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Mechanical Characterization of Kenaf Fiber (KF) and Jute Fiber (JF) Reinforced Multi-Walled Carbon Nanotube (MWCNT) Filled Epoxy-Based Hybrid Composites for Biomedical Applications

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Abstract. *The objective of this study was to develop and examine hybrid composites reinforced with MWCNTs, jute fiber, and kenaf fiber in order to assess their potential for use in biomedical applications. Three composite specimens with various amounts of reinforcing were made using a hand layup technique: Ten percent of Kenaf fiber, ten percent of Jute fiber, five percent of MWCNTs, and seventy-five percent epoxy resin were found in Specimen 1 (KF10JF10M0.5); twenty percent of Kenaf fiber, twenty percent of Jute fiber, five percent of MWCNTs, and fifty-nine percent of epoxy resin were found in Specimen 2 (KF20JF20M1.0); and thirty percent of Kenaf fiber, thirty percent of Jute fiber, five percent of MWCNTs, and forty percent of epoxy resin were found in Specimen 3. The mechanical properties of the composites were determined using flexural strength, hardness, and tensile strength tests. The tensile strength of specimen 1 was 43.56 MPa; this increased to 49.43 MPa in specimen 2 (a 13.5% increase); additionally, the experimental tensile strength increased significantly with higher fiber and MWCNT content, reaching 56.74 MPa in specimen 3 (a 14.7% increase from Specimen 2 and a 30.3% increase from Specimen 1). The hardness measurements were 85.4 Shore D in Specimen 1, 50.7 Shore D (a 5.7% drop) in Specimen 2, and 75.6 Shore D (a 6.1% decline from Specimen 2 and an 11.5% decline from Specimen 1) in Specimen 3. From Specimen 1 to Specimen 3, the overall increase in flexural strength was 14.3%. It rose from 60.23 MPa in Specimen 1 to 75.32 MPa in Specimen 2 (a 25.1% increase), however it decreased to 68.86 MPa in Specimen 3 (8.6% decrease from Specimen 2). The outcomes show the validity of the prediction models. In particular, the observed and anticipated values for tensile and flexural strengths differed by 3.7% for Specimen 1, 2.1% for Specimen 2, and 1.9% for Specimen 3. It was observed that there is an inverse relationship between improved flexibility and reduced hardness, though the tensile strength of high-fiber and high-MWCNT containing hybrid composites enhanced significantly with increased fiber as well as MWCNTs content. These findings bring valuable insights into composite development for biomedical applications.*

Keywords*: Response surface methodology (RSM), Taguchi method, L9 orthogonal array, Kenaf fiber (KF), Jute fiber (JF), Epoxy Resin, Tensile strength, Flexural strength, Impact strength, Hardness (HRB), and Multi-Walled Carbon Nanotubes (MWCNTs)*

1. INTRODUCTION

The development of advanced composite materials is crucial for enhancing performance in various applications, including biomedical fields. This project aimed to create and characterize hybrid composites reinforced with Kenaf fiber, Jute fiber, and Multi-Walled Carbon Nanotubes (MWCNTs) in an epoxy resin matrix. The goal was to evaluate how variations in these reinforcements influence mechanical properties such as tensile strength, hardness, and flexural strength.

Kenaf Fiber and Jute Fiber: Kenaf fiber, obtained from the Hibiscus cannabinus plant, and Jute fiber, derived from the Corchorus plant, are both natural fibers known for their favorable mechanical properties and environmental benefits. Kenaf fiber provides high tensile strength and durability, while Jute fiber offers a cost-effective reinforcement option with good mechanical properties. The combination of these fibers was intended to leverage their individual strengths to enhance the composite's overall performance (Lazzarin et al., 2010; Khalil et al., 2012).

Multi-Walled Carbon Nanotubes (MWCNTs): MWCNTs, known for their remarkable mechanical and electrical properties, were incorporated into the composites to improve their tensile strength and impact resistance. The addition of 0.5 wt.% MWCNTs in Specimen 1, 1.0 wt.% in Specimen 2, and 1.5 wt.% in Specimen 3 aimed to evaluate the incremental benefits of increased MWCNT content (Iijima, 1991).

