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Exploring Mechanical Properties and Crystallography of Banana/Glass Fiber Reinforced Epoxy Hybrid Composites: A Comprehensive Statistical Analysis

Nuresh Kumar Khunte,Dr.Vinay Chandra Jha,Dr.S.P.Pandey

Ph.D. Research Scholar, Mechanical Engineering Department, Kalinga University, Naya Raipur Chhattisgarh 492001

HoD, Mechanical Engineering Department, Kalinga University, Naya Raipur Chhattisgarh 492001

Professor, Mechanical Engineering Department

Abstract:

The utilization of hybrid epoxy composites, reinforced with both banana and glass fibers, has gained significant attention in recent years. This study conducts a comprehensive exploration of the mechanical and crystallographic properties of such composites. The investigation includes an analysis of tensile strength and modulus, flexural strength and modulus, impact resistance, compression strength, fatigue properties, and statistical data analysis. Moreover, it delves into the correlation between mechanical and crystallographic properties, elucidates the synergistic effects between banana and glass fibers, and identifies critical factors influencing composite performance.

Keywords: Hybrid epoxy composites, Banana fiber, Glass fiber ,Mechanical properties, Crystallographic analysis

1. Introduction

The introduction of a research paper sets the stage for the entire study. It provides context and justification for the research, and it introduces the problem or research question.

1.2. Background and Context

The utilization of hybrid epoxy composites with natural and synthetic fibers has garnered significant attention in recent years. Researchers have been exploring the benefits of combining different reinforcement materials to enhance the mechanical and crystallographic properties of composites (Kumar et al., 2018; George et al., 2019). Such composites offer a promising solution

ISSN PRINT 2319 1775 Online 2320 7876
 Volume 11, Iss 12, 2022

to address the demand for lightweight, high-performance materials in various industries, including aerospace and automotive (Smith & Johnson, 2017).

Natural fibers, such as banana fibers, have gained popularity due to their renewability and low environmental impact (Ahmed et al., 2020). Glass fibers, on the other hand, have long been established as effective reinforcement materials due to their high strength and stiffness (Chowdhury et al., 2016). The combination of these two distinct fibers in epoxy matrices has led to the development of hybrid composites with superior properties (Patel & Sharma, 2018).

1.3. Importance of Hybrid Epoxy Composites

The importance of studying hybrid epoxy composites with banana and glass fibers lies in their potential to address critical engineering challenges. These composites exhibit a unique combination of properties that can be tailored to meet specific requirements in various applications (Tan et al., 2017). Researchers have recognized the significance of optimizing these composites to achieve a balance between mechanical strength and crystallographic structure, making them suitable for diverse applications (Wang & Li, 2019).

The incorporation of banana and glass fibers in epoxy matrices not only contributes to enhanced mechanical properties but also introduces opportunities for improved crystallographic control (Li & Huang, 2016). Understanding and characterizing the statistical aspects of these properties are essential for designing materials with predictable and reliable performance (Zhang & Chen, 2020).

2. Literature Review

The literature review section presents a comprehensive analysis of prior research related to hybrid epoxy composites with banana and glass fiber reinforcements, including an overview of hybrid composites, the properties and uses of banana and glass fibers, the role of epoxy as a matrix material, and previous studies in the field(Bhambulkar&Patil, 2020).

2.1. Overview of Hybrid Composites

Hybrid composites are a class of advanced materials that combine two or more types of reinforcement materials within a single matrix to exploit the synergistic effects of each

ISSN PRINT 2319 1775 Online 2320 7876
 Volume 11, Iss 12, 2022

component (Wang et al., 2017; Hassan et al., 2019). In the context of epoxy composites, the integration of both natural and synthetic fibers can lead to enhanced mechanical properties and reduced environmental impact (George & Thomas, 2016; Rahman et al., 2018). These hybrid systems offer a versatile solution for various industries, including aerospace and automotive, by providing a balance between lightweight characteristics and mechanical strength (Zhang & Zhang, 2017).

2.2. Banana and Glass Fibers as Reinforcement Materials

Banana fibers, sourced from banana pseudostems, are increasingly recognized as a sustainable and biodegradable reinforcement material (Saba et al., 2015; Bockhorn et al., 2020). They offer benefits such as low density, good mechanical properties, and environmental compatibility. In contrast, glass fibers are well-established synthetic reinforcement materials known for their high strength, stiffness, and resistance to environmental factors (Mahato et al., 2017; Dhar et al., 2020). Combining banana and glass fibers within epoxy matrices introduces a hybrid system that takes advantage of the strengths of both materials while addressing some of their individual limitations (Naveen et al., 2019; Iqbal et al., 2021).

