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Experimental investigation of Nanoparticles-Enhanced Epoxy Composites Reinforced with Sisal and Palm Tree Natural Fibres

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***Abstract*—Recent research into sustainable composite materials has focused on natural fibre-reinforced polymers enhanced with nanomaterials. This study explores the mechanical and thermal behavior of epoxy composites reinforced with alkali-treated sisal and palm fibres, and modified with aluminum oxide (Al_2O_3) nanoparticles. Al_2O_3 was incorporated into the epoxy resin at 1 wt%, 3 wt%, and 5 wt% before fibre reinforcement. Composites were fabricated using hand lay-up followed by compression molding. Mechanical tests, including tensile and flexural strength, showed that the addition of nano-Al_2O_3 significantly improved strength and stiffness. The best performance was observed at 3 wt% Al_2O_3 with an equal mix of sisal and palm fibres. These findings highlight the potential of using hybrid natural fibres and nanoparticles to develop eco-friendly, high-performance composites for applications in automotive, construction, and packaging industries.**

***Index Terms*—Natural Fibre, palm, Sisal, Epoxy, Aluminium Oxide, Mechanical Properties.**

1 INTRODUCTION

The increasing demand for lightweight, high-strength, and sustainable materials has led to significant interest in natural fiber-reinforced polymer composites. These materials offer several environmental advantages over conventional synthetic composites, including renewability, biodegradability, and a lower carbon footprint. Among the various natural fibers, sisal and palm tree fibers stand out due to their abundant availability, low cost, and adequate mechanical performance. Epoxy resin, a widely used thermosetting polymer, is well-known for its high mechanical strength, chemical resistance, and dimensional stability. However, it tends to be brittle and lacks sufficient toughness when used alone. The incorporation of natural fibers into epoxy can enhance its mechanical behavior, but further improvements are necessary to achieve properties comparable to those of synthetic fiber composites.To enhance the tensile and flexural strength two critical mechanical properties for structural applications nanoparticles are increasingly integrated into the polymer matrix. In particular, aluminum oxide (Al_2O_3) nanoparticles are gaining attention due to their high hardness, thermal stability, and their ability to enhance interfacial bonding between fibers and the matrix. Even at low weight percentages, Al_2O_3 nanoparticles can significantly improve load transfer, stiffness, and crack resistance within the composite.

This study focuses on the fabrication and mechanical characterization of hybrid epoxy composites reinforced with sisal and palm tree fibers, and enhanced with varying concentrations of Al_2O_3 nanoparticles (1 wt%, 3 wt%, and 5 wt%). Special emphasis is placed on evaluating the tensile and flexural properties of the composites, which reflect their capacity to withstand stretching and bending loads, respectively—qualities essential in load-bearing and structural components. Prior to fabrication, the natural fibers are subjected to alkali treatment to remove surface impurities, thereby improving adhesion with the epoxy matrix. The composites are prepared using the hand lay-up method, followed by compression molding to ensure uniform nanoparticle dispersion and optimal fiber alignment. Mechanical tests are conducted following standard protocols to assess the influence of both Al_2O_3 content and fiber hybridization on the overall performance of the composites. Through this experimental investigation, the study aims to explore how the synergistic effects of nano-Al_2O_3 particles and natural hybrid fibers can lead to the development of environmentally friendly, mechanically durable, and lightweight composites. The outcomes of this research are expected to support the growing use of bio-composites in sectors such as automotive, construction, and consumer goods.

2 MATERIALS AND METHODS

2.1 Materials

Sisal and palm fibres were alkali-treated using NaOH solution to remove impurities. Epoxy LY556 resin and hardener HY951 were used as the matrix. Al_2O_3 nanoparticles (20-50 nm) with 99.9% purity were added to the resin at 1 wt%, 3 wt%, and 5 wt% concentrations

2.2 Fabrication Process

Composite laminates were prepared by hand lay-up followed by compression molding. Three sets were fabricated: pure sisal, pure palm, and a 50:50 sisal-palm hybrid. Samples were tested with and without Al_2O_3 nanoparticles.

2.3 Testing Procedures

Tensile tests followed ASTM D3039 and flexural tests followed ASTM D790 using a Universal Testing Machine (UTM). Parameters like ultimate load, stress, and displacement were recorded

2.4 Tensile Testing

Tensile tests were conducted following the ASTM D3039 standard, which is specifically designed for evaluating the tensile properties of plastic materials. Type I dog-bone specimens, measuring 165 mm in length, 13 mm in width, and 3 mm in thickness, were fabricated using additive manufacturing with consistent print orientation and infill parameters to ensure reproducibility The machine was equipped with precision-calibrated wedge grips to minimize slippage and alignment errors. Real-time stress-strain data were collected using an extensometer attached within the gauge section of the specimen. Key tensile properties obtained from the test included the Ultimate Tensile Strength (UTS), the Young's Modulus (modulus of elasticity), and the elongation at break. These metrics provided insight into the material's load-bearing capacity and ductility under tensile forces.