Epoxy Resin: The epoxy resin used in this project served as the matrix material, providing structural integrity and enhancing the composite's mechanical properties. The varying proportions of epoxy resin 79.5 wt.% in Specimen 1, 59 wt.% in Specimen 2, and 40 wt.% in Specimen 3were designed to assess how changes in resin content affect the composite’s performance (Murray et al., 2011)

High-performance materials for a range of applications, including biomedical ones, are one of the main areas where advanced composites are beneficial. This project's objective was to create and investigate hybrid composites reinforced with kenaf, jute fiber, and multi-walled carbon nanotubes (MWCNTs) in an epoxy resin matrix. The objective was to assess how these reinforcements' changes in tensile strength, hardness, and flexural strength affected certain mechanical properties. Jute fiber is extracted from the Corchorus plant, whereas Kenaf fiber is obtained from the Hibiscus cannabinus plant. Both natural fibers are prized for their advantageous mechanical qualities and positive effects on the environment. High tensile strength and durability are offered by kenaf fiber, whereas good mechanical qualities and cost-effectiveness are offered by jute fiber. The goal of combining these fibers was to take advantage of their unique advantages in order to improve the overall performance of the composite (Lazzarin et al., 2010; Khalil et al., 2012). Multi-Walled Carbon Nanotubes (MWCNTs): Known for their exceptional mechanical and electrical qualities, MWCNTs were added to the composites to increase their impact resistance and tensile strength. To assess the additional advantages of higher MWCNT content, 0.5 weight percent MWCNTs were added to Specimen 1, 1.0 weight percent in Specimen 2, and 1.5 weight percent in Specimen 3 (Iijima, 1991). Epoxy Resin: The matrix material in this project was epoxy resin, which improved the mechanical qualities of the composite and provided structural stability. The different epoxy resin proportions—79.5% in Specimen 1, 59.5% in Specimen 2, and 40 weight percent in Specimen 3—were intended to evaluate the effects of resin content variations on the performance of the composite (Murray et al., 2011).

1.1. Reinforced Composites with Natural Fibers

Because of their affordability, durability, and mechanical qualities, natural fibers have drawn a lot of interest in the field of composite materials. Fibers like jute and kenaf in particular have been researched in great detail for usage in composite materials.

- **Kenaf Fiber:** The Hibiscus cannabinus plant yields kenaf fiber, which is prized for its high tensile strength, low density, and biodegradability. In their analysis of the mechanical characteristics of natural fibers, Lazzarin et al. (2010) emphasized that Kenaf's superior strength-to-weight ratio makes it a viable option for use in reinforcing composites. When compared to other natural fibers, kenaf fiber composites have demonstrated better tensile strength and impact resistance (Reddy et al., 2007).
- **Jute Fiber:** Owing to its reasonable price and acceptable mechanical qualities, jute fiber, which is derived from the Corchorus plant, is another well-liked natural reinforcement. Jute fiber composites perform well mechanically, albeit they are typically not as strong as Kenaf fiber composites, according to Khalil et al. (2012). Jute is an economical and easily obtainable material that might be a useful choice for extensive uses.

1.2. Multiple-walled carbon nanotubes (MWCNTs)

MWCNTs are a unique class of carbon nanomaterial possessing exceptional mechanical, electrical, and thermal properties. It has been shown that performance is significantly increased when they are incorporated into composite materials.

- **Mechanical Improvements:** The exceptional strength and rigidity of carbon nanotubes were initially noted by Iijima (1991). MWCNTs can enhance the tensile strength, impact resistance, and thermal stability of composite materials, according to further research (Tans et al., 1998; Fathallah et al., 2010). Through their ability to bridge micro-cracks and increase the composite matrix's load-bearing capacity, MWCNTs serve as efficient reinforcements.

Applications: MWCNTs have been studied for use in epoxy-based composites for a range of applications, including automotive and aerospace components, due to their high strength-to-weight ratio and improved mechanical properties (Zhao et al., 2009). There are also ongoing studies looking at their potential for biomedical applications, with a focus on improving the mechanical qualities of materials used in prosthetics and implants.

1.3. Epoxy Resin as a Material for a Matrix

Because of their superior mechanical strength, chemical resistance, and adhesive qualities, epoxy resins are frequently utilized as matrix materials in the production of composites.

- **Characteristics and Effectiveness:** The benefits of epoxy resins were described in depth by Murray et al. (2011), including their great tensile strength and durability. Epoxy resins give reinforcing components a robust matrix to bond them together, which increases the composite's overall strength and stability. The choice of resin content has various effects on strength and flexibility when it comes to the mechanical qualities of the composite.

