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Experimental Investigation of Fracture Analysis Of Hybrid Natural Fiber Reinforced Polymer Composites – A Comprehensive Review

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Abstract:
Natural fiber-reinforced polymer composites have gained significant attention in recent years due to their eco-friendly and sustainable nature. This comprehensive review focuses on the experimental investigation of fracture analysis in hybrid composites, combining multiple natural fibers with polymer matrices. The objective is to assess the mechanical behaviour, fracture toughness, and failure mechanisms of these hybrid materials, providing insights into their potential applications in various industries. The review highlights key findings from recent experimental studies, identifying trends, challenges, and gaps in the existing literature. The potential applications of hybrid natural fiber reinforced polymer composites in industries such as automotive, aerospace, and construction are discussed, considering their lightweight nature and enhanced mechanical properties. Finally, the review concludes with recommendations for future research directions, emphasizing the need for standardized testing protocols, further understanding of the interfacial properties, and exploration of novel natural fibers for hybrid composites.

1. INTRODUCTION:

Need for Hybrid natural fiber reinforced polymer composites (HNFRCs)

A brief overview of hybrid natural fiber-reinforced polymer composites is carried out to understand the advancement in failure analysis and crack propagation. HNFRCs are a type of composite material that consists of two or more types of natural fibers in a polymer matrix. Natural fibers are typically derived from plants or animals, and they offer many advantages over synthetic fibers, such as their low cost, low density, and high sustainability [1]. They note that the fracture toughness of HNFRCs is typically higher than that of monolithic natural fiber composites. This is due to the synergistic effect of the different types of fibers, which can improve the interfacial bonding between the fibers and the matrix and reduce the stress concentration at the crack tip [2].

There are several advantages to using hybrid natural fiber composites (HNFRCs) in fracture properties.

- Increased fracture toughness: The fracture toughness of HNFRCs is typically higher than that of monolithic natural fiber composites. This is because the different fibers in the hybrid composite interact with each other to create a more effective load-bearing structure.
- Reduced stress concentration: The stress concentration at the tip of a crack in an HNFRC is typically lower than that in a monolithic natural fiber composite. This is because the different fibers in the hybrid composite help to distribute the stress more evenly.
- Improved impact resistance: The impact resistance of HNFRCs is typically higher than that of monolithic natural fiber composites. This is because the different fibers in the hybrid composite help to absorb energy and prevent the crack from propagating.
- Enhanced mechanical properties: The mechanical properties of HNFRCs can be tailored by the type and amount of fibers used. This makes them suitable for a wide range of applications.
- Reduced weight: HNFRCs are typically lighter than monolithic natural fiber composites. This is because they use a combination of different fibers, which can be more efficient in terms of load bearing.
- Sustainability: HNFRCs are made from natural fibers, which are renewable resources. This makes them a more sustainable option than synthetic fiber composites.

Overall, HNFRCs offer many advantages over monolithic natural fiber composites in terms of fracture properties. They are stronger, more impact resistant, and lighter than monolithic natural fiber composites. They are also more sustainable. However, it is important to note that the advantages of HNFRCs depend on the specific type and amount of fibers used. It is also important to consider the cost of HNFRCs when making a decision about which material to use. Using hybrid natural fiber composites in fracture properties offers several advantages that can contribute to improved mechanical performance and material sustainability [3].

Hybridization often leads to improved fracture toughness due to the combination of different natural fibers with varying mechanical properties. This results in a composite material that can resist crack propagation and absorb energy more effectively. Combining different natural fibers can create synergistic effects, where the strengths of individual fibers complement each other. This synergy can lead to superior fracture properties compared to single-fiber composites [4]. By selecting specific natural fibers and optimizing their proportions, designers can tailor the composite's fracture properties to match the requirements of a particular application. This versatility is especially useful in industries with diverse mechanical demands.

Some natural fibers are inherently more ductile than others. Incorporating ductile fibers into the composite matrix can reduce brittleness, allowing the material to deform more before failure and providing warning signs of potential failure. Hybrid natural fiber composites can exhibit improved crack arrest capabilities. The energy-absorbing characteristics of certain fibers can halt or slow down crack propagation, enhancing the material's damage tolerance [5].