Tensile Performance

SPECIMEN	FLEXURAL TEST VALUE FOR ULTIMATE LODE IN (N)	
	With Nanoparticle (Al_2O_3)	Without Nanoparticle (Al_2O3)
Sisal Triple Layer	39.62	50.94
Palm Triple Layer	37.5	67.21
Sisal + Palm Triple Layer	51.64	54.47

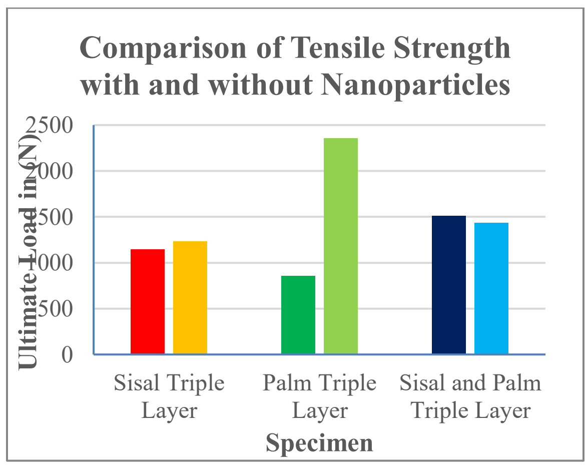

Figure 1. Tensile Strength

2.5. Flexural Testing

Flexural behavior was evaluated using the ASTM D790 standard, which governs the testing of plastic materials under bending loads. Rectangular bar specimens of 125 mm × 13 mm × 3 mm were used in a three-point bending configuration. The specimens were supported at both ends with a span length set according to standard guidelines, while a centrally applied load was introduced at a constant crosshead speed of 2 mm/min until the specimen either fractured or underwent significant deformation. This test enabled the assessment of the flexural strength and flexural modulus, which are critical for understanding the material's behavior under out-of-plane loading—an important consideration for structural aerospace components subjected to complex stress distributions.

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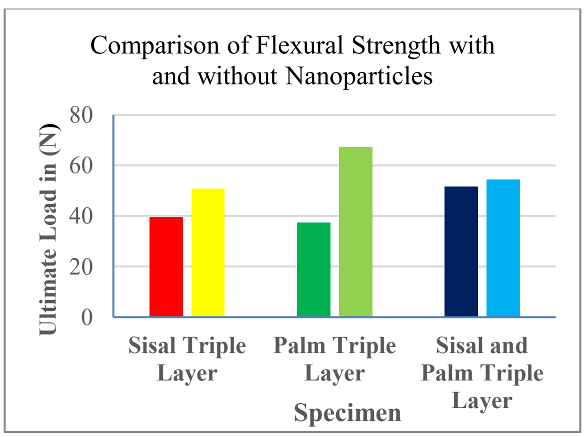


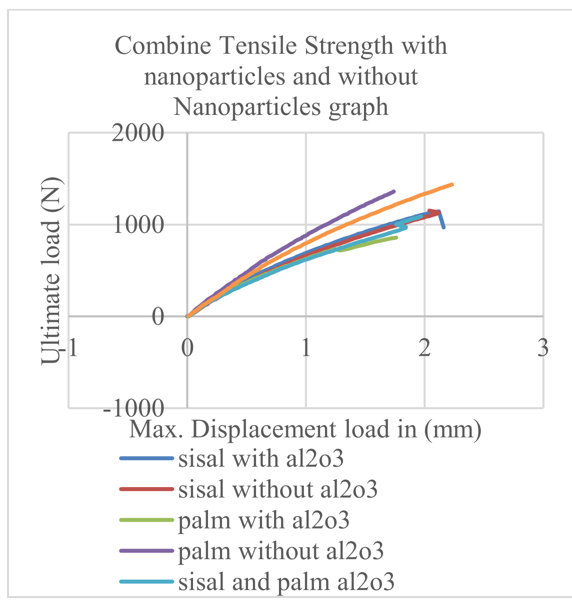
Figure 2. Flexural Strength

3 RESULTS AND DISCUSSION

The incorporation of nanoparticles Al_2O_3 (Aluminum Oxide) into epoxy composites significantly enhanced the tensile and flexural strength. Composites with hybrid reinforcement exhibited improved mechanical performance compared to single-fiber composites.

