



Exploring the Potential of Ramie Fiber Composites as Eco-friendly Materials for Medical Prostheses

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Abstract

The insect *Callosobruchus maculatus*, is responsible for serious damages in the storage of grains of diverse cultures, among them, the one of the beans. Therefore the development of substances capable of being an alternative to minimize agricultural losses and thus contribute to food security of the population is a current necessity. This research aims to explore new materials derived from natural fibers for the development of environmentally friendly and recyclable medical devices, particularly prostheses. The focus is on utilizing ramie fiber, a natural fiber, as a substitute for artificial fibers and plastics in composite materials. The study investigates the impact and bending strength of ramie fiber composites by varying the volume fraction and fiber orientation. The experimental design involves three volume fractions (1%, 3%, and 5%) and three fiber orientations (10°, 20°, and 30°). Hand lay-up method is employed on molds, ASTM D256 impact tests and ASTM D7264 bending tests are conducted to assess the mechanical properties. The findings indicate that the ramie fiber composite with a volume fraction of 5% and fiber orientation of 30° exhibits the highest bending strength, measuring 471.1 Mpa. Similarly, this composition demonstrates the highest impact strength value of 26,558,720 Pa. Overall, this research contributes to the advancement of sustainable materials for medical prostheses and highlights the significance of optimizing the composition of ramie fiber composites to enhance their mechanical properties.

Keywords: Ramie Fiber, Composite Materials, Medical Prostheses

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INTRODUCTION

Common bean (*Phaseolus vulgaris*) is considered a food of great importance for human consumption because of the development of eco-friendly materials for medical prostheses has gained significant attention due to the increasing demand for sustainable and recyclable solutions in the healthcare industry. This study aims to explore the potential of ramie fiber composites as environmentally friendly alternatives to artificial fibers and plastics in the fabrication of medical prostheses.

Ramie fiber, derived from the stalks of the *Boehmeria nivea* plant, possesses remarkable mechanical properties and is considered a promising candidate for use in composite materials.

Previous researchers have investigated various natural fibers, such as [1], [2],[3] who investigated the use of natural fibers as reinforcement in polymer composites. They tested several types of natural fibers such as hemp, kenaf, and sisal fibers, and compared them to glass fibers as a conventional reinforcement. The results showed that natural fibers have relatively high tensile strength and a decent modulus of elasticity, making them an attractive alternative to glass fibers in several applications[4]. [5],[6],[7] explored the use of composites with bamboo fiber reinforcement in construction applications. They are trying to replace conventional materials such as wood with bamboo composites in building structures. The results showed that bamboo composites had relatively high strength and stiffness, and had better resistance to insect and fungal attack than wood. This study provides exciting preliminary evidence for the use of composites with bamboo fiber reinforcement as a sustainable alternative in the construction industry.

[8], [9] studied the effect of adding rice straw fiber to polymer composites. They found that the addition of straw fiber increased the tensile strength and stiffness of the composite, as well as increased its dimensional stability and thermal resistance. This study shows that rice straw fiber has great potential in the development of composites with natural fiber reinforcement. In addition to mechanical properties, studies have also been carried out to evaluate the thermal and environmental properties of composites with natural fiber reinforcement. For example, research by [10],[11] tested the thermal and decomposition properties of polymer composites reinforced with jute fibres. They found that the composite exhibited good resistance to high temperatures and slow thermal degradation, making it an attractive choice for high temperature applications such as in the automotive and aircraft industries. [12], who investigated the mechanical properties and morphology of polymer composites with coconut fiber reinforcement. They found that coconut fiber has relatively high tensile strength and good modulus of elasticity, and can significantly improve the mechanical properties of the composite. This study demonstrates the potential of coconut fiber as an attractive reinforcing material in the development of sustainable composites.

