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MECHANICAL PROPERTIES OF SHORT NATURAL FIBER-REINFORCED THERMOPLASTIC COMPOSITES

Priyanka Jhavar1, Dr G.R.Selokar2
Research Scholar, Department of Mechanical Engineering, Sssutms Sehore [1]
Professor, Department of Mechanical Engineering, Sssutms Sehore [2]

Abstract:

This study investigates the mechanical properties of thermoplastic composites reinforced with natural fibers and fillers. Epoxy composites with jute fibers and aluminum oxide (Al2O3) fillers were analyzed, alongside hybrid composites made from banana, kenaf, sisal, and glass fibers. Various fabrication techniques, such as hand lay-up and compression molding, were utilized, and treatments like sodium lauryl sulfate and alkali treatments were applied to enhance fiber-matrix bonding. Mechanical properties, including tensile, flexural, and impact strengths, were evaluated, and morphological analysis using scanning electron microscopy (SEM) provided insights into fiber/matrix adhesion. Dynamic testing under different support conditions examined composite behavior. The study revealed that fiber content, orientation, and filler composition significantly influence mechanical performance. The optimal configurations demonstrated enhanced strength and stiffness, making these composites suitable for high-performance applications in aerospace, shipping, and sports industries. This research underscores the potential of natural fiber composites in advanced engineering applications.

Keywords: *Thermoplastic composites, Natural fibers, Mechanical properties, Fiber-matrix bonding, Hybrid composites, Filler materials.*

1. Introduction

In recent years, the growing emphasis on sustainability and environmental consciousness has driven a significant shift toward the use of natural fibers in composite materials. These materials, often combined with thermoplastic or thermosetting polymers, offer a compelling alternative to synthetic fibers due to their biodegradability, lower cost, and reduced environmental impact. The mechanical properties of thermoplastic composites reinforced with natural fibers have become a focal point for researchers aiming to develop materials that balance

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environmental benefits with high performance. Natural fibers such as jute, banana, kenaf, sisal, and glass fibers have been increasingly utilized in composite fabrication for various engineering applications. These fibers are often combined with fillers like aluminum oxide (Al_2O_3) to further enhance the material properties. The fabrication methods employed, such as hand lay-up and compression molding, along with treatments like sodium lauryl sulfate and alkali treatments, have been shown to significantly improve fiber-matrix adhesion and overall mechanical performance. Understanding the mechanical properties of these composites, including tensile, flexural, and impact strengths, is essential for their application in industries such as aerospace, shipping, and sports equipment. Additionally, the study of fiber orientation, content, and the composition of fillers plays a crucial role in determining the strength, stiffness, and durability of the composites. Morphological analyses, often conducted using scanning electron microscopy (SEM), provide valuable insights into the quality of fiber/matrix bonding, a key factor in the material's mechanical behavior. This study delves into the mechanical properties of thermoplastic composites reinforced with natural fibers and fillers, highlighting the potential of these materials for high-performance applications. The results demonstrate that optimizing fiber content, orientation, and filler composition can lead to enhanced strength and stiffness, making natural fiber composites a viable solution for advanced engineering needs.

2. Literature Review

Literature Summary

Authors	Work Done	Findings
Akter et al. (2024)	Reviewed plant fiber-reinforced polymer composites.	Discussed modifications, fabrication, properties, and applications.
Kennedy et al. (2024)	Explored polymer-based hybrid composites for bone plate uses.	Highlighted advancements and future prospects in bone plate applications.
Bhong et al. (2023)	Reviewed composite materials and their applications.	Provided an overview of various composite materials and their industrial uses.
Elfaleh et al.	Reviewed natural fibers and	Emphasized the sustainability and benefits

