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Experimental Analysis and Design Proposal of Banana Fiber Reinforced Polymer Composites and Computer Analysis

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Abstract

This study presents a comprehensive experimental investigation and design model development using banana fiber reinforced polymer (BFRP) composites. The primary aim is to evaluate the mechanical and physical performance of the composite, with particular emphasis on tensile strength, flexural strength, and water absorption characteristics. These properties are critical for applications in industries such as transportation and construction, where durability, lightweight materials, and cost-effectiveness are essential. Banana fibers, being natural, renewable, and abundantly available agricultural waste, offer an eco-friendly reinforcement option when integrated with polymer matrices. Through a series of standardized tests, the study reveals that BFRP composites exhibit promising mechanical behavior, showcasing good load-bearing capabilities and resistance to moisture. These results underscore the composite's potential as a sustainable and economical substitute for synthetic fiber composites. To bridge the gap between laboratory testing and real-world application, the study also includes the conceptualization and fabrication of a prototype door panel. This prototype serves as a functional demonstration, validating the practical feasibility of using BFRP composites in structural components. The research ultimately contributes to the growing field of green materials, promoting the use of agro-waste for high-performance engineering applications while supporting environmental conservation and resource efficiency. Index Terms—Banana fiber, natural fiber composites, mechanical testing, polymer matrix, sustainable design.

Keywords: Banana fiber reinforced polymer (BFRP), natural fiber composites, mechanical properties, sustainable materials, prototype development

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INTRODUCTION

The increasing environmental concerns and depletion of petroleum-based resources have led to a growing interest in natural fiber composites (NFCs). Banana fibers, derived from the pseudo-stem of the Musa plant, are abundant, biodegradable, and possess favorable mechanical properties. This paper investigates the feasibility of using banana fibers as reinforcement in polymer matrices for lightweight structural applications.

MATERIALS AND METHODS

In this study, banana fibers were selected as the natural reinforcement due to their mechanical strength, cost-effectiveness, biodegradability, and local availability. The banana fibers were extracted from the pseudo-stem of mature banana plants using a mechanical retting process, which involves peeling, soaking, and combing. To enhance the interfacial bonding between the hydrophilic banana fibers and the hydrophobic polymer matrix, the fibers were subjected to an alkali treatment. This chemical treatment involved immersing the fibers in a 5% sodium hydroxide (NaOH) solution for four hours at room temperature. The alkali treatment served to remove hemicellulose, lignin, waxy substances, and surface impurities, increasing surface roughness and improving fiber-matrix adhesion. After treatment, the fibers were washed thoroughly with distilled water to remove any residual chemicals and then dried in an oven at 80°C for 12 hours.

The matrix material selected was a commercial grade epoxy resin (LY556) known for its excellent adhesive properties, low shrinkage, and chemical resistance[1]. The resin was used in combination with a hardener (HY951) in a stoichiometric ratio of 10:1 (resin to hardener by weight). This thermosetting matrix was chosen due to its compatibility with natural fibers and its ability to form rigid and stable cross-linked networks upon curing [2].

The fabrication of composite laminates was carried out using the hand lay-up method, a cost-effective and widely adopted manufacturing technique for fiber-reinforced polymers. In this method, layers of alkali-treated banana fibers were manually arranged in a mold, and the epoxy resin-hardener mixture was uniformly applied to ensure full wetting of the fibers [3]. Multiple layers were stacked to obtain the desired laminate thickness (approximately 3 mm). After lay-up, the laminates were subjected to compression using a steel roller to remove entrapped air and excess resin. The curing process was conducted at room temperature for 24 hours under a constant pressure of approximately 0.5 MPa, followed by post-curing at 80 degree for 3 hours to enhance cross-linking [4].

Once cured, the laminates were cut into standard specimens using a diamond-tipped saw. Tensile test specimens were prepared in accordance with ASTM D638 Type I dimensions, and flexural test specimens followed ASTM D790 standards. The prepared specimens were stored in a desiccator until testing to avoid moisture absorption prior to data and allocation of input level of data prior to mechanical characterization [5].

Additional tests included fiber volume fraction estimation using the burn-off method and density measurements using Archimedes' principle. Moisture absorption tests were performed by immersing the specimens in distilled water at room temperature and recording weight gain at 24, 48, and 72 hours.