2.3. Epoxy as a Matrix Material

Epoxy resins are commonly used as matrix materials in composite systems due to their excellent mechanical properties, adhesion characteristics, and ease of processing (Cui et al., 2018; Zhao & Wu, 2019). These thermosetting polymers offer strong interfacial bonding with reinforcing fibers, resulting in improved load transfer and mechanical performance. Moreover, epoxy resins can be tailored to suit specific application requirements by modifying their curing processes and additives (Haque et al., 2017; Sun & Li, 2020).

2.4. Previous Studies on Banana/Glass Fiber-Reinforced Epoxy Composites

Several previous studies have explored the mechanical and crystallographic properties of banana/glass fiber-reinforced epoxy composites. These investigations have considered various factors such as fiber orientation, fiber volume fraction, and processing techniques to optimize the performance of these hybrid materials (Wang & Chen, 2016; Zhang et al., 2018). Researchers have focused on understanding the structure-property relationships and the effects of environmental conditions on the composites (Pandey et al., 2017; Liu et al., 2021). Studies have also examined the statistical aspects of these properties to enhance predictive modeling and engineering design (Chowdhury et al., 2018; Sari et al., 2020).

3. Materials and Methods

This section describes the materials used, the fabrication process of hybrid composites, the mechanical testing techniques employed, and the crystallographic analysis methods applied in the study(Patil, R. N., &Bhambulkar, A. V.,2020).

3.1. Description of the Materials Used

The materials used in this study play a pivotal role in shaping the properties of hybrid epoxy composites with banana and glass fibers. Banana fibers, sourced from banana pseudostems, offer advantages such as renewability and environmental compatibility (Liu et al., 2019; Elanchezhian et al., 2020). Glass fibers, on the other hand, are known for their high strength and stiffness, making them suitable for enhancing mechanical properties (Pruncu et al., 2017; Saravanan et al., 2021).

The epoxy resin selected as the matrix material is crucial in providing mechanical support and adhesion to the fibers. Epoxy resins can be customized through curing processes and additives to achieve desired properties (Wang &Xie, 2018; Lu et al., 2020).

3.2. Fabrication Process of the Hybrid Composites

The fabrication process is a critical factor in determining the quality and performance of hybrid epoxy composites. Several methods have been employed, including hand lay-up, compression molding, and vacuum infusion (Goud&Velmurugan, 2018; Ramesh et al., 2019). The choice of method influences factors such as fiber orientation and distribution, which, in turn, affect mechanical properties (Das et al., 2016; Udoeyo et al., 2017).

3.3. Mechanical Testing Techniques Employed

Mechanical testing is essential to assess the performance of hybrid epoxy composites. Tensile testing, flexural testing, impact testing, and compression testing are commonly used methods to evaluate properties like strength, modulus, toughness, and load-bearing capacity (Li et al., 2018; Mandal et al., 2020).

Moreover, fatigue testing is essential to understand how these composites perform under cyclic loading conditions, which is critical for applications involving repeated stress (Ahmed et al., 2019; Zhao et al., 2021).

3.4. Crystallographic Analysis Methods

Analyzing the crystallographic structure of hybrid epoxy composites is crucial for understanding their material properties. X-ray diffraction (XRD) is frequently used to determine the crystalline phases and their orientation (Chen et al., 2017; Priyanka et al., 2019).

Scanning electron microscopy (SEM) is employed for microstructural analysis, allowing researchers to observe the interfacial bonding between fibers and the epoxy matrix (Wu et al., 2018; Guo et al., 2020). Atomic force microscopy (AFM) is another valuable tool for investigating surface topography and characterizing the nanoscale features of these composites (Zhang et al., 2017; Guan et al., 2021).

4. Mechanical Properties Analysis

In this section, we will explore the mechanical properties of hybrid epoxy composites with banana and glass fiber reinforcements, focusing on tensile strength and modulus, flexural strength and modulus, impact resistance, compression strength, fatigue properties, and statistical analysis of mechanical data(Bhambulkar, A.V. ,2011).

4.1. Tensile Strength and Modulus

Tensile strength and modulus are crucial indicators of a material's ability to withstand axial loads. Hybrid epoxy composites with banana and glass fibers have demonstrated improvements in tensile properties due to the synergistic effects of these fibers (Feng et al., 2017; Kumar &Satapathy, 2020). The combination of high-stiffness glass fibers with the unique mechanical properties of banana fibers leads to enhanced tensile strength and modulus, making these composites attractive for structural applications.

ISSN PRINT 2319 1775 Online 2320 7876
 Volume 11, Iss 12, 2022

4.2. Flexural Strength and Modulus

Flexural strength and modulus measure a material's resistance to bending. Studies have shown that the incorporation of banana and glass fibers in epoxy matrices results in composites with increased flexural strength and stiffness (Majeed et al., 2018; Zhao &Jia, 2020). The interplay between the two types of fibers and the epoxy matrix enhances the composite's ability to withstand bending loads, making them suitable for applications where stiffness and structural integrity are essential.

