
Mechanical Characterization of Eco-Friendly Hybrid Composites Reinforced with Camel Hair Fiber, Sisal Fiber, and Kenaf Fiber

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Abstract: - Natural fiber-reinforced composites have gained significant attention due to their eco-friendly nature, cost-effectiveness, and suitability for lightweight applications. This study explores the fabrication and mechanical characterization of a hybrid composite reinforced with camel hair, sisal, and kenaf fibers, combined with epoxy resin as the matrix material. Specimens were fabricated using the hand lay-up method and tested for tensile strength, compression strength, flexural stress, impact toughness, and hardness following ASTM standards. The hybrid composite demonstrated superior mechanical properties, including a tensile strength of 35.12 MPa, a compressive strength of 142.23 MPa, and a Brinell hardness number (BHN) of 41.90. The addition of camel hair fiber significantly enhanced the composite's performance, making it a viable alternative to conventional synthetic fiber composites. The results indicate the potential for hybrid composites to be utilized in industries such as automotive, aerospace, and construction, offering a sustainable solution with improved mechanical properties.

Keywords: Hybrid composites, Camel hair fiber, Natural fibers, Mechanical properties, Sustainable materials.

1. Introduction

The push for environmentally sustainable materials has led to a surge in interest in natural fiber-reinforced composites. These composites are highly valued for their lightweight nature, cost-effectiveness, and ability to reduce environmental impact. Industries such as automotive, aerospace, and construction are increasingly adopting these materials to meet performance demands while prioritizing sustainability [1][2].

Sisal, kenaf, and camel hair fibers have emerged as promising reinforcements for composites due to their unique properties. Sisal fiber, widely used in composite development, is known for its strength, availability, and affordability, making it a practical option for reinforcement [3]. Similarly, kenaf fiber offers excellent mechanical characteristics, including high tensile and flexural strengths, combined with biodegradability. These features make it a desirable component for eco-friendly composite production [4]. Camel hair fiber, though less studied in the field, has shown potential due to its high thermal insulation and mechanical properties, presenting an opportunity for further exploration [5].

Hybrid composites, which integrate two or more fiber types into a single matrix, have demonstrated superior mechanical performance over single-fiber composites. The combination of fibers with complementary properties can enhance characteristics such as tensile strength, impact resistance, and overall durability. Despite the extensive study of hybrid composites involving synthetic fibers, the application of natural fiber-based hybrids remains relatively unexplored [6]. Such combinations offer dual benefits: improved mechanical attributes and reduced environmental impact through biodegradability and renewable resource utilization [7].

This study seeks to bridge the gap by fabricating and analysing a hybrid composite incorporating camel hair, sisal, and kenaf fibers, with epoxy as the binding matrix. Using a cost-effective hand lay-up method, test specimens were fabricated and subjected to tensile, compression, flexural, impact, and hardness testing. The findings of this research shed light on the mechanical behavior of natural fiber-based hybrid composites and their potential as sustainable alternatives to conventional materials in engineering applications.

2. Literature review

The utilization of natural fiber composites has emerged as a promising solution to the environmental and performance challenges associated with conventional materials. This section reviews studies highlighting advancements in hybrid composites and their applications.

Advances in Natural Fiber Composites

Natural fiber composites have gained attention for their ability to enhance material performance while remaining sustainable. Recent studies have explored their mechanical behavior and ecological advantages. For example, Zafeiropoulos et al. [8] examined surface treatments for natural fibers to improve compatibility with polymer matrices, finding significant enhancements in tensile strength and durability. Similarly, Mishra et al. [9] developed novel biocomposites using biodegradable polyester amide reinforced with natural fibers, showcasing improved mechanical performance.