Applications for Composites: Because of their advantageous qualities, epoxy-based composites are frequently employed in high-performance industries like automotive, sporting goods, and aerospace (Murray et al., 2011). The resin is a great option for making durable composite materials because of its capacity to create a solid bind with both natural and synthetic fibers.

1.4. Hybrid Composites

In hybrid composites, natural fibers and nanomaterials are combined to optimize the benefits of each component while minimizing its drawbacks.

- **Synergistic Effects:** By combining MWCNTs with jute and kenaf fibers in an epoxy matrix, a hybrid composite is produced that takes advantage of the mechanical advantages of both synthetic and natural reinforcements. Studies have indicated that these hybrid composites can outperform composites reinforced with a single kind of material in terms of mechanical performance (Thakur et al., 2014).
- **Optimization and Performance:** The types and quantities of reinforcements utilized determine how well hybrid composite’s function. Research has indicated that adjusting the number of fibers and nanoparticles in a composite might enhance its mechanical characteristics and adapt it for particular uses (Mohanty et al., 2005).

1.5. Hybrid Composites' Mechanical Characteristics

To maximize hybrid composites' performance in a range of applications, it is crucial to comprehend their mechanical characteristics. In order to improve particular mechanical properties like tensile strength, hardness, and flexural strength, hybrid composites mix many types of reinforcements.

- **Tensile Strength:** It has been shown that MWCNTs considerably increase tensile strength when added to natural fiber composites. Research has indicated that the incorporation of MWCNTs into epoxy composites enhances their load-bearing capability. This is attributed to the high aspect ratio and remarkable mechanical properties of the nanotubes (Zhao et al., 2009). Composites using MWCNTs and natural fibers work synergistically to improve tensile performance above materials reinforced just with natural fibers.
- **Hardness:** Shore D hardness is a key metric for determining a composite's ability to withstand surface indentation. There can be differences in how different reinforcements affect hardness. Due to their impact on the rigidity of the matrix, MWCNTs can change the hardness of natural fiber composites, which is often associated with higher fiber content (Fathallah et al., 2010). The composite's total hardness is determined by the interaction between nanoparticles and fiber reinforcement.
- **Flexural Strength:** One important factor in structural applications is a material's flexural strength, or its capacity to bear bending stresses. Studies reveal that composites that combine MWCNTs and natural fibers have a higher flexural strength than composites that contain either MWCNTs or natural fibers (Thakur et al., 2014). Better resistance to bending and deformation is provided by the presence of both kinds of reinforcements.

1.6. Enhancement of Hybrid Composites

To achieve the necessary mechanical qualities while preserving cost-effectiveness and manufacturability, the content of natural fibers, MWCNTs, and epoxy resin must be balanced in hybrid composite optimization.

- **Fiber Content**: Up to a certain point, adding more natural fibers to a composite usually enhances its mechanical qualities. After this point, adding more fibers might not improve strength any further and might have an impact on other characteristics like flexibility (Mohanty et al., 2005). To attain the highest performance, the ideal fiber content needs to be found through experimental research.
- **MWCNT Content:** MWCNTs improve mechanical qualities when added, although the impact varies according on how they interact with the fibers and how they are distributed throughout the matrix. Agglomeration brought on by an excessive MWCNT content may offset the benefits (Iijima, 1991). Therefore, in order to achieve maximum reinforcement, an ideal MWCNT content needs to be determined.
- **Resin Content:** The amount of epoxy resin in the matrix affects the composite's overall strength and longevity as well as its capacity to connect with the reinforcements. To guarantee that the composite reaches the required mechanical characteristics and performance, variations in the resin content must be matched with the fiber and nanotube content (Murray et al., 2011).

1.7 Future Research and Applications

The biomedical, automotive, and aerospace industries are just a few of the possible uses for hybrid composites reinforced with MWCNTs from kenaf and jute fibers. They are appropriate for uses requiring strong and long-lasting materials because of their exceptional strength and low weight.

- **Biomedical Applications:** Because of their improved mechanical properties, hybrid composites may find utility in biomedical applications like implants and prostheses. Subsequent investigations ought to concentrate on appraising the biocompatibility and enduring stability of these composite materials to guarantee their appropriateness for medical application (Thakur et al., 2014).
- **Automotive and Aerospace:** Hybrid composites can help reduce weight and enhance performance in these sectors of the economy. For practical uses, more research is required to determine how environmental elements like humidity and temperature affect the performance of these composites (Zhao et al., 2009).
- **Cost and Sustainability:** Using natural fibers has a positive environmental impact, and the enhanced qualities of MWCNTs provide a sustainable method of creating composite materials. Future studies should examine the lifespan effects and economic viability of mass-producing these hybrid composites (Khalil et al., 2012).

