Advances in Hybrid Composite Analysis: A Review of Banana/Glass Fiber Epoxy Composites

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Abstract:
Hybrid composites, particularly those incorporating banana and glass fibers in an epoxy matrix, have emerged as innovative materials with a broad spectrum of applications. This review paper explores the advances in the analysis of banana/glass fiber epoxy composites, focusing on their mechanical and crystallographic properties. We delve into the unique characteristics of these materials and their influence on tensile strength, flexural strength, impact resistance, compression strength, and fatigue properties. Additionally, we examine the methods of crystallographic analysis, the role of crystallography in composite properties, and microstructural findings. The synergy between natural and synthetic fibers in these composites, along with the versatile epoxy matrix, offers a compelling avenue for optimizing composite performance. This review encapsulates recent research developments in the field, shedding light on the exciting prospects and challenges of these hybrid materials.

Keywords: Hybrid composites, Banana fibers, Glass fiber, Epoxy matrix, Mechanical properties, Crystallographic analysis
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1. Introduction

1.1 Introduction to Hybrid Composites

Hybrid composites represent a fascinating and promising area in materials science, blending the unique properties of various materials to achieve superior performance. These composites have been increasingly adopted in diverse industries, including aerospace, automotive, construction, and more (Hou et al., 2016; Kazi et al., 2019).

Hybridization typically involves combining two or more types of reinforcing fibers with a matrix material, such as epoxy, to create a composite that capitalizes on the strengths of each component (Arif& Kumar, 2017; Bai et al., 2021). This approach allows for tailoring composites to meet specific requirements, resulting in enhanced mechanical properties, thermal stability, and other critical characteristics.

1.2 Background and Significance

The exploration of hybrid composites is particularly relevant due to its potential to address contemporary challenges, including the demand for lightweight yet strong materials, environmental concerns, and the quest for sustainable practices (Elanchezhian et al., 2020; Othman et al., 2021).

Banana and glass fiber-reinforced epoxy composites, in particular, have gained attention due to their unique combination of natural and synthetic fibers. Banana fibers, sourced from agricultural waste, offer environmental advantages, while glass fibers provide exceptional strength and stiffness (Jayabal et al., 2017; Nagarajan et al., 2019).

2. Hybrid Composite Materials

2.1 Explanation of Hybrid Composites

Hybrid composites, at the intersection of materials science and engineering, have garnered considerable attention due to their unique combination of different types of reinforcing fibers within a common matrix material (Mishra et al., 2018; Saba et al., 2020). The rationale behind hybridization is to harness the advantages of diverse materials while mitigating their individual drawbacks.

In these composites, the matrix material, typically epoxy in the context of this study, serves as a binding agent, while the reinforcing fibers, which can include both natural and synthetic fibers, impart specific characteristics to the composite. The interaction between these components influences properties such as strength, stiffness, thermal stability, and durability, depending on the application (Corujeira Gallo et al., 2017; Sharma et al., 2019).

2.2 Advantages and Applications

Hybrid composites offer a plethora of advantages that contribute to their broad range of applications. These materials have gained popularity for their enhanced mechanical properties, including improved tensile strength, flexural strength, and impact resistance (Jayaramudu et al., 2016; Jumahat et al., 2019). Moreover, hybrid composites can be tailored to meet specific engineering requirements, making them versatile for diverse industries.

Applications of hybrid composites span various sectors, including aerospace, automotive, construction, and sports equipment (Ma et al., 2018; Misri et al., 2021). The lightweight yet robust nature of these materials makes them attractive for use in aircraft components, automotive body parts, and structural elements in construction. The scope of applications is continually expanding as researchers uncover new ways to harness the benefits of hybrid composites.

2.3 Types of Fibers Used in Hybrid Composites

A defining feature of hybrid composites is the use of multiple types of reinforcing fibers. In the context of this review, we focus on banana and glass fibers as they form a significant portion of hybrid composites (Pugazhenthi et al., 2016; Sathishkumar et al., 2019).

Banana fibers, derived from agricultural waste, are valued for their eco-friendly attributes and impressive mechanical properties, including good tensile strength and damping characteristics (Silva et al., 2017; Zhang et al., 2019). Glass fibers, on the other hand, are synthetic fibers known for their exceptional stiffness, strength, and thermal stability (Natarajan et al., 2018; Renuga et al., 2020).

The synergy between these two distinct fiber types, combined with the epoxy matrix, plays a crucial role in shaping the mechanical and crystallographic properties of the composite materials.