Hybrid Composites

Hybrid composites combine multiple types of fibers to achieve synergistic properties, such as higher tensile strength, better impact resistance, and enhanced thermal stability. Silva and Al-Qureshi [10] demonstrated that hybrid composites reinforced with a mix of natural and synthetic fibers exhibit superior mechanical behavior compared to single-fiber composites. Additionally, Bilba et al. [11] analysed the influence of lignocellulosic fiber content in hybrid configurations, revealing improvements in flexural and compressive properties.

Role of Camel Hair Fiber

Research on camel hair fiber as a composite reinforcement is relatively novel but promising. Cichocki and Thomason [12] reported that its thermal insulation properties, combined with adequate mechanical strength, make it a viable alternative for hybrid composite development. Further investigations are necessary to understand its behavior when combined with other natural fibers.

Sisal and Kenaf Fibers

Sisal and kenaf fibers are widely researched for their mechanical properties and biodegradability. Mohanty et al. [13] highlighted the versatility of sisal fiber composites in automotive applications, demonstrating their strength and durability. Similarly, Gassan and Bledzki [14] conducted extensive tests on kenaf fiber-reinforced composites, emphasizing their potential for lightweight structural applications.

Research Gap

Despite advancements in natural fiber composites, hybrid combinations involving camel hair, sisal, and kenaf fibers have not been extensively explored. This study addresses this gap by evaluating the mechanical behavior of a hybrid composite made of these fibers, highlighting its potential for sustainable engineering solutions.

3. Materials and Methods

Materials

This study utilized sisal, kenaf, and camel hair fibers as reinforcements, combined with epoxy resin (LY 556) and a hardener (HY 951) as the matrix material. Sisal fibers were chosen for their high tensile strength and availability [15], while kenaf fibers are well-known for their biodegradability and excellent mechanical properties [16]. Camel hair fiber, a less explored material, was incorporated for its thermal insulation and reinforcing capabilities [17]. The matrix was prepared by mixing epoxy resin and hardener in a 10:1 ratio, which ensures optimal curing and mechanical performance [18].

Figure 1: Sisal, kenaf, and camel hair fibers used as reinforcements in this study.

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Figure 2: Epoxy resin (LY 556) and hardener (HY 951) used as the matrix material.

Fabrication of Composites

The hybrid composites were fabricated using the hand lay-up method, a simple and cost-effective process widely used in polymer matrix composites [19]. The fibers were cut into the required dimensions and weighed according to predetermined weight ratios. The composite configurations included varying percentages of sisal, kenaf, and camel hair fibers, with epoxy as the binding matrix. The layers of fibers were arranged sequentially, ensuring uniform distribution of resin using a brush.

The curing process was carried out at room temperature for 24 hours under compression to achieve optimal bonding between fibers and matrix. Post-curing, the composites were cut into specimens of standard dimensions as per ASTM guidelines for mechanical testing.

Preparation of Test Specimens

The fabricated composites were cut into standard dimensions as per ASTM standards for tensile (ASTM D3039), compression (ASTM D3410), flexural (ASTM D790), impact (ASTM D256), and hardness (ASTM E10) testing. Each specimen was carefully polished to avoid irregularities that could affect test results.

Mechanical Testing

The specimens were subjected to the following mechanical tests:

1.Tensile Testing: Conducted using a universal testing machine to evaluate ultimate tensile strength.

2.Compression Testing: Assessed using a compression testing machine to measure maximum compressive strength.

3.Flexural Testing: Performed using a three-point bending setup to analyze flexural stress and strain.

4.Impact Testing: Measured using a Charpy impact testing machine to determine impact toughness.

5.Hardness Testing: Carried out using a Brinell hardness tester to evaluate surface hardness.

4. Results and Discussion

Hardness Test

The Brinell hardness number (BHN) of the fabricated composites indicates the significant influence of fiber composition on the surface hardness.