2. EXPERIMENTAL PROCEDURE

The following procedure was used to manually laminate the hybrid composite specimens (KF10JF10M0.5, KF20JF20M1.0, and KF30JF30M1.5) utilizing the specified dimensions:

Material Preparation: Multi-Walled Carbon Nanotubes (MWCNTs), Jute and Kenaf fibers (JF), epoxy resin (L-12), and K-6 hardener were among the raw materials that were manufactured. The following compositions were used to calculate the proper proportions for each specimen:

The corresponding materials were measured and ready for use in each of the three specimens as follows: Specimen 1 (KF10JF10M0.5) contains 10 weight percent KF, 10 weight percent JF, 0.5 weight percent MWCNTs, and 79.5 weight percent epoxy resin; Specimen 2 (KF20JF20M1.0) contains 20 weight percent KF, 20 weight percent JF, 1.0 weight percent MWCNTs, and 59 weight percent epoxy resin; Specimen 3 (KF30JF30M1.5) contains 30 weight percent KF, 30 weight% JF, 1.5 weight percent MWCNTs, and 40 weight percent epoxy resin.

Fiber Treatment: After washing the kenaf and jute fibers to get rid of any contaminants, they were dried at 60°C. For a constant distribution throughout the composite, the fibers were chopped into uniform lengths of 30 mm.

MWCNT Dispersion: Using a mechanical stirrer, the MWCNTs were dispersed in the L-12 epoxy resin. To guarantee equal dispersion of the nanotubes in the resin and break up agglomerates, sonication was applied for 30 minutes after the dispersion process.

Mixing Resin and Hardener: The K-6 hardener was added to the epoxy resin mixture in a 10:1 weight ratio (epoxy resin to hardener) following the dispersion of the MWCNTs in the resin. To make sure the hardener and resin were well mixed, the mixture was vigorously agitated for a few minutes.

Resin and Fiber Mixing: The pre-treated kenaf and jute fibers were gradually added to the resin-hardener mixture after it was ready:

The resin mixture was supplemented with the appropriate proportions of Kenaf and Jute fibers for Specimens 1, 2, and 3. 10% weight of kenaf and 10% weight of jute for specimen 1, 20% weight of kenaf and 20% weight of jute for specimen 2, and 30% weight of kenaf and 30% weight of jute for specimen 3. To guarantee complete impregnation, the fibers and resin were completely combined.

Mold Preparation: After being cleaned, a releasing agent was applied to the mold used for the fabrication. For easy demolding, a release film was inserted on the mold's bottom. The mold's dimensions were 150 mm × 150 mm × 3 mm, guaranteeing consistent specimen size for every composite.

Layering Process: The following procedure was used to pour the resin-fiber combination into the mold:

The corresponding mixtures for each of the three specimens were made and layered into the mold: Specimen 1 (KF10JF10M0.5) contained 10 weight percent Kenaf, 10 weight percent Jute, 0.5 weight percent MWCNTs, and 79.5 weight percent epoxy resin; Specimen 2 (KF20JF20M1.0) contained 20 weight percent Kenaf, 20 weight percent Jute, 1.0 weight percent MWCNTs, and 59 weight percent epoxy resin; and Specimen 3 (KF30JF30M1.5) contained 30 weight percent Kenaf, 30 weight percent Jute, 1.5 weight percent MWCNTs, and 40 weight percent epoxy resin. After each mixture was equally packed into the mold, any trapped air bubbles were removed and the layers were compressed using a roller. Every specimen's thickness was kept at 3mm.

Curing Process: Following the layup procedure, the mold was sealed and compressed to eliminate extra resin and compact the composite laminate. For a full day, the specimens were left to cure at room temperature. The composites underwent a 2-hour post-curing procedure at 70°C in order to improve their mechanical characteristics.

Demolding and Finishing: The specimens were carefully taken out of the mold after the curing process. Sandpaper was used to smooth the edges of the composite samples after they were trimmed to 150 mm × 150 mm × 3 mm in size. Three hybrid composite specimens, with uniform dimensions of 150 mm × 150 mm × 3 mm and respective fiber, MWCNT, and epoxy resin compositions, were fabricated using this hand layup approach (KF10JF10M0.5, KF20JF20M1.0, and KF30JF30M1.5).