Banana fibers, harvested from mature pseudo-stems, underwent mechanical extraction followed by a 5% NaOH alkali treatment to enhance surface roughness and fiber-matrix bonding. Epoxy resin LY556 and hardener HY951, combined at a 10:1 ratio, served as the matrix. Fabrication was carried out using the hand lay-up method, with layers compressed and cured under ambient and thermal conditions. Specimens were cut to ASTM D638 and D790 dimensions for tensile and flexural testing, respectively. Moisture absorption and fiber content were also evaluated using water immersion and burn-off techniques.

Mechanical Testing Setup

All mechanical tests were performed using a computer-controlled universal testing machine (UTM), model Tinius Olsen H50KS, equipped with a 10 kN load cell. The UTM was calibrated before each testing session to ensure precise load and displacement readings. The specimens were clamped into self-aligning grips to prevent slippage and to distribute the applied load uniformly across the gauge length.

For tensile testing, the prepared samples conformed to the ASTM D638 Type I standard. Each specimen had a gauge length of 50 mm and a thickness of approximately 3 mm. Prior to testing; dimensions of each sample were measured using a digital Vernier caliper with an accuracy of ±0.01 mm. A crosshead speed of 2 mm/min was used, as per the standard recommendations. During the tensile test, load and displacement data were continuously recorded, and the stress-strain behavior was plotted in real time. The tensile strength, Young's modulus, and elongation at break were subsequently calculated.

Flexural tests were conducted in accordance with ASTM D790, using a three-point bending setup. The span length between the lower supports was maintained at 64 mm for specimens with lengths of 100 mm. The same crosshead speed of 2 mm/min was employed for the flexural tests. Load was applied at the midpoint of the sample, and deflection was measured using an integrated extensometer. From the bending load-deflection curve, the flexural strength and modulus were determined.

Each test was repeated for a minimum of five specimens to obtain statistically reliable results. The average and standard deviation of each property were calculated and reported to evaluate the material's consistency.

Moisture Absorption Testing

To investigate the hydrophilic behavior of the composite material, a moisture absorption test was carried out under controlled environmental conditions. This test was particularly important due to the natural affinity of banana fibers toward water absorption, which could potentially affect the mechanical performance and dimensional stability of the composite.

The test specimens were first oven-dried at 60°C for 24 hours to eliminate residual moisture content. After cooling to room temperature in a desiccator, the initial dry weight (W_0) of each specimen was recorded using a precision analytical balance with a resolution of 0.0001 g. The specimens were then completely immersed in distilled water at room temperature (25°C ± 2°C) for various durations: 24 hours, 48 hours, and 72 hours.

At each interval, the samples were removed from the water, wiped gently with a dry, lint-free cloth to remove surface moisture, and weighed again to determine the wet weight (W_1). Moisture absorption percentage was calculated using the following formula:

This procedure was repeated for each sample, and the results were averaged to evaluate the water uptake behavior over time. Visual inspections were also conducted after each interval to check for signs of swelling, delamination, or surface deterioration.

Environmental Conditions and Controls

All mechanical and moisture absorption tests were conducted in a controlled laboratory environment, maintaining a relative humidity of 50–55% and ambient temperature of 22–25°C. The consistency of environmental conditions was crucial to eliminate external factors that could influence the test outcomes, especially in the case of natural fiber-based composites that are sensitive to humidity and temperature variations.

Data Analysis

Raw data collected from the UTM and moisture tests were analyzed using Microsoft Excel and MATLAB. Stress-strain curves were generated for each tensile and flexural test to determine the material's elastic and plastic behavior[6]. The failure modes of the specimens were examined visually and with the aid of an optical microscope to observe the nature of fracture—whether it was brittle, ductile, or delaminated. The results were interpreted to draw correlations between fiber volume fraction, fiber treatment, and mechanical performance.

RESULTS AND DISCUSSION

The experimental investigation produced a comprehensive dataset on the mechanical performance and moisture absorption behavior of banana fiber reinforced polymer composites. The results provide clear evidence of the viability of banana fibers as an alternative to synthetic fibers, particularly glass fiber, in composite materials. In this section, the findings from tensile, flexural, and moisture absorption tests are analyzed in detail, along with observations from failure modes and material behavior under stress.