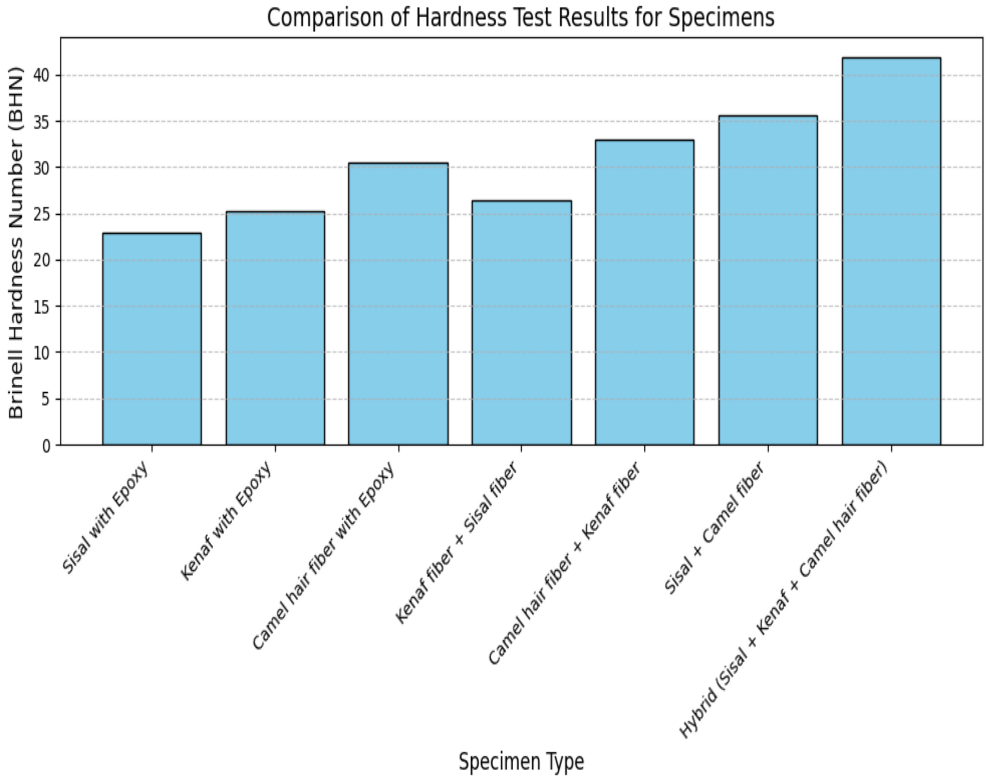

Figure 3: Brinell hardness number comparison for fabricated composites.

The hybrid composite (sisal + kenaf + camel hair fibers) exhibited the highest BHN of 41.90, outperforming single-fiber composites. This improvement is attributed to the reinforcing effect of camel hair fiber, which enhances the load distribution within the matrix [20]. The synergistic interaction among fibers contributes to superior hardness, as reported by Gupta et al. [21].

Tensile Test

The tensile strength of the hybrid composite was recorded as 35.12 MPa, significantly higher than the tensile strengths of composites reinforced with individual fibers. This can be attributed to the uniform distribution of stresses across the fibers in the hybrid configuration. Similar results were observed in natural fiber composites, where hybridization improved tensile properties [22]. The addition of camel hair fiber further contributed to the increased tensile strength by enhancing interfacial adhesion between fibers and the epoxy matrix [23].

