and mixed very well.



Figure 8: Mix PLA in Resin

E. Fiber Layup and Resin Impregnation

PALF and kenaf fibers were uniformly arranged within the prepared mould to ensure consistent reinforcement. A pre-mixed bio-epoxy – PLA system was then poured to achieve complete wetting and impregnation. The laminate was manually consolidated to remove air voids and enhance interfacial bonding, followed by compression under a hydraulic press at 30–40 KN for 24 h to ensure proper curing.



Figure 9: Final layup

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IV. FINAL COMPOSITE AND EXPERIMENTATION



Figure 10: Final composite (Cut into test specimen)

A. Tensile Test (ASTM D 3039)

The specimens for tensile strength analysis will prepared in line with the ASTM D 3039 standard.The tensile strength analysis will be carried out on the universal testing machine. The dimension of fabricated specimen was 125mm× 25mm× 3 mm.



Figure 11: Tensile testing on UTM

B. Compression Test (ASTM D 3410)

Compression test is conducted to determine a material's behavior under applied crushing loads, and are typically conducted by applying compressive pressure to a test specimen. As per ASTM D3410 Specimens should have a uniform rectangular cross section, 140 mm long. The recommended width can be 12 mm or 25 mm and thicknesses of t mm.



Fig 12: Compression test on UTM

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C. Flexural Test (ASTM D 790)

The specimen for the analysis of flexural strength was prepared in accordance with ASTMD-790 standard. The dimension of the tested samples was 127mm× 12.70mm× t mm.



Fig 13: Flexural test at UTM

D. Impact Test (ASTM D 256)

The impact strength was performed on composite samples to determine the impact strength. ASTM D-256 standard was adapted to prepare specimens. The dimension of specimen was 64mm× 12.7mm × t mm.



Fig 14: Impact testing on IZOD impact equipment

E. Hardness Test (ASTM D 2240)

Hardness of the composite was evaluated using the Brinell hardness test, which involves indentation with a hardened steel or carbide ball indenter of 10 mm diameter. The test provides a measure of surface resistance to deformation and helps assess material suitability for applications. Specimens of size 20 mm × 20 mm × t mm were prepared in accordance with ASTM standards.

V. RESULT AND DISCUSSION

SI No.	Properties	Trial 1	Trial 2	Average
1	Tensile Strength (ASTM D 3039)	42.1 N/mm^2	39.48 N/mm^2	40.79 N/mm^2
2	Compressive Strength (ASTM D 3410)	94.26 N/mm^2	96 N/mm^2	95.13 N/mm^2
3	Flexural Strength (ASTM D 790)	80.06 N/mm^2	77.8 N/mm^2	78.93 N/mm^2
4	Impact Strength (ASTM D 256)	3.2 J/cm	3.8 J/cm	3.5 J/cm
5	Hardness (ASTM D 2240)	80 Shore D	76.4 Shore D	78.2 Shore D

The developed bio-based hybrid composite reinforced with PALF and kenaf fibers exhibited satisfactory mechanical performance across all evaluated tests. The composite demonstrated good flexural strength (78.93 N/mm²), tensile strength (40.79 N/mm²), and compressive strength (95.13 N/mm²), indicating its ability to withstand various loading conditions. Additionally, the impact strength (3.5 J/cm) and hardness (78.2 RHN) confirm adequate resistance to sudden loads and surface deformation. The hybridization of PALF and kenaf fibers contributed to a balanced combination of stiffness and toughness, enhancing overall material performance.

VI. CONCLUSION

A biodegradable hybrid composite reinforced with PALF and kenaf fibers using a PLA-modified bio-epoxy matrix was successfully developed through the hand lay-up process. The fabricated laminates exhibited good structural integrity and consistent quality. Mechanical evaluation confirmed that the optimized composition demonstrated superior performance in terms of strength, stiffness, impact resistance, and hardness, attributed to effective fiber distribution and strong interfacial bonding.