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(2023)	composites as eco-friendly options.	of natural fiber composites.
Iqbal et al. (2023)	Studied effect of fiber content and orientation on bending strength.	Found that both fiber content and orientation significantly influence mechanical properties.
Kangishwar et al. (2023)	Reviewed polymer matrix composites: selection, fabrication, and applications.	Offered insights into material selection and applications of polymer composites.
Sidde et al. (2023)	Compared non-biodegradable plastics with natural fiber composites.	Suggested that natural fiber composites are more environmentally friendly for automotive designs.
Uzoma et al. (2023)	Developed automotive parts using kenaf fiber composites.	Demonstrated successful use of kenaf fiber composites for both interior and exterior parts.
Ramasubbu & Madasamy (2022)	Fabricated automobile components with hybrid natural fiber composites.	Reported improved performance of hybrid composites in automotive applications.
Mai Nguyen Tran et al. (2021)	Studied eco-composites with bio-waste additives.	Found that bio-waste additives enhanced flame retardancy and mechanical properties.
Yogeshwaran et al. (2021)	Investigated waste tire particle reinforcement in fiber composites.	Found that waste tire particles improved mechanical properties of jute and abaca composites.
Valášek et al. (2021)	Analyzed alkali treatment effects on fiber microstructure.	Confirmed that alkali treatment improved the mechanical properties of coir and abaca fibers.
Ghosh et al. (2020)	Discussed sustainable materials in the automotive industry.	Highlighted the importance of renewable materials for sustainable automotive solutions.
Pashkova et al. (2020)	Characterized modern polymer materials for automotive use.	Provided insights into the application of various polymer materials in the automotive sector.

3. Research Gap

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Despite the growing interest in short natural fiber-reinforced thermoplastic composites, significant research gaps remain. Existing studies often focus on the mechanical properties of specific fiber types or thermoplastics, lacking comprehensive comparisons across various combinations. Additionally, the effects of processing methods and fiber orientation on performance are inadequately explored. There is a need for standardized testing protocols to evaluate durability and environmental impacts comprehensively. Furthermore, limited investigations into the long-term behavior and recyclability of these composites hinder their broader application in sustainable industries.

4. Methodology

The methodology of this study involved a systematic approach to investigate the mechanical properties of thermoplastic composites reinforced with short natural fibers and fillers. Natural fibers such as jute, banana, kenaf, and sisal were selected, and treated with sodium lauryl sulfate and alkali solutions to enhance fiber-matrix adhesion. Epoxy and polyester resins served as the matrix materials, with composites fabricated using hand lay-up and compression molding techniques. Mechanical properties were evaluated through standardized tests for tensile, flexural, and impact strengths. Morphological analyses were conducted using scanning electron microscopy (SEM) to assess fiber/matrix adhesion and debonding mechanisms. The impact of fiber orientation, content, and layer count on mechanical performance was also studied, alongside dynamic testing under different support conditions. Data analysis aimed to identify correlations between these variables, contributing to the understanding of how fillers and natural fibers can enhance the properties of thermoplastic composites for advanced engineering applications.

5. Result & Discussion

Influence of Filler on Mechanical Properties: The physical and mechanical properties of epoxy composites reinforced with jute fibers and filled with Al2O3 were investigated to determine how the addition of filler affects composite properties. It was observed that the presence of the filler significantly influenced various properties of the composites. Specifically, hardness, strength, flexural modulus, and tensile modulus increased with higher fiber and filler content. However, the interlaminar shear strength improved only with an increase in fiber, while the addition of filler led to a decrease. The mechanical properties of woven composites made

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from banana fiber, kenaf fiber, and banana/kenaf hybrid fibers were also examined. The mechanical strength of the woven hybrid composites was enhanced due to the combination of kenaf and banana fibers. The tensile, flexural, and impact strengths of the banana/kenaf woven hybrid composites surpassed those of the individual fibers. Treatment with sodium lauryl sulfate (SLS) further improved mechanical strength by enhancing interfacial bonding. Morphological analyses of fractured samples were conducted using scanning electron microscopy (SEM) to investigate fiber/matrix adhesion and de-bonding mechanisms.