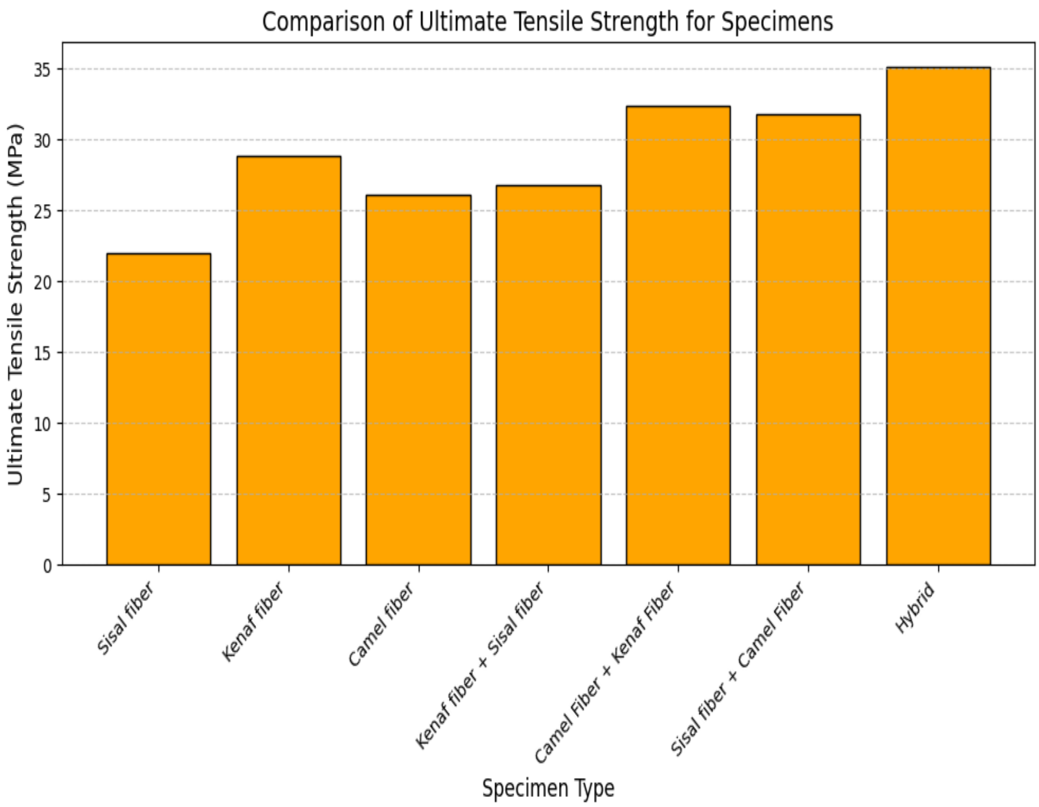

Figure 4: Stress-strain behavior of composites during tensile testing.

Compression Test

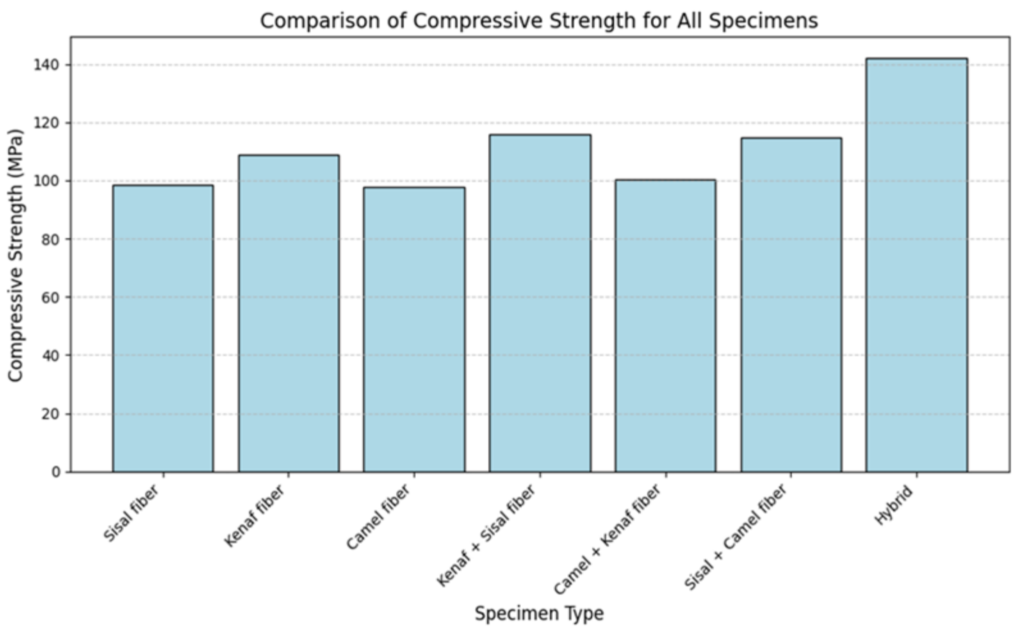

Figure 5: Compressive strength comparison for different composites.