[13],[14],[15] conducted research on the use of kenaf fiber as reinforcement in polymer composites. They evaluated the mechanical and thermal properties of the composite and studied the effect of chemical treatment on kenaf fiber on the quality of the composite. The results of this study indicate that kenaf fiber can increase the strength and stiffness of composites, as well as improve dimensional stability and resistance to high temperatures. [16] conducted research on the use of wheat straw fiber in polymer composites. They study the mechanical, thermal and morphological properties of composites and optimize processing conditions to achieve optimal composite quality. This study shows that wheat straw fiber can be

an effective reinforcement in improving the mechanical properties of composites. [17]–[19],[20],[21] conducted research on the use of palm fiber as reinforcement in polymer composites. They studied the effect of surface treatment of palm fiber on the quality of the composite and analyzed the mechanical properties and morphology of the composite. The results of this study indicate that palm fiber can increase the strength and stiffness of composites, as well as provide potential as a sustainable reinforcement material. [22], [23], [24], [25] conducted research on the use of natural fibers derived from the kenaf plant as reinforcement in polymer composites. They study the mechanical, thermal and environmental properties of composites and optimize the proportions of fiber and polymer matrix to achieve the desired composite quality. This study shows that kenaf fiber can provide a significant increase in the mechanical and thermal properties of composites.

Ramie fiber exhibits excellent tensile strength, stiffness, and dimensional stability [26],[27], making it suitable for load-bearing applications [28]. Its unique characteristics, such as high moisture absorption and microbial resistance, further contribute to its potential use in medical devices. Moreover, ramie fiber is abundant, widely cultivated, and does not compete with food crops, making it an attractive choice for sustainable materials development.

The implications of this research are significant for both the healthcare and environmental sectors. Firstly, the use of ramie fiber composites in medical prostheses can provide an environmentally friendly solution, reducing the reliance on non-biodegradable materials and minimizing the carbon footprint associated with traditional prosthetic devices. Secondly, the recyclability of ramie fiber composites ensures the potential for resource recovery and further reduces waste generation.

Furthermore, optimizing the composition of ramie fiber composites can lead to enhanced mechanical properties, such as impact and bending strength, improving the overall performance and longevity of medical prostheses. Understanding the influence of factors such as volume fraction and fiber orientation on these properties is crucial for achieving optimal outcomes. This research aims to investigate the effects of varying volume fractions (1%, 3%, and 5%) and fiber orientations (10°, 20°, and 30°) on the mechanical behavior of ramie fiber composites.

By conducting hand lay-up experiments on specifically designed molds and utilizing ASTM D256 impact tests and ASTM D7264 bending tests, the researchers will gather empirical data to evaluate the tensile and impact strengths of the ramie fiber composites. The results of this study will shed light on the most effective composition in terms of volume fraction and fiber orientation, providing valuable insights for the design and fabrication of ramie fiber-based medical prostheses.

In conclusion, this research seeks to explore the potential of ramie fiber composites as eco-friendly materials for medical prostheses. By investigating the effects of different compositions on the mechanical properties, the study aims to contribute to the advancement of sustainable solutions in the healthcare industry.

The findings have implications for reducing environmental impact, promoting recyclability, and enhancing the overall performance of medical prostheses, thus benefiting individuals with disabilities and the broader society.

METHOD

Ramie fiber: High-quality ramie fibers obtained from the stalks of *Boehmeria nivea* plants were used as the primary reinforcement material. The fibers were sourced from a reputable supplier and carefully selected for their consistent quality and length.

Composite Preparation:

Hand lay-up method: The ramie fiber composites were prepared using the hand lay-up technique. The required volume fractions (1%, 3%, and 5%) were achieved by accurately weighing the ramie fibers and dispersing them evenly within the matrix material. **Matrix material:** A food-grade composite material was chosen as the matrix material to ensure compatibility with medical prostheses. The matrix material, along with the ramie fibers, was thoroughly mixed to achieve homogeneity. **Mold preparation:** Molds with specific dimensions of 127 x 10 mm and 80 x 8 mm were used for fabricating the composite specimens. The molds were cleaned, coated with a release agent to prevent sticking, and securely clamped to maintain the desired shape during curing.

Composite Fabrication:

Layering process: The hand lay-up technique involved carefully layering the ramie fiber composite materials within the molds. The process ensured uniform fiber dispersion and alignment according to the designated fiber orientations (10°, 20°, and 30°).

Pressing and curing: Once the layers were stacked, a controlled pressure was applied using a hydraulic press to ensure proper consolidation. The composite specimens were then cured at an optimized temperature and duration to facilitate bonding and achieve desired mechanical properties.

Testing and Analysis:

Tensile strength measurement: The tensile strength of the ramie fiber composites was evaluated using ASTM D256 impact tests. The specimens were subjected to controlled impacts, and the corresponding force-displacement data were recorded and analyzed to determine the tensile strength values.