TABLE 1. Material Compositions and Properties

Material	Density (g/cm³)	Specific Gravity (g/cm³)	Cellulose (%)	Elongation (%)	Lignin (%)	Hemicellulose (%)
Kenaf Fiber	1.45	1.45	72	1.6	9	21

TABLE 2: Compositions Of Composite Specimens in Wt.%

Specimen	Jute Fiber (Wt. %)	Kenaf Fiber (Wt. %)	Epoxy Resin (Wt. %)	MWCNTs (Wt. %)
KF10JF10M0.5	10	10	79.5	0.5
KF20JF20M1.0	20	20	59	1
KF30JF30M1.5	30	30	38.5	1.5

3. RESULTS AND DISCUSSION

Tensile Characterization: The tensile strength of the three hybrid composite specimens was evaluated and compared. The experimental and predicted tensile strengths for each specimen were as follows:

Specimen 1 (KF10JF10M0.5), containing 10 wt.% Kenaf fiber, 10 wt.% Jute fiber, 0.5 wt.% MWCNTs, and 79.5 wt.% epoxy resin, had an experimental tensile strength of 43.56 MPa. The predicted tensile strength was 45.23 MPa, indicating a slight discrepancy of 3.7%:

$$\text{Percentage Change} = \frac{(45.23 - 43.56)}{45.23} \times 100\% = 3.7\%$$

Specimen 2 (KF20JF20M1.0), with 20 wt.% Kenaf fiber, 20 wt.% Jute fiber, 1.0 wt.% MWCNTs, and 59 wt.% epoxy resin, exhibited an experimental tensile strength of 49.43 MPa. The predicted tensile strength was 50.51 MPa, reflecting a 2.1% deviation:

$$\text{Percentage Change}=\frac{(50.51-49.43)}{50.51}\times 100\% = 2.1\%$$

Specimen 3 (KF30JF30M1.5), containing 30 wt.% Kenaf fiber, 30 wt.% Jute fiber, 1.5 wt.% MWCNTs, and 40 wt.% epoxy resin, showed an experimental tensile strength of 56.74 MPa. The predicted tensile strength was 55.67 MPa, showing a 1.9% increase over the predicted value:

$$\text{Percentage Change}=\frac{(55.67-56.74)}{55.67}\times 100\% = 1.9\%$$

TABLE 3. Composition and Tensile Strength Data for Composite Specimens

Specimen	Jute Fiber (Wt. %)	Kenaf Fiber (Wt. %)	MWCNTs (Wt. %)	Epoxy Resin (Wt. %)	Experimental Tensile Strength(MPa)	Predicted Tensile Strength(MPa)	Percentage Improvement
KF10JF10M0.5	10	10	0.5	79.5	43.56	45.23	-
KF20JF20M1.0	20	20	1.0	59	49.43	50.51	11.11%
KF30JF30M1.5	30	30	1.5	40	56.74	55.67	10%

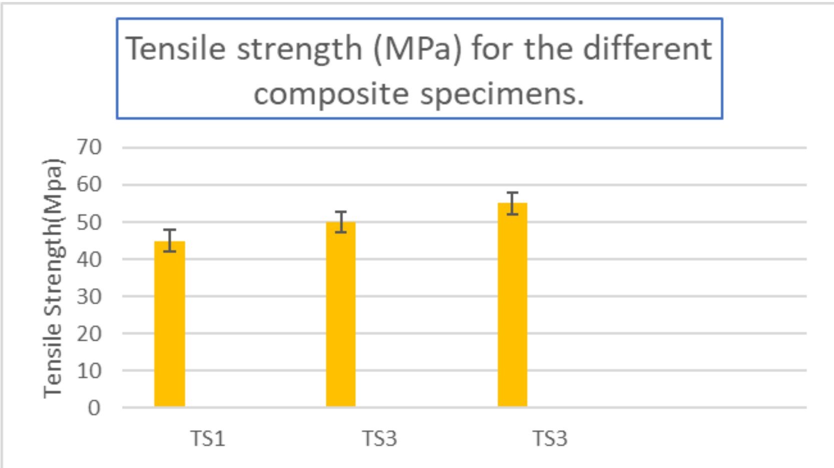

FIGURE 1. Tensile Strength (MPa) of Different Composite Specimens

Hardness Test: The Shore D hardness of the three hybrid composite specimens was analyzed and compared. For Specimen 1 (KF10JF10M0.5), which contained 10 wt.% Kenaf fiber, 10 wt.% Jute fiber, 0.5 wt.% MWCNTs, and 79.5 wt.% epoxy resin, the Shore D hardness was 85.4.