Compression testing revealed that the hybrid composite achieved a compressive strength of 142.23 MPa, outperforming single-fiber composites. The structural integrity of the hybrid configuration allows for better energy absorption under compressive loads [24]. This aligns with findings by Alamri and Low [25], where hybrid composites demonstrated superior compressive properties due to enhanced matrix-fiber bonding.

Flexural Test

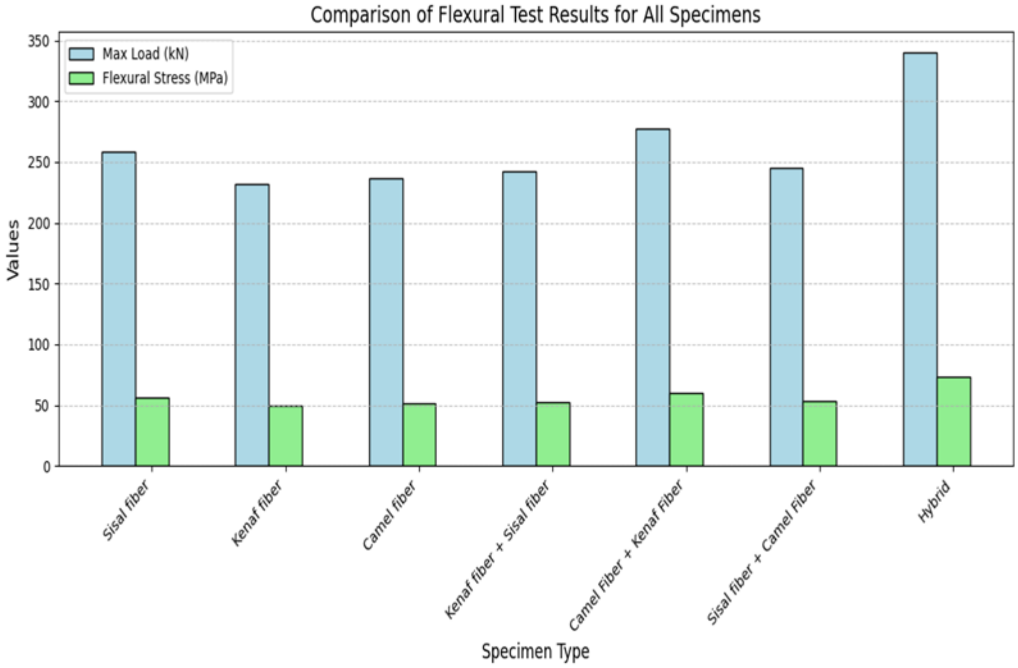

Figure 6: Comparison of flexural test results

The hybrid composite exhibited the highest flexural stress of 73.43 MPa, demonstrating excellent bending resistance. This is attributed to the layered arrangement of fibers, which distributes the bending stress effectively. Similar enhancements in flexural properties have been observed in other hybrid natural fiber composites [26]. The study by Li et al. [27] emphasized the importance of fiber orientation and hybridization in achieving superior flexural performance.