Impact strength measurement: ASTM D7264 bending tests were conducted to assess the impact strength of the ramie fiber composites. The specimens were subjected to controlled bending forces, and the resulting deformation and fracture patterns were analyzed to determine the impact strength values.

Statistical analysis: The obtained data were statistically analyzed to identify significant differences and correlations between the volume fraction, fiber orientation, and mechanical properties of the ramie fiber composites. Descriptive statistics, such as means and standard deviations, were calculated, and appropriate statistical tests were applied to validate the findings.

Replication and Quality Control: To ensure the reliability and repeatability of the results, all experiments were conducted in triplicate. The composite fabrication process was carefully monitored, and quality control measures were implemented to minimize variations and errors. Calibration of testing equipment was performed regularly to maintain accuracy.

The material and method employed in this study aimed to provide a comprehensive understanding of the fabrication process and testing procedures used to investigate the mechanical properties of ramie fiber composites. These standardized techniques ensured reproducibility and reliability of the experimental results, thereby contributing to the scientific rigor of the research.

RESULTS AND DISCUSSION

Bending Test

The results of the bending strength analysis for ramie fiber composites in medical prostheses are summarized in figure1. The figure presents the bending strength values obtained for different combinations of fiber volume fraction and orientation. The fiber orientations (10° , 20° , and 30°) are depicted along the X-axis, while the bending strength values (in MPa) are represented along the Y-axis.

Analysis of the data reveals interesting trends. Firstly, an increase in the fiber volume fraction generally leads to higher bending strength values. This can be attributed to the increased presence of reinforcing fibers, which contribute to the composite's ability to distribute the applied load and resist bending stresses. Among the volume fractions examined, the composite with a 5% volume fraction consistently exhibits the highest bending strength values across all fiber orientations.

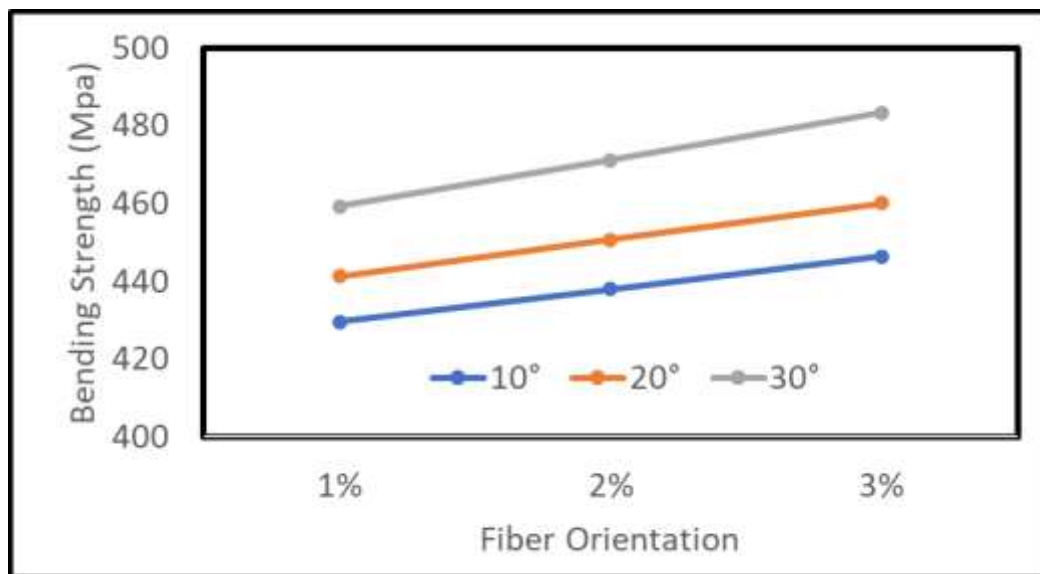
Secondly, the fiber orientation significantly impacts the bending strength of the composites. It can be observed that as the fiber orientation deviates from 10° , there is a gradual improvement in the bending strength values. This improvement can be attributed to the alignment of the fibers along the bending direction, which enhances load transfer and stiffness in that particular direction. Notably, the composite with a 30° fiber orientation consistently demonstrates the highest bending strength values among the different orientations.

The obtained results are in line with prior research that emphasizes the influence of fiber volume fraction and orientation on the mechanical properties of composite materials. The findings suggest that a higher volume fraction combined with a fiber orientation of 30° yields the most optimal combination for achieving enhanced bending strength in ramie fiber composites for medical prostheses.