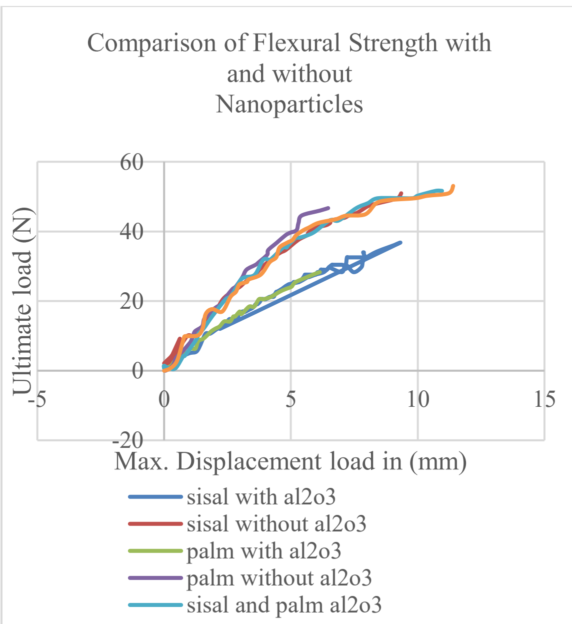
3.1. Tensile Strength with or without Test Value

The tensile strength performance of natural fiber composites with and without the addition of Al_2O_3 nanoparticles was evaluated based on ultimate load values in Newtons (N). For the Sisal Triple Layer, the ultimate load without nanoparticles was 1234.52 N, whereas with nanoparticles it slightly decreased to 1143.26 N, indicating a marginal reduction in strength due to nanoparticle addition. In contrast, the Palm Triple Layer exhibited a significant reduction in tensile strength with nanoparticles—dropping from 2357.26 N to 857.44 N—suggesting that the incorporation of Al_2O_3 nanoparticles negatively affected its structural integrity. However, the Sisal + Palm Triple Layer composite showed an improvement when nanoparticles were added, increasing from 1435.44 N without nanoparticles to 1508.3 N with them.Among the tested materials, the Palm Triple Layer without nanoparticles demonstrated the highest tensile strength (2357.26 N), making it the best-performing material in terms of ultimate load-bearing capacity. Nevertheless, the Sisal + Palm Triple Layer with nanoparticles showed a beneficial synergy and enhancement in tensile performance due to nanoparticle reinforcement, suggesting its potential as a high-performance composite when both fiber blending and nanoparticle modification are optimized.



3.2 Flexural Strength with or without Test Value

The flexural strength analysis of natural fiber composites with and without Al_2O_3 nanoparticles was assessed based on ultimate load values in Newtons (N). For the Sisal Triple Layer, the flexural strength decreased notably from 50.94 N (without nanoparticles) to 39.62 N (with nanoparticles), indicating a reduction in load-bearing capability due to nanoparticle addition. Similarly, the Palm Triple Layer showed a marked decline in strength, dropping from 67.21 N without nanoparticles to 37.5 N with nanoparticles. The Sisal + Palm Triple Layer composite also experienced a slight decrease in flexural strength when nanoparticles were introduced, going from 54.21 N to 51.64 N.Among all tested samples, the Palm Triple Layer without nanoparticles demonstrated the highest flexural strength at 67.21 N, making it the best-performing material in terms of flexural load capacity. Overall, the addition of Al_2O_3 nanoparticles generally resulted in a reduction of flexural strength across all fiber configurations, suggesting that, in this case, nanoparticle reinforcement did not enhance— and in some cases hindered— the flexural performance of the composites. These results suggest that the addition of Al_2O_3 nanoparticles did not improve flexural strength and may, in fact, reduce the performance of natural fiber composites in bending applications.



4 CONCLUSIONS

The mechanical performance of natural fiber composites reinforced with and without Al_2O_3 nanoparticles was evaluated through tensile and flexural strength tests, using ultimate load values in Newtons (N) as the metric.

Tensile Strength Analysis: In terms of tensile strength, the Sisal Triple Layer composite showed a decrease when nanoparticles were added, dropping from 1234.52 N to 1143.26 N. The Palm Triple Layer exhibited an even more significant reduction, from 2357.26 N to 857.44 N, indicating that Al_2O_3 nanoparticles adversely affected its tensile capacity. Interestingly, the Sisal + Palm Triple Layer composite showed improved performance with nanoparticles, increasing from 1435.44 N to 1508.3 N, suggesting a beneficial synergistic effect when both fiber types are combined with Al_2O_3 reinforcement.

Flexural Strength Analysis: results revealed a consistent decrease across all composite types when Al_2O_3 nanoparticles were introduced. The Sisal Triple Layer dropped from 50.94 N to 39.62 N, and the Palm Triple Layer saw a steep decline from 67.21 N to 37.5 N. Similarly, the Sisal + Palm Triple Layer experienced a slight decrease, from 54.21 N to 51.64 N. These results suggest that while Al_2O_3 nanoparticles may contribute to certain mechanical enhancements, they tend to negatively affect the flexural performance, potentially due to reduced matrix ductility or impaired fiber–matrix bonding.

In conclusion, the Palm Triple Layer without nanoparticles is identified as the best quality material, exhibiting superior performance in both tensile and flexural tests. While the addition of Al_2O_3 nanoparticles may offer advantages in hybrid fiber configurations (as seen in the Sisal + Palm composite for tensile strength), their overall impact on mechanical properties appears to be material and property specific.

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