For Specimen 2 (KF20JF20M1.0), with 20 wt.% Kenaf fiber, 20 wt.% Jute fiber, 1.0 wt.% MWCNTs, and 59 wt.% epoxy resin, the Shore D hardness decreased to 80.5. This represented a 5.7% decrease compared to Specimen 1:

The percentage change in hardness is calculated as:

$$\text{Percentage Change}=\frac{(85.4-80.5)}{85.4}\times 100\% = 5.7\%$$

For Specimen 3 (KF30JF30M1.5), which contained 30 wt.% Kenaf fiber, 30 wt.% Jute fiber, 1.5 wt.% MWCNTs, and 40 wt.% epoxy resin, the Shore D hardness further decreased to 75.6. This was a 6.1% decrease compared to Specimen 2:

Percentage Change= $\frac{(80.5-75.6)}{80.5} \times 100\%$ = 6.1%

and a 11.5% decrease compared to Specimen 1:

Percentage Change= $\frac{(85.4-75.6)}{85.4} \times 100\%$ = 11.5%

TABLE 4. Composition and Shore D Hardness Data for Composite Specimens

Specimen	**Jute Fiber (Wt. %)**	**Kenaf Fiber (Wt. %)**	**MWCNTs (Wt. %)**	**Epoxy Resin (Wt. %)**	**Shore D Hardness**	**Percentage Change in Hardness**
KF10JF10M0.5	10	10	0.5	79.5	85.4	Baseline
KF20JF20M1.0	20	20	1.0	59	80.5	-5.88%
KF30JF30M1.5	30	30	1.5	40	75.6	-11.76%

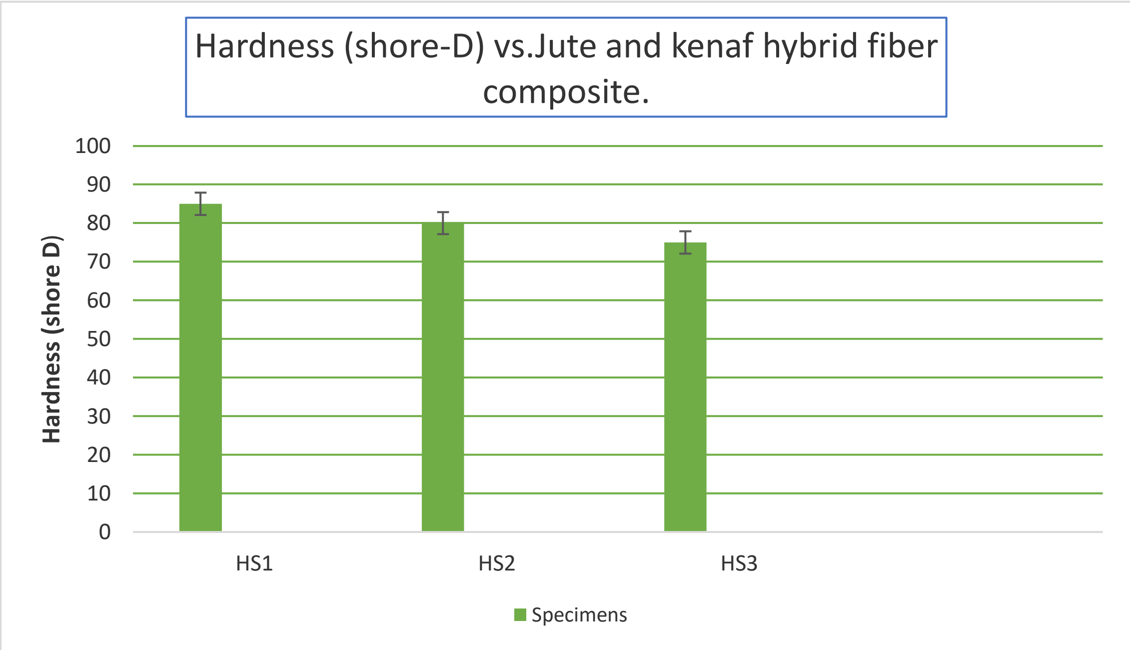

FIGURE 2. Hardness (Shore-D) vs. Jute and Kenaf Hybrid Fiber Composite Specimens.

