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Efficacy of jute-glass hybrid laminate composite wrapping under flexural loading

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Abstrak: The demand for sustainable engineering materials has catalyzed interest in hybrid composites that combine natural fibers like jute with synthetic fibers such as E-glass. This study investigates the flexural strength of jute/E-glass/epoxy hybrid composite laminates under different stacking sequences, employing the ANOVA method to analyze their mechanical performance. The materials, including jute fabric, E-glass fabric, and epoxy resin, were arranged in various configurations and tested for flexural strength following ASTM D790 standards. The results indicated significant variability, with the GJGJ configuration exhibiting the highest average flexural strength of 71.20 MPa, while the GJG configuration had the lowest at 26.33 MPa. The ANOVA analysis confirmed a statistically significant effect of laminate configuration on flexural strength ($F = 6.41$, $p = 0.004$). These findings underscore the critical role of laminate arrangement in enhancing the mechanical properties of hybrid composites. The superior performance of the GJGJ configuration suggests that alternating layers of jute and E-glass fibers can effectively distribute stress and enhance load-bearing capacity. Conversely, suboptimal configurations like GJG demonstrated lower performance, highlighting the importance of strategic fiber arrangement. This research contributes to the development of optimized hybrid composites for various engineering applications, providing valuable insights into the interplay between natural and synthetic fibers within a composite matrix. The study's conclusions support the broader use of hybrid composites in industries such as automotive, construction, and aerospace, where material sustainability and performance are paramount. Future research should explore further optimization of stacking sequences and volume fractions of fibers, as well as investigate other mechanical properties such as tensile and impact strength, to fully realize the potential of hybrid composites in advanced engineering applications.

Keywords: Jute-glass hybrid laminate composite; flexural strength; woven jute fabric; woven e-glass; Anova

1. INTRODUCTION

The increasing demand for sustainable materials in engineering applications has spurred significant interest in hybrid composites. These materials blend natural fibers, such as jute, with synthetic fibers like E-glass, offering a balanced combination of mechanical strength and environmental benefits. Jute fibers are particularly attractive due to their low density, biodegradability, and cost-effectiveness, while E-glass fibers are known for their high tensile strength and durability [1]. The integration of these fibers with epoxy resin creates a composite material that can be customized for specific structural applications, providing an optimal mix of stiffness, strength, and weight reduction. Additionally, the use of jute fibers helps reduce reliance on non-eco-friendly synthetic materials, contributing to lower carbon footprints in both production and usage phases [2].

However, the performance of these hybrid composites, especially their flexural strength, is highly dependent on the arrangement and proportion of the constituent materials. This study focuses on the flexural strength of jute/E-glass/epoxy hybrid composites to understand how different laminate configurations affect their mechanical properties [3]–[5]. By examining various laminate configurations, we can optimize the composites for specific applications, ensuring they meet the desired strength and reliability standards. This research aims to provide deeper insights into the optimal arrangement of natural and synthetic fibers within an epoxy matrix to achieve the best performance, paving the way for broader use of hybrid composites across various industries, from automotive to construction and aerospace [6]–[8].

Recent research has underscored the significant potential of hybrid composites in a wide range of applications, particularly within the automotive and aerospace industries. Studies conducted by have revealed that hybrid composites exhibit superior mechanical properties when compared to single-fiber composites, highlighting their enhanced performance in demanding applications [9]. Illustrated that incorporating natural fibers, such as jute, can substantially improve the toughness and impact resistance of these composites. These findings suggest that hybrid composites not only offer mechanical advantages but also contribute to sustainability by utilizing renewable resources [10]. Additionally, investigations by demonstrated that the strategic combination of natural and synthetic fibers can markedly enhance the flexural and tensile strengths of the composites, indicating a promising direction for material innovation in structural applications [11].

However, the performance of these hybrid composites, especially their flexural strength, is highly dependent on the arrangement and proportion of the constituent materials. This gap highlights the necessity for systematic studies aimed at providing comprehensive insights into the mechanical behavior of these materials under various loading conditions. Detailed investigations into laminate configurations are essential to optimize the composites for specific applications, ensuring they meet the desired strength and reliability standards. For example, found that the hybridization of jute and sisal fibers significantly improved the dynamic mechanical properties and thermal stability of epoxy composites [12]. Similarly, demonstrated that jute fibers contribute more to impact strength compared to glass fibers in hybrid composites. By addressing these gaps, researchers can develop more effective and reliable materials that meet the stringent requirements of modern engineering, paving the way for broader use of hybrid composites across various industries, from automotive to construction and aerospace [13].