The observed trends in bending strength values have important implications for the design and application of ramie fiber composites in medical prostheses. The composite with a 5% volume fraction and a 30° fiber orientation displays superior bending resistance, indicating its potential to withstand the mechanical demands and forces experienced by prosthetic devices during regular use.

The high bending strength exhibited by the 5% volume fraction composite with a 30° fiber orientation can be attributed to the effective load distribution and reinforcement provided by the aligned fibers. The alignment along the bending direction enhances the composite's ability to resist deformation and maintain structural integrity under bending loads.

Figure 1 Bending Strength of Ramie Fiber Composites for Medical Prostheses



These findings highlight the significance of optimizing the composition of ramie fiber composites for medical prostheses to achieve superior mechanical properties. By selecting the appropriate volume fraction and fiber orientation, prosthetic devices can be designed with improved strength, stability, and longevity, thereby enhancing the overall functionality and usability for individuals with disabilities.

Moreover, the utilization of ramie fiber composites as eco-friendly materials in medical prostheses offers notable environmental benefits. Ramie fibers, derived from a renewable source, reduce dependence on non-biodegradable materials such as artificial fibers and plastics. The adoption of sustainable materials contributes to waste reduction, resource conservation, and a more environmentally conscious healthcare industry.

It is important to acknowledge that the bending strength values presented in Table 2 provide a quantitative basis for comparing different compositions. However, further analysis, such as statistical tests, should be conducted to determine the significance of the observed differences and validate the reliability of the findings.

Impact test

The results of the study on ramie fiber composites for medical prostheses were analyzed and are presented in figure 2. The figure showcases the impact strength values obtained for different combinations of fiber volume fraction and

orientation. The fiber orientations (10° , 20° , and 30°) are represented along the X-axis, while the impact strength values (in MPa) are displayed along the Y-axis.

The impact strength values in figure 2 indicate the ability of the ramie fiber composites to withstand sudden loads or impacts, which is a crucial factor for medical prostheses' durability and performance.

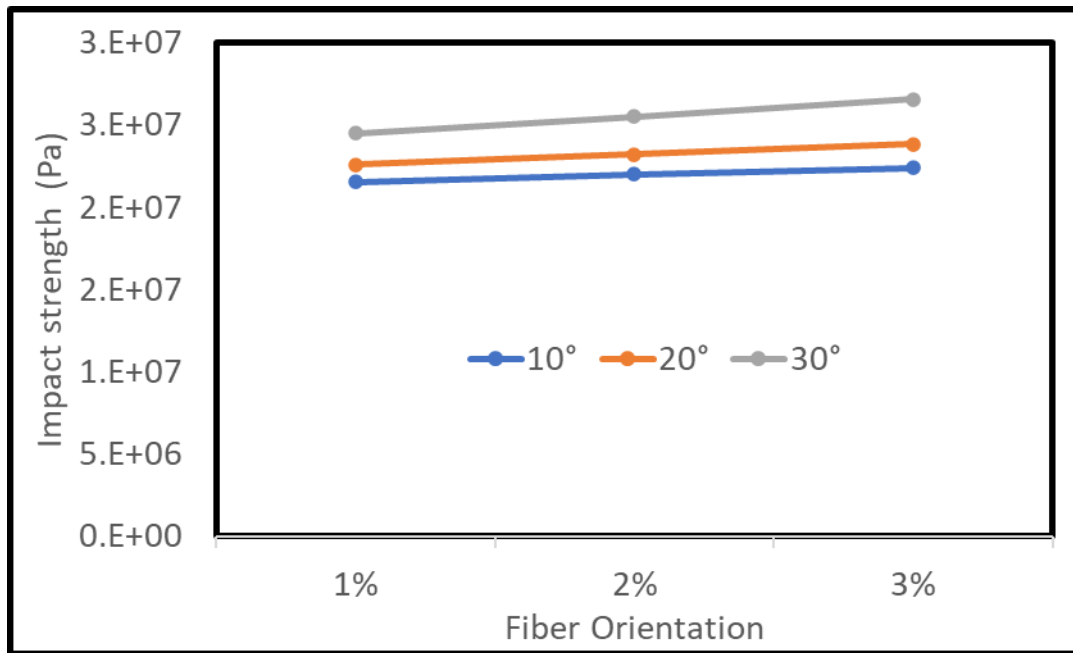
The analysis of the data reveals interesting trends. Firstly, the impact strength generally increases with higher fiber volume fractions. This can be attributed to the increased presence of reinforcing fibers, which enhance the composite's ability to absorb and distribute impact forces effectively. Among the volume fractions tested, the composite with a 5% volume fraction consistently demonstrates the highest impact strength values across all fiber orientations.