Table 1 Provides information about natural fibers available in the nature in different form

Fiber Type	Examples
Wood Fiber	Hardwood, Softwood, Sawdust
Stalk Fiber	Bamboo, Wheat, Rice, Grass, Barley, Corn
Fruit Fiber	Coconut, Betel Nut
Seed Fiber	Cotton, Oil Palm Seed, Kapok
Leaf Fiber	Sisal, Manila, Banana, Palm, Mengkuang, Abaka
Bast Fiber	Rattan, Hemp, Jute, Ramie, Flax, Sugar Cane, Kenaf, Roselle

Influence of Fillers on Mechanical Properties: The mechanical properties of polyester composites reinforced with sisal, jute, and glass fibers were studied. It was found that incorporating glass fiber into jute fiber composites resulted in maximum tensile strength. Additionally, composites made from a mixture of jute and sisal fibers exhibited the highest flexural strength, while the sisal fiber composite achieved the maximum impact strength. Variations in tensile, flexural, and compressive strengths of epoxy-based sisal-glass hybrid composites were also examined. It was observed that composites with a 2 cm fiber length demonstrated superior tensile, flexural, and compressive strengths compared to those with 1 cm and 3 cm fibers. Furthermore, alkali treatment was shown to enhance the strength of hybrid composites compared to untreated ones. Research on the mechanical behavior of jute fibers in polyester and epoxy matrices revealed that the processing time for jute-polyester composites was significantly shorter than that for jute-epoxy laminates. Sisal natural fiber composites, both with and without silica,

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were developed using 100% biodegradable sisal fibers as reinforcement in a polyester matrix. The findings indicated that the tensile strength and modulus of composites containing silica were significantly greater than those without it. The impact strength of composites with silica was also notably higher compared to those without silica and plain polyester. A study on the abrasive wear and mechanical properties of particulate-filled glass epoxy composites focused on randomly oriented glass fibers reinforced with epoxy resin and filled with various materials. Results showed that the wear of the composite was sensitive to changes in abrading distance but less affected by sliding velocity. The impact properties of bamboo fiber composites filled with cenosphere were investigated, revealing that the impact strength of bio-fiber reinforced composites increased with the addition of cenosphere up to a certain limit, after which it decreased. The optimal configuration was found to be a composite with seven layers and 1.5 wt% cenosphere, which exhibited the maximum impact strength. Finally, composites made from chemically treated fibers derived from arecanut husk and tamarind fruit fibers demonstrated better strength compared to untreated fibers. The strength of the hybrid composites increased with a higher volume fraction of fiber reinforcement, showing optimal mechanical properties at a reinforcement level of 40% to 50%.

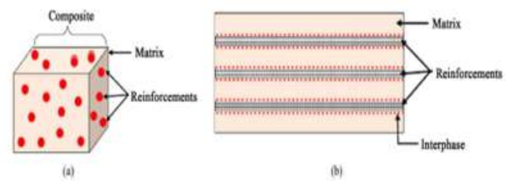

Figure 1 (a) Explains composition of laminate which include resin as a matrix and fiber as reinforcement and (b) shows inter-phase of matrix and reinforcement.

Effect of Process Parameters on Mechanical Characteristics: The mechanical properties of polypropylene-based composites reinforced with jute fiber improved with increasing jute content, peaking at 40%. Bamboo composite laminates exhibited higher tensile strength and stiffness than jute, but both were inferior to glass fiber composites. Jute composites showed greater compressive strength than bamboo but still fell short of glass composites. Fiber orientation also influenced strength, with 0-degree orientation providing the best results. In another study, a composite with 50% sisal-glass fiber and 50% resin achieved a maximum tensile strength of 97.71 MPa and a breaking load of 10.285 kN, outperforming sisal-coir-glass and coir-glass composites. A hybrid composite with

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40% sisal-coir-glass fibers demonstrated high flexural strength and impact strength. Research on jute/glass reinforced polyester composites revealed that their mechanical properties were affected by water absorption, making them unsuitable for underwater applications. Additionally, glass/carbon hybrid specimens showed improved tensile and flexural properties, particularly with carbon fiber at the ends.