Impact Toughness

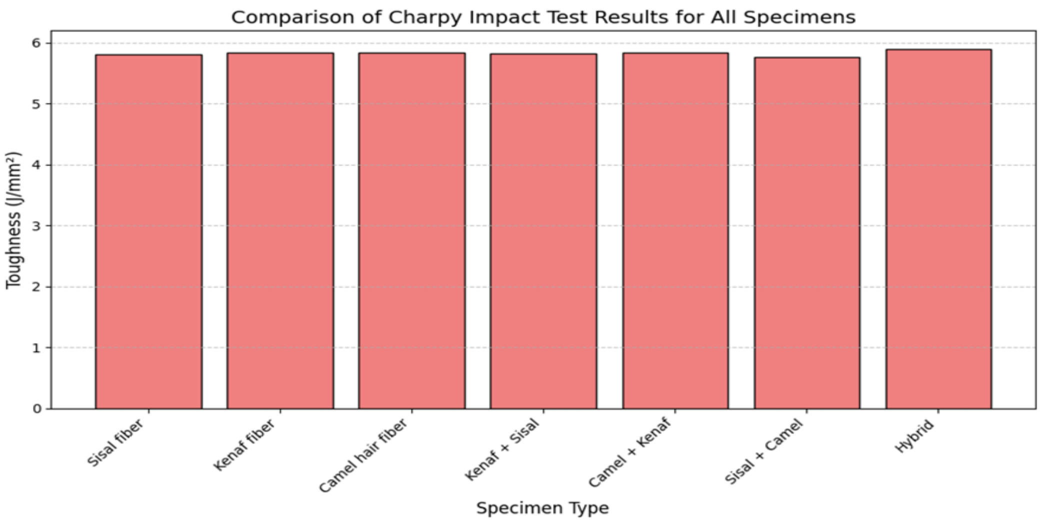

Figure 7: Impact toughness comparison of fabricated composites.

The hybrid composite achieved an impact toughness of 5.90 J/mm², highlighting its ability to resist fracture under dynamic loading. The toughening mechanism is attributed to the energy absorption by camel hair fibers, which act as crack stoppers within the composite structure. These findings are consistent with studies by Bagherpour et al. [28], who observed similar improvements in impact properties for natural fiber composites.

5. Conclusions

The investigation into hybrid composites reinforced with sisal, kenaf, and camel hair fibers has provided valuable insights into their mechanical behavior. This study highlights the potential of hybrid natural fiber composites as sustainable alternatives to conventional materials. The key conclusions are as follows:

- Hardness: The hybrid composite achieved the highest Brinell Hardness Number (BHN) of 41.90. This superior hardness is attributed to the synergistic reinforcement effect of sisal, kenaf, and camel hair fibers, which enhances surface durability.
- Tensile Strength: The ultimate tensile strength of the hybrid composite was measured at 35.12 MPa, surpassing the performance of single-fiber composites. This improvement demonstrates the effective stress distribution and enhanced adhesion between fibers and the matrix.
- Compressive Strength: With a compressive strength of 142.23 MPa, the hybrid composite showcased its ability to resist compressive loads. This strength can be linked to the optimized fiber-matrix interaction and hybrid configuration.
- Flexural Properties: The hybrid composite exhibited a flexural stress of 73.43 MPa, indicating excellent resistance to bending forces. The arrangement of fibers within the matrix played a critical role in achieving this enhanced performance.
- Impact Toughness: The highest toughness of 5.90 J/mm² was recorded for the hybrid composite, demonstrating its ability to absorb impact energy effectively. This property makes the composite suitable for applications requiring resistance to dynamic loads.
- Effect of Hybridization: The combination of sisal, kenaf, and camel hair fibers has been shown to significantly improve mechanical properties compared to single-fiber composites. This hybridization leverages the strengths of each fiber, resulting in a balanced and optimized material.
- Environmental Significance: The use of natural fibers not only improves mechanical performance but also offers a sustainable and eco-friendly alternative to synthetic materials. The hybrid composite contributes to reducing environmental impact while delivering excellent mechanical properties.

The findings of this study underline the versatility and practicality of hybrid composites in engineering applications. With their superior mechanical properties and sustainability, these materials hold promise for use in industries such as construction, automotive, and aerospace. Future studies could explore further optimization of fiber proportions, investigate the influence of surface treatments, and examine additional functional properties like thermal and electrical conductivity to expand their application potential.

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