3. Banana and Glass Fiber Reinforcements

3.1 Properties and Characteristics of Banana Fibers

Banana fibers, often considered a sustainable and eco-friendly reinforcement, possess unique properties that make them valuable in composite materials (Abdul Khalil et al., 2016; Anuar et al., 2020). They are derived from agricultural waste, primarily banana pseudostems, and have gained attention due to their natural origin.

Banana fibers are known for their impressive tensile strength, which makes them suitable for load-bearing applications. They also exhibit damping characteristics, which can enhance the impact resistance of composites. The fiber's biodegradability is an added benefit, aligning with environmental sustainability goals.

3.2 Properties and Characteristics of Glass Fibers

In contrast, glass fibers are synthetic fibers renowned for their mechanical strength and thermal stability (Bourmaud&Beaugrand, 2018; Huang et al., 2017). They are typically produced from molten glass and are characterized by their excellent stiffness and resistance to high temperatures.

Glass fibers contribute to the mechanical properties of composites by imparting high tensile and flexural strength. They are also electrically non-conductive and resistant to chemical corrosion. These properties make them a preferred choice in applications where durability and high performance are crucial.

3.3 Benefits and Challenges of Each Fiber Type

Both banana and glass fibers offer unique advantages, but they also come with their respective challenges.

Banana fibers provide environmental benefits, as they are sourced from renewable agricultural resources. Their damping properties enhance impact resistance and reduce vibrations, making them suitable for applications that require energy absorption, such as automotive components. However, banana fibers are sensitive to moisture and can degrade if not properly protected from environmental conditions.

On the other hand, glass fibers provide exceptional mechanical properties, including high tensile and flexural strength. They are highly resistant to heat and chemicals, making them ideal for demanding applications. Yet, glass fibers lack the sustainability factor of natural fibers and can be brittle, potentially resulting in reduced impact resistance.

The combination of these two fiber types in hybrid composites capitalizes on their strengths, addressing some of the challenges associated with each type. Synergistic effects between the two fiber types enhance the overall performance of the composite, creating a material with a unique balance of mechanical properties and sustainability.

4. Epoxy as a Matrix Material

4.1 Introduction to Epoxy Resins

Epoxy resins, a class of thermosetting polymers, are widely used as matrix materials in composite applications due to their remarkable versatility and adhesive properties (Joffe&Pegoretti, 2019; Majeed et al., 2018). Epoxy resins are characterized by a cross-linked molecular structure achieved through curing processes, making them exceptionally durable and resistant to chemical corrosion.

In hybrid composites, epoxy resins serve as the matrix material that binds the reinforcing fibers, such as banana and glass fibers. The choice of epoxy resin can significantly influence the overall performance of the composite, as different formulations offer varying mechanical, thermal, and chemical characteristics.

4.2 Characteristics and Properties

Epoxy resins are renowned for their exceptional adhesive strength, low shrinkage, and resistance to moisture and chemicals (Kumar et al., 2016; Lee et al., 2019). Their remarkable mechanical properties, including high tensile and flexural strength, make them ideal for load-bearing applications (Bhambulkar, A.V. ,2011).

Epoxy matrices are known for their excellent dimensional stability, which ensures that composites maintain their shape and structural integrity even under varying environmental conditions. Additionally, epoxies can be formulated to exhibit specific properties, such as flame resistance and thermal stability.

4.3 The Role of the Epoxy Matrix in Hybrid Composites

The epoxy matrix plays a pivotal role in hybrid composites by bonding the reinforcing fibers together (Munawar et al., 2017; Pethrick, 2021). It is responsible for transferring loads between the fibers, enhancing the overall mechanical properties of the composite. The compatibility between the epoxy matrix and the fibers is critical in determining the effectiveness of stress transfer and, consequently, the composite's performance.

The choice of epoxy formulation, curing processes, and the ratio of epoxy to reinforcing fibers all affect the composite's properties. Understanding the interactions between the epoxy matrix and the fibers is crucial for tailoring composites to specific applications, optimizing properties, and ensuring long-term durability.

5. Fabrication Methods

5.1 Techniques for Fabricating Banana/Glass Fiber Epoxy Composites

The fabrication of banana/glass fiber epoxy composites involves various techniques, including hand lay-up, vacuum infusion, and resin transfer molding (Abed, 2019; Gómez et al., 2020). Each method has its advantages and limitations, influencing the distribution of fibers and the overall quality of the composite.

Hand lay-up, for instance, offers simplicity and cost-effectiveness but may result in variations in fiber distribution. Vacuum infusion, on the other hand, allows for better fiber control and reduced void content, while resin transfer molding enables the production of complex geometries.

5.2 Composite Layering and Manufacturing Processes

The way in which composite layers are arranged, as well as the manufacturing processes, affect the composite's structural integrity and performance (Bashir et al., 2017; Sanjay &Arpitha, 2018). The orientation and stacking sequence of fibers play a crucial role in determining the composite's mechanical properties(Patil, R. N., &Bhambulkar, A. V.,2020).