Mechanical Properties of Thermoplastic Composites Reinforced with Short Natural Fibers: A review of jute and banana fiber composites highlights their mechanical and physical properties, as well as their chemical composition. This composite technology enables the use of cost-effective materials in high-performance applications across various fields, including sports goods, shipping, and aerospace. Consequently, these composites are increasingly regarded as essential in today's fast-evolving landscape. While the application of composites in structural facilities often focuses on enhancing strength through artificial fibers, it neglects the sustainability of the raw materials used. As the global population grows and purchasing power increases, the demand for sustainable raw materials for structural reinforcement is rising. Research into hybrid composites made from banana and kenaf fibers shows improved resistance to water absorption compared to non-hybrid versions. Investigations into coir-glass hybrid laminates indicate that coir fibers fail more quickly than glass fibers, but incorporating glass fibers at outer layers significantly enhances mechanical properties. The effects of layer count and fiber orientation on composite behavior demonstrate that increasing layers improves mechanical performance, peaking at five layers. Composites with fibers oriented at 0 degrees show superior mechanical properties compared to others. Notably, discrepancies between measured and predicted moduli may arise from assumptions about fiber-matrix bonding. Further advancements include processes to enhance the mechanical properties of jute/poly lactic acid composites, where controlling hydrolysis is crucial for optimal performance. Additionally, dynamic analysis of reinforced concrete slabs under different support conditions reveals that simply supported configurations yield higher modal properties, while free-free conditions provide more accurate experimental results.

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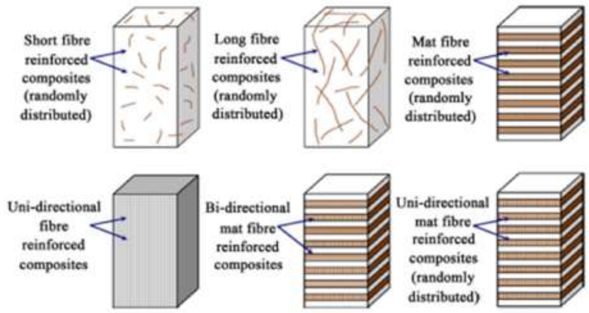

Figure 2 Different type of fiber orientation used for the laminate manufacturing

Table 2 Properties of various natural fibers

Fibre type	Density (Kg/m³)	Water absorption (%)	Modulus of elasticity E (GPa)	Tensile strength (MPa)
Sisal	800 - 700	56	15	268
Roselle	800 - 750	40 - 50	17	170 - 350
Banana	950 - 750	60	23	180 - 430
Date palm	463	60 - 65	70	125 - 200
Coconut	145 - 380	130 - 180	19 - 26	120 - 200
Reed	490	100	37	70 - 140

Figure 3 Varieties of Natural Fiber which are produced by plants.

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6. Conclusion

This study explores the impact of fillers and natural fibers on the mechanical properties of thermoplastic composites. Epoxy composites were reinforced with jute fibers and aluminum oxide (Al2O3) fillers, while hybrid composites combined fibers like banana, kenaf, sisal, and glass for enhanced strength. Various fabrication techniques, such as hand lay-up and compression molding, were employed, with treatments like sodium lauryl sulfate and alkali treatments to improve fiber-matrix bonding. Mechanical tests, including tensile, flexural, and impact strength assessments, were conducted to evaluate the composites' performance. Morphological analysis using scanning electron microscopy (SEM) helped understand fiber/matrix adhesion, while dynamic testing under free-free and simply supported conditions examined the composites' behavior in different configurations. Data analysis revealed that fiber content, orientation, and filler composition significantly influenced strength and stiffness, with optimal configurations offering improved mechanical properties for applications in high-performance fields such as aerospace, shipping, and sports goods.

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