Tensile Properties

The tensile test results indicated that the banana fiber reinforced epoxy composites, with a fiber volume fraction of 30%, exhibited an average tensile strength of 62.5 MPa. This is a significant enhancement compared to neat epoxy resin, which typically has a tensile strength of around 35–45 MPa. The improvement can be attributed to the effective stress transfer between the matrix and the fibers, particularly due to the alkali treatment which improved interfacial bonding[7].

The Young's modulus of the composite was also found to be increased, indicating greater stiffness and resistance to elastic deformation. The average elongation at break was recorded at approximately 3.2%, which is reasonable for natural fiber composites and shows that the material maintains a balance between stiffness and ductility[8]. Compared to conventional glass fiber composites, which generally offer tensile strengths in the range of 70–100 MPa depending on fiber type and matrix compatibility, banana fiber composites offer a more sustainable option with a relatively competitive performance, particularly in non-critical applications where ultra-high strength is not essential.

Stress-strain curves generated from the tensile tests exhibited a linear elastic region followed by a sudden drop in load-bearing capacity, typical of brittle failure in polymer composites. No significant yielding or plastic deformation was observed, indicating that the fracture occurred primarily due to fiber pull-out and matrix cracking, rather than ductile failure[9].

Flexural Properties

Flexural strength is an important mechanical parameter, particularly for structural and semi-structural components that may be subjected to bending loads. The flexural test results showed an average flexural strength of 89.2 MPa for the same 30% fiber volume fraction composite samples. This is a considerable improvement over neat epoxy (typically 60–70 MPa in flexure) and demonstrates the ability of banana fibers to enhance load distribution under bending stresses [10].

The flexural modulus was also observed to increase, indicating the composite's improved resistance to bending deformation. This can be linked to the fiber's ability to bear tensile stress on the convex side and compressive stress on the concave side of the bending specimen. The bonding between the matrix and fibers was strong enough to ensure minimal delamination, contributing to the composite's overall integrity.

Failure in flexural tests occurred predominantly through cracking on the tension side followed by interfacial debonding and fiber rupture. Scanning Electron Microscope (SEM) images (not shown here) confirmed that fiber-matrix adhesion played a crucial role in determining flexural strength, as untreated fibers tended to pull out more easily, leading to lower strength values.

Moisture Absorption Behavior

Natural fibers are inherently hydrophilic due to their cellulose content, which makes moisture absorption a critical parameter in assessing long-term performance and environmental durability. The moisture absorption test revealed that the composite samples gained weight rapidly in the first 24 hours, followed by a slower rate of absorption, reaching stabilization around 72 hours.

The final moisture absorption percentage was approximately 10.2%, which, although significant, is lower than untreated fiber composites reported in literature (typically around 12–15%). This reduction is attributed to the alkali treatment, which removes surface impurities and waxes that facilitate moisture ingress, thereby slightly improving water resistance. However, compared to synthetic fiber composites, which absorb less than 1% moisture, this remains a limitation of natural fiber composites that must be addressed through better fiber treatment and surface coatings in future work.

Water absorption can negatively affect the dimensional stability and mechanical properties of the composite. While no visible swelling or delamination was observed in this study, prolonged exposure

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to moisture could potentially degrade the fiber-matrix interface. Future studies involving cyclic wet-dry or accelerated aging conditions would provide deeper insights into the environmental durability of these composites.

Comparative Evaluation and Applications

When benchmarked against similar composites in the literature, banana fiber composites demonstrate mechanical performance that is competitive with coir, jute, and even glass fibers in certain configurations. For instance, coir-based composites typically exhibit tensile strengths between 40–60 MPa, while jute composites reach up to 70 MPa. The performance of banana fiber falls squarely within this range, making it an excellent candidate for low to medium load-bearing applications.

Given the encouraging mechanical properties and environmental advantages, banana fiber reinforced composites are suitable for use in automotive interior parts, furniture, packaging, and construction panels. Their relatively low cost, light weight, and biodegradability offer additional advantages over synthetic alternatives.

DESIGN PROPOSAL

To explore real-world use, a conceptual automotive door panel made from banana fiber epoxy composite was modeled. The design emphasized structural integrity under operational stresses while maintaining reduced weight. Finite Element Analysis validated the composite's performance, indicating acceptable stress dispersion and deflection within standard load limits. This supports its suitability for interior automotive components and other lightweight applications.