Various manufacturing processes, including autoclave curing, compression molding, and filament winding, influence the density and void content of the composite, affecting properties like stiffness and strength.

5.3 Influence of Fabrication Methods on Composite Properties

The choice of fabrication method has a direct impact on the properties of banana/glass fiber epoxy composites (Khan et al., 2020; Kizhakeyil et al., 2019). Controlling factors such as fiber alignment and void content is critical for optimizing mechanical, thermal, and electrical properties(Bhambulkar&Patil, 2020).

The fabrication process also affects the interfacial bonding between fibers and the epoxy matrix, which in turn influences the composite's strength and durability.

6. Mechanical Properties Analysis

6.1 Tensile Strength and Modulus

Tensile strength and modulus are crucial mechanical properties that indicate a material's ability to withstand tension. In the context of banana/glass fiber epoxy composites, research has demonstrated that the combination of these two fiber types can lead to significantly enhanced tensile strength (Ma et al., 2020; Sen et al., 2017). The alignment and distribution of fibers, as well as the epoxy matrix's role in stress transfer, contribute to this improvement.

6.2 Flexural Strength and Modulus

Flexural strength and modulus are key indicators of a material's ability to resist bending and deformation under load. Hybrid composites have exhibited remarkable flexural properties due to the combination of banana and glass fibers (Budhe et al., 2018; Fu et al., 2016). The distribution of fibers within the matrix and the interfacial adhesion between fibers and the epoxy matrix play vital roles in enhancing these properties.

6.3 Impact Resistance

The impact resistance of composites is essential for applications where sudden force or shock may be encountered (George et al., 2018; Karmakar et al., 2017). Research indicates that banana/glass fiber epoxy composites demonstrate improved impact resistance compared to single-fiber composites. The damping characteristics of banana fibers and the high strength of glass fibers combine to create composites that effectively absorb energy during impacts.

6.4 Compression Strength

Compression strength is a vital property, especially in load-bearing applications where materials are subjected to compressive forces. Hybrid composites have exhibited increased compression strength (Gupta et al., 2019; John & Thomas, 2020). The distribution of fiber types and orientation, as well as the epoxy matrix's role in load-bearing, are significant factors influencing this property.

6.5 Fatigue Properties

Understanding the fatigue behavior of composite materials is critical for applications involving cyclic loading (Kumar et al., 2019; Zampaloni et al., 2017). The combination of banana and glass fibers, along with the durability of epoxy matrices, has shown promise in enhancing fatigue resistance. The microstructural properties and interface quality also contribute to the fatigue performance of these composites.

7. Crystallographic Analysis

7.1 Methods for Crystallographic Analysis

Crystallographic analysis involves the study of the arrangement and behavior of crystals within a material (Furman & White, 2016; Ramana et al., 2018). In the context of hybrid composites, various techniques, including X-ray diffraction and electron microscopy, have been employed to examine the crystallographic structure of the materials. These methods provide insights into the orientation and distribution of crystalline regions within the composite.

7.2 The Influence of Crystallography on Composite Properties

Crystallography plays a pivotal role in shaping the properties of hybrid composites. Research has shown that the crystallographic structure of both the fibers and the epoxy matrix can influence mechanical properties, thermal stability, and electrical conductivity (Elbadawi et al., 2017; Sun et al., 2019). Understanding the crystallographic aspects of these composites is crucial for tailoring them to specific applications.

7.3 Microstructural Examination and Findings

Microstructural examination involves the study of small-scale features within a material. In the case of hybrid composites, researchers have examined the microstructure of these materials to gain insights into fiber dispersion, interfacial bonding, and the presence of voids or defects (Kandola et al., 2017; Liu et al., 2019). These findings are essential for optimizing composite properties and ensuring long-term performance.

8 Conclusion:

In conclusion, the analysis of banana/glass fiber epoxy composites represents a burgeoning field of research with significant potential. These hybrid materials exhibit remarkable mechanical properties, including enhanced tensile strength, flexural strength, impact resistance, compression strength, and fatigue properties, owing to the synergy between banana and glass fibers. The versatile epoxy matrix plays a pivotal role in binding these fibers and facilitating stress transfer, resulting in well-balanced composite performance. Crystallographic analysis techniques provide insights into the structural aspects of these composites, allowing for tailored optimization. The exploration of microstructural characteristics further refines our understanding of these materials. Advances in hybrid composite analysis offer promising opportunities across various industrial sectors, driven by the quest for sustainable and high-performance materials.

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