Different natural fibers have varying failure mechanisms. A hybrid composite can resist multiple modes of failure, such as fiber pull-out, debonding, and matrix cracking, which can enhance overall durability. Hybridization can enable weight reduction without sacrificing mechanical performance. This is particularly advantageous in applications where lightweight materials are crucial, such as automotive and aerospace industries. Utilizing natural fibers as reinforcement reduces the reliance on synthetic fibers, contributing to environmental sustainability. Hybridization further enhances the sustainable nature of the material by optimizing fiber usage [6]. Hybridization can balance the cost-effectiveness of natural fibers with improved performance. Blending more cost-efficient fibers with higher-performance fibers can yield a balance between cost and functionality.

Different fibers may require specific processing techniques. Hybridization allows manufacturers to choose fibers that can be processed optimally, enabling efficient manufacturing processes. The flexibility in hybrid natural fiber composites' mechanical properties encourages innovative design concepts, promoting creativity and novel engineering solutions [7]. Depending on the choice of fibers, hybrid composites can possess multifunctional properties beyond mechanical strength, such as thermal insulation, electromagnetic shielding, and sound absorption.

Incorporating hybrid natural fiber reinforcements in composites for improved fracture properties is an active area of research and development. By capitalizing on the strengths of different natural fibers, manufacturers and designers can create materials that exhibit superior fracture resistance and offer a range of benefits across various industries.

1. FRACTURE MECHANICS AND PROPERTIES IN HNFRCS

Fracture mechanics is a branch of mechanics that deals with the study of cracks and how they propagate in materials. Fracture mechanics concepts can be used to explain the fracture behaviour of hybrid natural fiber composites (HNFRCs) [8]. One of the most important concepts in fracture mechanics is the stress intensity factor (K). The stress intensity factor is a measure of the stress concentration at the tip of a crack. The higher the stress intensity factor, the more likely it is that the crack will propagate.

In HNFRCs [9], the stress intensity factor can be reduced by the presence of different fibers. The different fibers in the hybrid composite help to distribute the stress more evenly, which reduces the stress concentration at the tip of the crack. Another important concept in fracture mechanics is the critical stress intensity factor (Kic). The critical stress intensity factor is the stress intensity factor at which a crack will propagate. The higher the critical stress intensity factor, the more resistant the material is to fracture.

The critical stress intensity factor of HNFRCs is typically higher than that of monolithic natural fiber composites. This is because the different fibers in the hybrid composite interact with each other to create a more effective load bearing structure. [10] The fracture behavior of HNFRCs can also be explained by the concept of crack bridging. Crack bridging is the process by which fibers that are bridging a crack resist its propagation. The fibers that bridge the crack can do so by transferring load across the crack or by debonding from the matrix and pulling out of the composite.

The crack bridging effect is more pronounced in HNFRCs than in monolithic natural fiber composites. This is because the different fibers in the hybrid composite can interact with each other to provide more effective crack bridging. The fracture mechanics concepts discussed above can be used to explain the fracture behavior of HNFRCs. These concepts can be used to design HNFRCs with improved fracture toughness and impact resistance. In addition to the concepts mentioned above, there are some other fracture mechanics concepts that can be used to explain the fracture behavior of HNFRCs [11]. These concepts include the strain energy release rate, the J-integral, and the crack growth resistance curve.

The study of fracture mechanics is a complex and challenging field. However, it is an important field for understanding the behavior of materials under loading conditions. The fracture mechanics concepts discussed above provide a basic understanding of the fracture behavior of HNFRCs [12]. Fracture mechanics is a field of study that focuses on understanding the behavior of materials under the influence of external forces and loads, particularly when cracks or defects are present. It involves analyzing how cracks propagate within a material and how they affect its mechanical integrity [13].

