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Comprehensive survey of Mechanical Properties of Natural Fiber

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Abstract

Natural fibers represent a renewable resource and serve as supplements for polymer-based materials. The development of composite materials using natural fibers, known as environmentally friendly composites, has gained widespread acceptance in society. These natural fibers offer a viable alternative to synthetic materials and contribute to applications requiring reduced weight and energy conservation. The utilization of natural fiber-reinforced polymer composites and natural-based resins has led to the replacement of existing synthetic polymer or glass fiber reinforced materials on a large scale. Industries such as automotive and aircraft are particularly interested in exploring various types of natural fibers, notably hemp, flax, and sisal, along with bio-resin systems for their interior components. The attractiveness of natural fiber composites lies in their high specific properties coupled with lower costs compared to traditional materials. This combination of superior performance characteristics and affordability makes natural fiber composites a compelling choice for a wide range of applications across industries, contributing to sustainable practices and environmental stewardship.

Keywords: Biocomposites, Sustainability, Performance Optimization, Multi-scale Design, Next-Generation Materials

1. Introduction

Natural fibers have emerged as proficient materials capable of replacing synthetic counterparts, particularly in applications requiring reduced weight and energy conservation. The utilization of natural fiber reinforced polymer composites and natural-based resins has witnessed significant growth, leading to the displacement of existing synthetic polymer or glass fiber reinforced materials on a large scale. Industries such as automotive and aircraft are actively exploring various types of natural fibers, notably hemp, flax, and sisal, along with bio-resin systems for their interior components. The appeal of natural fiber composites stems from their high specific properties coupled with lower costs, making them attractive for various applications.

The applications of natural fibers are diversifying across numerous sectors, including automobiles, furniture, packaging, and construction. This trend is driven by the advantages offered by natural fibers, including their low cost, lightweight nature, minimal damage to processing equipment, improved surface finish of molded parts, good mechanical properties relative to synthetic fibers, and their abundance as renewable resources. Natural fibers find use in an array of applications, such as building materials, particle boards, insulation boards, human and animal feed, cosmetics, medicine, as well as in the production of biopolymers and fine chemicals. Historically, natural fibers such as flax, jute, and hemp have been utilized by humans for thousands of years, dating back to at least 7000 years in Egypt. The interest in natural fibers has surged in recent times, with these fibers being combined with thermoset or thermoplastic polymers to create natural fiber composites, renowned for their sustainability attributes. Key sustainability properties of natural fibers include their status as renewable resources that absorb CO2 and release O2 into the environment, short growth cycle times, low energy production requirements, recyclability, biodegradability, and low hazard manufacturing processes.

In addition to pure natural fiber composites, the combination of natural fibers with filler materials such as fly ash and red mud has garnered attention in research endeavors. This approach has shown promise in enhancing mechanical properties, reducing costs, and improving accessibility in the industrial market. For instance, the inclusion of industrial waste materials like fly ash and red mud has been found to enhance the mechanical properties of composite materials, contributing to their improved performance. Composite materials, which are combinations of two or more materials, have become increasingly prevalent. Polymer matrix composites, in particular, are commonly used, with various reinforcing materials incorporated into a resin matrix. These composites find application in diverse fields, including rehabilitation and strengthening of pre-existing structures, seismic retrofitting, and damage recovery. Composite materials offer the advantage of tailorable properties, making them versatile solutions for various engineering

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challenges. They are typically classified into metal matrix composites (MMC), ceramic matrix composites (CMC), and polymer matrix composites (PMC), each offering unique properties and applications.
In summary, the proliferation of natural fibers and their integration into composite materials represent a significant advancement in materials science and engineering. These materials offer sustainable solutions across a wide range of industries, contributing to resource conservation, energy efficiency, and environmental sustainability.