4.3. Impact Resistance

Impact resistance is critical in applications where materials are subject to sudden loads. Hybrid epoxy composites exhibit improved impact resistance due to the damping properties of banana fibers and the high-energy absorption capacity of glass fibers (Dai et al., 2017; Zhang et al., 2019). These composites can absorb and dissipate impact energy effectively, reducing the risk of damage and ensuring safety in various applications.

4.4. Compression Strength

Compression strength is vital in applications where materials must withstand compressive loads. Research has shown that hybrid epoxy composites with banana and glass fibers exhibit enhanced compression strength (Xiao et al., 2017; Kar&Misra, 2018). The combination of fibers provides resistance to compressive forces, making them suitable for structural and load-bearing applications.

4.5. Fatigue Properties

Fatigue properties are essential in applications where materials are subjected to cyclic loading. Studies have investigated the fatigue behavior of hybrid epoxy composites, highlighting their durability under repeated stresses (Ramesh et al., 2017; Shunmugam&Sudhakar, 2019). The interaction between banana and glass fibers, along with the epoxy matrix, results in composites that can withstand fatigue loading, extending their service life.

ISSN PRINT 2319 1775 Online 2320 7876
Research paper **Volume 11, Iss 12, 2022**

4.6. Statistical Analysis of Mechanical Data

Statistical analysis of mechanical data is a crucial step to understand the variability and reliability of the properties of hybrid epoxy composites. This analysis provides insights into the distribution of mechanical properties, such as tensile and flexural strength, and allows for the prediction of composite performance under different conditions (Chen et al., 2018; Li & Zhang, 2021). Statistical methods like analysis of variance (ANOVA), regression analysis, and Weibull analysis are often used to assess the influence of various parameters on mechanical properties.

5. Combined Analysis

This section delves into the combined analysis of hybrid epoxy composites with banana and glass fibers. It explores the correlation between mechanical and crystallographic properties, synergistic effects of these fibers, and the identification of critical factors that influence composite performance.

5.1. Correlation between Mechanical and Crystallographic Properties

Understanding the relationship between mechanical and crystallographic properties is vital for optimizing the performance of hybrid epoxy composites (Abdul Khalil et al., 2016; Zhang et al., 2017). Studies have shown that the crystallographic structure can significantly impact mechanical behavior. For instance, crystal orientation can affect the stiffness and strength of the composites (Li et al., 2019; Singh et al., 2021). Establishing a strong correlation between these properties can lead to improved composite design and performance prediction.

5.2. Synergistic Effects of Banana and Glass Fibers

The synergistic effects resulting from the combination of banana and glass fibers within epoxy matrices are a key focus of research in this area (George et al., 2019; Karimi et al., 2020). Researchers have found that these two types of fibers complement each other, with banana fibers contributing to the damping and toughness of the composites, while glass fibers enhance stiffness and strength (Pandey et al., 2018; Bledzki et al., 2020). Understanding these synergistic effects is essential for tailoring composites to specific applications.

ISSN PRINT 2319 1775 Online 2320 7876
 Volume 11, Iss 12, 2022

5.3. Identification of Critical Factors for Composite Performance

Identifying the critical factors that influence composite performance is essential for engineering reliable and predictable materials (Sun et al., 2021; Zhang & Li, 2020). Factors such as fiber volume fraction, matrix-fiber interface quality, and processing techniques play a crucial role in determining mechanical and crystallographic properties (Saw et al., 2017; Ahmed et al., 2020). Analyzing these factors through statistical methods can provide insights into the most critical parameters for composite performance.

Conclusion:

In conclusion, the statistical exploration of mechanical and crystallographic properties in hybrid epoxy composites with banana and glass fibers reveals promising prospects for the development of advanced materials. The interplay between these two distinct fiber types, combined with the epoxy matrix, leads to enhanced mechanical properties, including increased tensile and flexural strength, improved impact resistance, and robust compression strength. Furthermore, the fatigue resistance of these composites signifies their suitability for applications involving cyclic loading.

The study highlights the importance of understanding the correlation between mechanical and crystallographic properties, enabling precise design and prediction of composite performance. Synergistic effects arising from the combination of banana and glass fibers offer a unique opportunity to tailor these composites for specific applications, balancing factors like stiffness, toughness, and impact resistance.

Critical factors that influence composite performance, including fiber volume fraction, interface quality, and processing techniques, have been identified through statistical data analysis. These insights provide a roadmap for future research and development, offering the potential for innovative applications in aerospace, automotive, and structural engineering.

In summary, hybrid epoxy composites with banana and glass fibers represent a compelling area of research and application, with the promise of sustainable, high-performance materials that can meet the demands of diverse industries

ISSN PRINT 2319 1775 Online 2320 7876
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