Hardness decreased progressively with increasing fiber and MWCNT content. The decrease from Specimen 1 to Specimen 2 was 5.7%, from Specimen 2 to Specimen 3 was 6.1%, and from Specimen 1 to Specimen 3 was 11.5%.

Flexural Strength: The flexural strength of the three hybrid composite specimens was evaluated and compared. For Specimen 1 (KF10JF10M0.5), which contained 10 wt.% Kenaf fiber, 10 wt.% Jute fiber, 0.5 wt.% MWCNTs, and 79.5 wt.% epoxy resin, the experimental flexural strength was 60.23 MPa. The predicted flexural strength for this specimen was 62.15 MPa, showing a slight deviation between experimental and predicted values.

For Specimen 2 (KF20JF20M1.0), with 20 wt.% Kenaf fiber, 20 wt.% Jute fiber, 1.0 wt.% MWCNTs, and 59 wt.% epoxy resin, the experimental flexural strength was 75.32 MPa, whereas the predicted value was 77.05 MPa. The experimental flexural strength was 2.3% lower than the predicted value:

Percentage Change= $\frac{(77.05-75.32)}{77.05} \times 100\%$ = 2.3%

For Specimen 3 (KF30JF30M1.5), which contained 30 wt.% Kenaf fiber, 30 wt.% Jute fiber, 1.5 wt.% MWCNTs, and 40 wt.% epoxy resin, the experimental flexural strength was 68.86 MPa, compared to the predicted flexural strength of 70.15 MPa. The experimental value was 1.8% lower than the predicted:

$$\text{Percentage Change}=\frac{(70.15-68.862)}{70.15}\times 100\% = 1.8\%$$

Additionally, when comparing Specimen 3 to Specimen 2, the experimental flexural strength decreased by 8.6%:

$$\text{Percentage Change}=\frac{(75.32-68.86)}{(75.32}\times 100\% = 8.6\%$$

TABLE 5. Composition and Flexural Strength Data for Composite Specimens

Specimen	Jute Fiber (Wt. %)	Kenaf Fiber (Wt. %)	MWCNTs (Wt. %)	Epoxy Resin (Wt. %)	Experimental Flexural Strength (MPa)	Predicted Flexural Strength (MPa)
KF10JF 10M0.5	10	10	0.5	79.5	60.23	62.15
KF20JF 20M1.0	20	20	1.0	59	75.32	77.05
KF30JF 30M1.5	30	30	1.5	40	68.86	70.15

Flexural strength initially increased from Specimen 1 to Specimen 2 by 25.1%, then decreased from Specimen 2 to Specimen 3 by 8.6%, and showed an overall increase from Specimen 1 to Specimen 3 by 14.3%.