2. Overview

The inverse thermal analysis of heat conduction is a method utilized to estimate the in-plane thermal conductivity of composite materials. This technique involves conducting numerical simulations to determine the optimal configuration of the heating system, ensuring a unidirectional heat transfer within the composite sample. Typically, composite plates made of materials like unsaturated polyester resin and unidirectional glass fibers are fabricated through injection molding to validate this methodology. Subsequently, a heating and cooling cycle is applied to the top and bottom surfaces of the sample to induce temperature variations, allowing for the analysis of thermal conductivity. A recent study by Ochi focused on investigating PLA composites fabricated from kenaf fibers and PLA. The study demonstrated notable tensile and flexural strengths of 223 MPa and 254 MPa, respectively. Such biodegradable composite materials present a promising alternative to petroleum-based products, addressing environmental concerns related to disposal and emissions. Natural fiber composites, including those utilizing kenaf fibers, are gaining traction for low to medium load applications across various industries, particularly in automotive sectors.
Natural fibers, including those derived from sources such as abaca, banana, bamboo, cotton, coir, hemp, jute, pineapple, and sisal, are abundantly available in regions like India. These fibers are being increasingly integrated into composite materials, often combined with glass fiber reinforced polymers to enhance their mechanical properties for engineering and technology applications. For example, the compressive behavior and post-collapse behavior of natural fiber composite tubes have been studied extensively. The development of multifunctional composites, particularly those incorporating natural fibers, is gaining momentum for applications in wearable electronics and actuating devices. These composites not only address environmental concerns associated with traditional materials but also offer unique properties suitable for diverse applications across industries such as transportation, textiles, and construction. While natural fibers offer advantages such as low cost, reduced density compared to glass fibers, and comparable specific properties, challenges remain, including issues related to resin compatibility and water absorption. Efforts are underway to address these challenges through surface treatments of natural fibers and the incorporation of nano-cellulose to enhance composite properties.
Researchers have explored various combinations of natural fibers with different matrix materials to develop composites with tailored properties. For instance, composites made of PCL, BDF, and hemp fibers at different concentrations have been analyzed for their mechanical and physical properties. Additionally, studies have focused on fabricating composites using phenolic resin, glass fibers, and sisal with varying fiber lengths to optimize engineering and technology applications. The literature review encompasses a wide range of research efforts, including investigations into the mechanical properties of natural fiber composites, studies on the utilization of fillers such as red mud to enhance composite properties, and evaluations of novel manufacturing processes for producing composite structures. These studies collectively contribute to advancing the understanding and application of natural fiber composites across industries.

Table 1: Literature Survey

Author Name	Research Gap	Finding	Suggestion
Ashori, A. et al.	Limited understanding of optimal maleic anhydride grafting for jute-polypropylene adhesion	Maleic anhydride grafting improves adhesion, but optimal level varies with processing conditions	Investigate impact of processing parameters on graft level and adhesion
Mishra, S. et al.	Lack of data on short coir fiber performance in polylactic acid	Coir fibers improve PLA's tensile and flexural strength, but moisture sensitivity remains	Explore strategies for moisture resistance improvement in coir-PLA composites
Sghaier, S. et al.	Unclear influence of multiple static and dynamic loading on kenaf-polypropylene composites	Multiple loading regimes impact composite stiffness and strength differently	Conduct fatigue testing under representative loading conditions for real-world applications
Arjmandi, M. et al.	Combined effect of fiber volume and modification on PVA-wood flour tensile properties unknown	Fiber volume and modification interact, impacting tensile strength non-linearly	Develop models to predict composite tensile strength based on fiber volume and modification level
Pickering,	Need for comprehensive review of	Extensive potential for various	Identify promising applications and

K. L. et al.	natural fiber applications in green composites	applications, but challenges and limitations exist	address key challenges for broader adoption
Bledzki, A. K. et al.	Limited exploration of hybrid natural fiber-nanocellulose composites	Hybrid systems offer potential for synergistic improvements in properties	Optimize fiber-nanocellulose combinations and fabrication methods for enhanced performance
Peijs, T. et al.	Synergistic effects of fiber length and surface modification on flax-polypropylene properties unclear	Both factors influence adhesion and performance, but their combined effect needs further study	Design experiments to quantify the joint influence of fiber length and modification on key properties
Wambua, A. et al.	Scaling up production of biocomposites from natural fibers and biopolymers remains a challenge	Cost-effective and sustainable production methods are crucial for wider use	Investigate and develop scalable processing techniques for economically viable biocomposites
Rana, S. et al.	Comprehensive overview of natural fiber-reinforced composites needed	Processing methods, properties, and applications are diverse and require systematic analysis	Provide a critical review highlighting advancements, challenges, and future directions

3. Conclusion

Scaling up production sustainably remains a hurdle. Wambua et al. (2018) call for exploring cost-effective and sustainable processing techniques. Utilizing agricultural waste or developing continuous fiber processing methods are crucial for bridging the gap between lab-scale successes and widespread commercialization.

Consolidating existing knowledge and charting future directions is essential. Comprehensive reviews like Rana et al. (2019) pave the way for collaborative efforts to overcome limitations and accelerate development. By focusing on interfacial adhesion, complex loading scenarios, predictive modeling, hybrid systems, and sustainable processing, researchers can unlock the full potential of natural fiber composites and contribute to a more sustainable future. In conclusion, the field of natural fiber composites is brimming with potential. Embracing these challenges and focusing on key areas of research will bridge the gap between sustainability and performance, paving the way for a future where these innovative materials contribute to a greener and more responsible world.

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