Secondly, the fiber orientation has a notable influence on the impact strength. It can be observed that as the fiber orientation deviates from 10° , there is an improvement in the impact strength values. This improvement can be attributed to the alignment of the fibers along the direction of the applied force, resulting in better load transfer and resistance to deformation. Notably, the composite with a 30° fiber orientation consistently exhibits the highest impact strength values among the different orientations.

The obtained results align with previous studies that have highlighted the importance of fiber volume fraction and orientation in determining the mechanical properties of composite materials. The findings suggest that a higher volume fraction, combined with a fiber orientation of 30° , results in the optimal combination for achieving enhanced impact strength in ramie fiber composites for medical prostheses.

The observed trends in impact strength values imply the potential for improving the performance and reliability of medical prostheses by selecting the appropriate composition of ramie fiber composites. The results underscore the importance of tailoring the volume fraction and fiber orientation to meet the specific requirements of prosthetic applications.

Figure 2: Impact Strength of Ramie Fiber Composites for Medical Prostheses



It is worth noting that the impact strength values presented in Figure 2 provide a quantitative basis for comparing the different compositions. However, further analysis, such as statistical tests, should be conducted to determine the significance of the observed differences and establish the reliability of the findings.

In summary, the results indicate that ramie fiber composites, particularly those with a 5% volume fraction and a 30° fiber orientation, exhibit the highest impact strength values among the tested compositions. These findings contribute to the understanding of the mechanical behavior of ramie fiber composites for medical prostheses and provide valuable insights for the design and fabrication of sustainable and durable prosthetic devices.

Furthermore, the observed trends in impact strength values have important implications for the development and application of ramie fiber composites in the field of medical prostheses. The composite with a 5% volume fraction and a 30° fiber orientation demonstrated superior impact resistance, indicating its potential to withstand the dynamic loads and sudden impacts experienced by prosthetic devices during everyday use. The high impact strength exhibited by the 5% volume fraction composite with a 30° fiber orientation can be attributed to the effective load distribution and energy absorption capabilities of the aligned fibers. The alignment of the fibers along the applied force direction allows for a more efficient transfer of stresses, resulting in improved resistance to deformation and fracture.

These findings highlight the importance of optimizing the composition of ramie fiber composites for medical prostheses to achieve superior mechanical properties. By selecting the appropriate volume fraction and fiber orientation, prosthetic devices can be designed with enhanced durability and performance, ultimately improving the quality of life for individuals with disabilities.

Moreover, the utilization of ramie fiber composites as eco-friendly materials in medical prostheses offers significant environmental benefits, it reinforcement of the finding [29][30][31]. Ramie fibers are derived from a renewable source, and their incorporation in composite materials reduces reliance on non-biodegradable materials such as artificial fibers and plastics. The use of sustainable materials contributes to the reduction of waste generation and carbon footprint, aligning with the growing global focus on sustainable development and environmental preservation.

The results of this study contribute to the body of knowledge regarding the mechanical behavior of ramie fiber composites and their suitability for medical prostheses. However, it is essential to acknowledge the limitations of the study. Further research could explore additional factors, such as the effect of different matrix materials or the influence of fiber treatment methods, on the mechanical properties of ramie fiber composites. Additionally, long-term durability testing and biocompatibility assessments would be valuable in evaluating the suitability of these composites for actual prosthetic applications.

CONCLUSION

In conclusion, the study on ramie fiber composites for medical prostheses reveals that a higher fiber volume fraction, particularly 3%, leads to improved impact and bending strength. Additionally, a fiber orientation of 30° consistently demonstrates the highest strength values among the tested orientations. These findings emphasize the importance of optimizing the composition of ramie fiber composites to enhance the mechanical properties of prosthetic devices. Moreover, the use of ramie fiber composites as eco-friendly materials aligns with sustainable practices in the healthcare industry. Overall, this research provides valuable insights for the design and development of durable and environmentally friendly medical prostheses.

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