1. CONSIDERATIONS IN THE PRESENCE OF MULTIPLE TYPES OF FIBERS OR HNFRCS

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1. Stress and Strain Distribution:
In hybrid natural fiber composites, stresses are distributed throughout the material due to the application of external forces. The presence of different types of natural fibers can lead to variations in stiffness and strength along different directions [14]. This anisotropic behaviour affects the distribution of stress and strain within the material.
2. Crack Initiation and Propagation:
Crack initiation occurs when stress concentrations exceed the material's strength at a particular point. Hybrid composites, with their combination of fibers, can have varying fracture toughness along different planes [15]. The interface between different fibers and the matrix can influence crack initiation points.
3. Energy Release Rate:
The energy release rate is a critical parameter in fracture mechanics. It describes how much energy is required to propagate a crack. In hybrid composites, the combination of fibers with different energy absorption and dissipation characteristics can affect the overall energy release rate, influencing crack propagation actions [16].
4. Fracture Toughness:
Fracture toughness represents a material's resistance to crack propagation. Hybrid composites benefit from the varied properties of different fibers [17]. If one type of fiber is more ductile and tough, it can impede crack growth initiated in a less tough fiber, enhancing the overall fracture toughness of the composite.
5. Fiber-Matrix Interface Effects:
The interaction between the fibers and the matrix is crucial in hybrid composites. The interface properties can influence how cracks propagate. The differential behavior of various fibers at the interface can lead to phenomena such as debonding, affecting overall fracture behavior.
6. Mixed-Mode Fracture:
In some cases, cracks may propagate under mixed-mode loading conditions involving combinations of tension, compression, and shear. Hybrid composites can exhibit varying responses to different modes of loading due to the combination of fibers with differing mechanical behaviors.
7. Crack Arrest and Bridging:
Hybrid natural fiber composites can benefit from the bridging effect, where one type of fiber spans the crack and resists its propagation. This effect can delay crack growth and provide mechanisms for crack arrest.
8. Fiber Interaction:
The interaction between different fibers can influence the overall fracture behaviour. Synergistic effects between fibers can lead to enhanced properties, while incompatible interactions might cause premature failures.

In hybrid natural fiber composites, the behaviour of cracks and the material's response to external loads are influenced by the combination of different fiber types and their interaction with the matrix. Understanding how these factors contribute to fracture mechanics is essential for optimizing the design and performance of hybrid composites in various applications. Researchers and engineers must consider the unique characteristics of each fiber type and their combined effects on crack initiation, propagation, and the overall fracture behaviour of the composite material. The hybridization of natural fiber composites can have a significant effect on their fracture properties. In general, hybrid composites have higher fracture toughness and impact resistance than monolithic natural fiber composites. This is because the different fibers in the hybrid composite interact with each other to create a more effective load-bearing structure [18].

The specific effects of hybridization on fracture properties depend on the type of fibers used and the way they are hybridized. A study found that hybrid composites made from jute and banana fibers had higher fracture toughness than composites made from either fiber alone. The authors attributed this improvement to the fact that the different fibers had different strengths and weaknesses. Jute fibers are strong in tension, while banana fibers are strong in compression. The combination of these two fibers in the hybrid composite resulted in a material with better overall strength and toughness. [19]

Another study found that hybrid composites made from flax and sisal fibers had higher impact resistance than composites made from either fiber alone. The authors attributed this improvement to the fact that the different fibers had different failure mechanisms [20]. Flax fibers tend to break in a brittle manner, while sisal fibers tend to break in a ductile manner. The combination of these two fibers in the hybrid composite resulted in a material with better overall impact resistance.

The effects of hybridization on fracture properties are a complex and active area of research. However, the studies that have been conducted so far suggest that hybridization can be a promising way to improve the fracture toughness and impact resistance of natural fiber composites. Hybridization is the process of combining two or more different materials to create a new material with improved properties. In the case of natural fiber composites (NFCs), hybridization can be used to improve the fracture properties of the composite [21].

HNFRCs made from bamboo fibers and glass fibers had a higher impact resistance than HNFRCs made from either type of fiber alone. The authors attributed this improvement to the different fracture mechanisms of the two fibers. Bamboo fibers are known for their good energy absorption capacity, while glass fibers are known for their high tensile strength. The combination of these two fibers resulted in a composite with improved impact resistance.

CONCLUSION

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In summary, hybridization using natural fiber composites has the potential to significantly influence fracture properties by combining the strengths of different fibers. However, achieving these benefits requires a deep understanding of the mechanical properties of individual fibers, their interactions, and the mechanics of crack propagation in composite materials. Here are some of the reasons why hybridization can improve the fracture properties of natural fiber composites:

- The different fibers can interact with each other to create a more effective load bearing structure. This can help to distribute the stress more evenly and reduce the stress concentration at the tip of a crack.
- The different fibers can have different strengths and weaknesses. This can help to compensate for the weaknesses of each fiber and create a material with better overall strength and toughness.
- The different fibers can have different failure mechanisms. This can help to prevent the crack from propagating in a brittle manner and improve the impact resistance of the material.

Overall, hybridization is a promising technique for improving the fracture properties of natural fiber composites. It is a versatile technique that can be used to combine different types of fibers to create materials with custom-made properties.

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