The composite also showed a favorable strength-to-weight ratio, making it suitable for lightweight structural applications such as machine panels and industrial components. The use of natural fibers and biodegradable materials enhances environmental sustainability. Overall, the study highlights the potential of hybrid natural fiber composites as efficient and eco-friendly alternatives to conventional synthetic materials, with scope for further optimization and broader engineering applications.

VII. ACKNOWLEDGEMENT

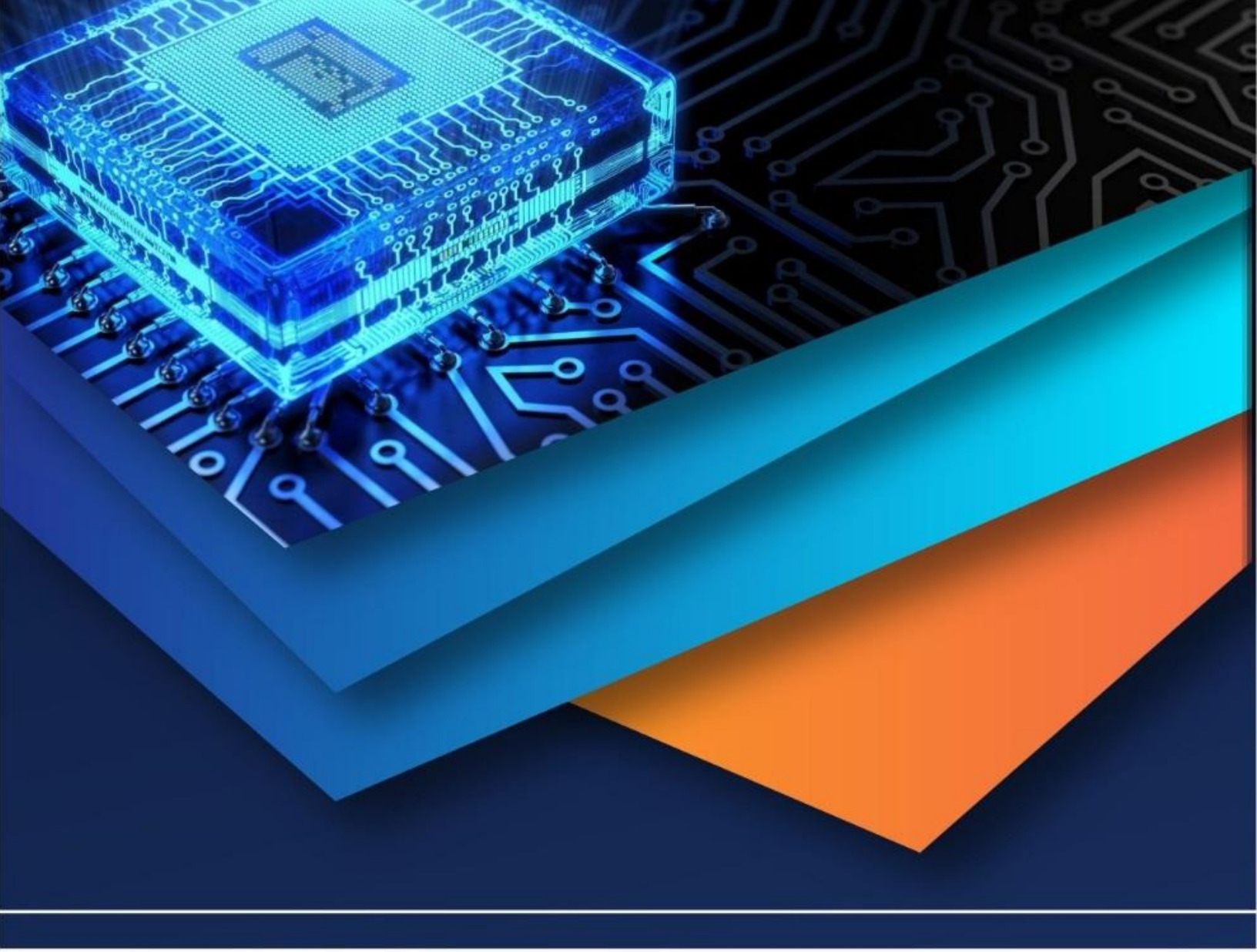
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