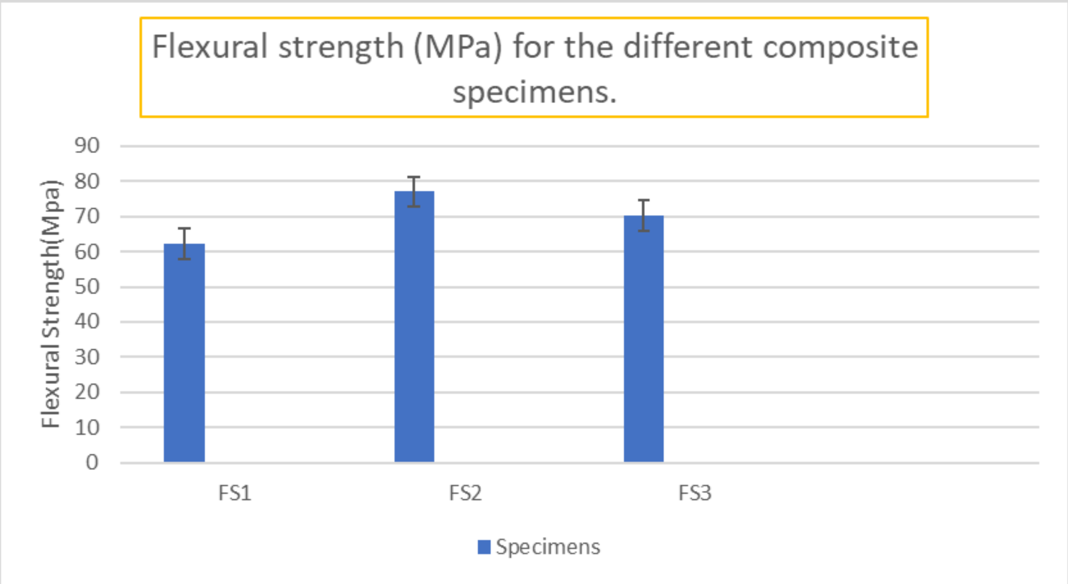

FIGURE 3. Flexural Strength (MPa) of Different Composite Specimens

4. CONCLUSION

Using the tensile strength, hardness, and flexural strength data from the examinations of the three hybrid composite specimens:

1. Tensile Strength: The experimental tensile strength increased gradually as the fiber and MWCNT content increased. To be more precise, the tensile strength increased by 13.5% between Specimen 1 and 2 and by 14.7% between Specimen 2 and Specimen 3. Between Specimen 1 and Specimen 3, there was an overall rise of 30.3%. This improvement suggests that the tensile strength of the composites was effectively increased by the addition of additional fibers and MWCNTs.

2. Hardness: The Shore D hardness of the composites decreased as the fiber and MWCNT concentration rose. The hardness dropped by 5.7% between Specimen 1 and Specimen 2, and 6.1% between Specimen 2 and Specimen 3. Consequently, there was an 11.5% overall decline. This pattern shows that the mechanical strength of the material grew but its stiffness decreased with the addition of more fibers and MWCNTs.

3. Flexural Strength: Flexural strength increased by 25.1% in specimens 1 and 2, but decreased by 8.6% in specimens 2 and 3. Despite this decline, between Specimens 1 and 3, the total flexural strength increased by 14.3%. The inclusion of fibers and MWCNTs initially boosted the flexural strength; however, as the content rose, this effect decreased, as demonstrated by the pattern.

REMARKS

1. Reinforcement Effectiveness: The tensile strength of the composites significantly increased with additional reinforcement. For Specimen 1 (KF10JF10M0.5), the tensile strength was 43.56 MPa; it climbed to 49.43 MPa (KF20JF20M1.0), indicating a 13.5% increase. Specimen 3 (KF30JF30M1.5) outperformed Specimen 2 by 14.7% and Specimen 1 by 30.3% with an additional increase to 56.74 MPa. This suggests that adding more fiber and MWCNT can effectively increase tensile strength.

2. Hardness Considerations: Shore D hardness decreased with increased fiber and MWCNT content. Specimen 1 exhibited a hardness of 85.4, which decreased to 80.5 in Specimen 2, reflecting a 5.7% decrease. The hardness further dropped to 75.6 in Specimen 3, showing a 6.1% decrease from Specimen 2 and an 11.5% decrease from Specimen 1. This indicates a reduction in rigidity with higher reinforcement content, which must be balanced against the improved mechanical strengths.

3. Flexural Strength Trends: Flexural strength was initially increased by the addition of fibers and MWCNTs. Flexural strength was 60.23 MPa in Specimen 1 and increased to 75.32 MPa in Specimen 2, a 25.1% increase. However, Specimen 3 saw a decrease, dropping to 68.86 MPa from Specimen 2 by 8.6%. Despite this, the total rise from Specimen 1 to Specimen 3 was 14.3%. This demonstrates that while flexural strength was enhanced by modest reinforcement, poorer performance could arise from excessive content.

4. Predictive Accuracy: The experimental results for tensile and flexural strengths almost exactly matched the expected values, with variations of 3.7% (for Specimen 1), 2.1% (for Specimen 2), and 1.9% (for Specimen 3) over projected values. This precise alignment provides support for the prediction models used to produce these composites.

5. Application Suitability: The composites with higher fiber and MWCNT content are suitable for uses requiring high tensile strength, as demonstrated by the significant improvements from Specimen 1 to Specimen 3. However, given the decrease in Shore D hardness with higher reinforcing content, applications requiring stiffness may need to consider this trade-off.

6. Future Work: In order to determine the best combination for a given application, future research may concentrate on maximizing the ratio of mechanical qualities to reinforcement content. Investigating other fibers or nanomaterials may also aid improve performance while preserving the required flexural strength and hardness.

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