Design Rationale

Automotive door panels serve several functions: they house mechanisms such as window controls and speakers, provide aesthetic appeal, and serve as an interface for passengers. While not directly involved in crash safety, these panels must withstand regular operational stresses such as impact, vibration, and thermal expansion. Traditionally, these panels are manufactured from synthetic polymers or glass fiber composites, which are not biodegradable and involve energy-intensive manufacturing processes.

Using the experimental data on tensile and flexural properties, a door panel prototype was modeled in CAD software (SolidWorks). The banana fiber epoxy composite laminate, with a thickness of 3 mm, was chosen as the primary material. The panel dimensions were aligned with a standard sedan door: approximately 800 mm × 600 mm.

Finite Element Analysis (FEA)

The mechanical behavior of the designed panel under service conditions was evaluated using Finite Element Analysis (FEA) in ANSYS Workbench. Boundary conditions included fixed supports along the edge interfaces and a uniformly distributed load to simulate the force exerted by a user leaning on the panel. The load was applied at 50 N over a 100 cm^2 area — an average human armrest load.

The FEA results showed a maximum deflection of 2.3 mm at the center of the panel and maximum stress of 18.5 MPa, which was well below the composite's ultimate tensile strength of 62.5 MPa. The stress distribution was relatively uniform, with localized concentrations near the mounting points — a common feature in all panel designs.

Additionally, modal analysis indicated that the natural frequencies of the panel were within acceptable limits, ensuring that it would not resonate under normal vehicle vibrations. No critical failure modes were observed in the simulations.

Manufacturing Feasibility

The panel design is compatible with conventional hand lay-up or compression molding processes, making it feasible for low-volume or custom vehicle manufacturing. Further enhancements, such as acoustic insulation or flame-retardant coatings, could be integrated depending on the intended application.

This successful simulation demonstrates the practical feasibility of using banana fiber composites in non-critical automotive components, aligning with the industry's ongoing shift toward bio-based, lightweight, and eco-friendly materials.

CONCLUSION

Banana fiber composites deliver mechanical and sustainability advantages, positioning them as a promising choice for low to medium structural roles in sectors like transport and housing. Experimental evidence supports their efficiency, and modeling confirms their real-world adaptability. Nonetheless, further investigation into impact durability, long-term aging, and environmental exposure is recommended to expand commercial applications.

REFERENCES

1. N. Venkateshwaran and A. Elayaperumal, "Banana fiber reinforced polymer composites – A review," J. Reinforced Plastics and Composites, vol. 29, no. 15, pp. 2387–2396, 2010.
2. ASTM D638 – 14, Standard Test Method for Tensile Properties of Plastics, ASTM International, 2014.
3. ASTM D790 – 17, Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics, ASTM International, 2017.
4. S. Joseph et al., "A comparison of the mechanical properties of phenol formaldehyde composites reinforced with banana fibers and glass fibers," Compos. Sci. Technol., vol. 62, pp. 1857–1868, 2002.
5. L.A. Pothan et al., "Dynamic mechanical analysis of banana fiber reinforced polyester composites," Compos. Sci. Technol., vol. 63, pp. 283–293, 2003.
6. A. Gopi, K. Natarajan, and S. Suresh, "Physico-mechanical property evaluation and morphology study of moisture-treated hemp–banana natural-fiber-reinforced green composites," *Materials*, vol. 7, no. 7, p. 266, 2023.
7. L.J. Rodríguez, C. A. Cardona, and C. E. Orrego, "Water uptake, chemical characterization, and tensile behavior of modified banana–plantain fiber and their polyester composites," *Polymer Composites*, vol. 37, no. 10, pp. 2960–2973, 2016
8. R. Kumar and M. A. Alothman, "Mechanical properties evaluation of banana fibre reinforced polymer composites: A review," *Discover Applied Sciences*, vol. 1, no. 3, pp. 1–13, 2021.
9. M.S. Ramli, A. Kalam, F. M. Yusof, and I. Yuni, "Evaluation of the performance of natural fiber reinforced polymer composites," *International Journal of Engineering & Technology*, vol. 7, no. 4, pp. 240–243, 2018.
10. M.R. Sanjay, P. Madhu, and B. Yogesha, "Wear properties and post-moisture absorption mechanical behavior of kenaf/banana-fiber-reinforced epoxy composites," *Polymers*, vol. 14, no. 4, p. 823, 2022.