Although the benefits of hybrid composites are well-documented, there is a noticeable gap in the literature regarding the detailed analysis of different laminate configurations and their impact on flexural strength. Most studies have focused on general mechanical properties without delving into the specific effects of laminate stacking sequences. This lack of detailed investigation limits the ability to optimize these composites for practical applications. Moreover, while the ANOVA method has been widely used in mechanical testing to determine the significance of different factors, its application in analyzing the flexural strength of jute/E-glass/epoxy composites is relatively unexplored. Addressing this gap is crucial for advancing the knowledge in this field and providing a solid foundation for future material design and application.

The primary objective of this study is to evaluate the flexural strength of jute/E-glass/epoxy hybrid composite laminates with different stacking sequences using the ANOVA method. By systematically analyzing the mechanical performance of various laminate configurations, this research aims to identify the most effective combinations that maximize flexural strength. The study also seeks to provide a comprehensive understanding of how the interaction between jute and E-glass fibers influences the overall performance of the composite material. Ultimately, the findings of this research will contribute to the development of optimized hybrid composites for engineering applications, offering a valuable reference for material scientists and engineers aiming to design high-performance, sustainable composites.

2. METHOD

This research was conducted in the Mechanical Engineering Laboratory at Universitas Medan Area over a period of six months. The equipment utilized in this study included a vacuum cleaner, digital scales, a Universal Testing Machine (UTM), and a laptop. The vacuum cleaner was employed to create a vacuum environment within the specimen mold. The UTM, specifically the hydraulic model WEW-300D with a capacity of 300 kN, was used to measure the flexural strength of the composite specimens.

Figure 1 shows the materials used in this research, consisting of jute fabric, E-glass fabric, and epoxy resin. Composite laminates are made using these materials in various configurations, as detailed in Table 1. The configurations include different stacking sequences of jute and E-glass layers. Each specimen was manufactured in accordance with ASTM D790 standards for flexural testing.

(a) (b) (c)

Figure 1. Materials: (a) jute fabric [14], (b) E-glass fabric [15], and (c) epoxy resin [16]

Table 1. Specimen configurations

No.	Combination	Quantity
1	JJG	3
2	JGJ	3
3	GJG	3
4	JJJG	3
5	JGJG	3
6	GJGJ	3
Total		**18**

The preparation of the flexural test specimens encompassed several meticulous steps to ensure accuracy and consistency. Initially, jute and E-glass fabrics were precisely cut to dimensions of 150 mm in length and 100 mm in width. To facilitate the effortless removal of the composite specimens after curing, the surface of the mold was thoroughly coated with wax. The epoxy resin, a crucial binding agent, was then mixed with its hardener in a precise 1:1 ratio and stirred rigorously to achieve a homogeneous mixture. This resin mixture was subsequently poured into the prepared mold, and the first layer of either jute or E-glass fabric was placed according to the configurations detailed in Table 1. This layering process was systematically repeated for the subsequent layers, ensuring uniformity and alignment. Once the layering was complete, the mold containing the composite structure was placed in a vacuum chamber. This step was essential to eliminate any trapped air bubbles, which could compromise the integrity of the specimens. Following this, the specimens were allowed to cure, a critical phase during which the epoxy resin hardens completely, forming a solid and durable composite material. The careful execution of each step ensured that the resulting flexural test specimens met the required standards for further analysis. Figure 2 shows the shape of the flexural test specimen of the Jute/E-Glass/Epoxy hybrid laminate composite.

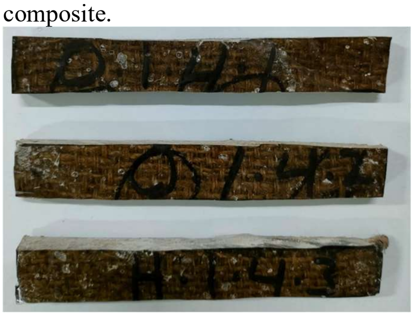

Figure 2. Hybrid specimens [17].

The assessment of the flexural strength of the prepared specimens was conducted through a series of methodical steps, ensuring precision and reliability in the results. Figure 3 shows a three-point bending test using a Universal Testing Machine (UTM). Initially, each specimen underwent a thorough cleaning process to eliminate any surface contaminants that could potentially affect the testing outcomes. Following this, the specific testing parameters were meticulously input into the software of the UTM, tailored to the requirements of the experiment. The specimens were then carefully placed on two supports, which were precisely spaced 100 mm apart to provide consistent testing conditions. A loading nose, an essential component for applying force, was positioned at the center of each specimen to ensure uniform load distribution. The load was applied at a controlled rate of 0.05 mm/min, continuing incrementally until the specimen reached its failure point. Throughout this process, the UTM software automatically recorded the load and deflection data, capturing detailed measurements essential for analyzing the material's performance. The test was deemed complete when the specimen experienced failure, characterized by its breakage. This comprehensive approach to testing provided critical insights into the flexural strength of the specimens, contributing valuable data for subsequent analyses and applications.

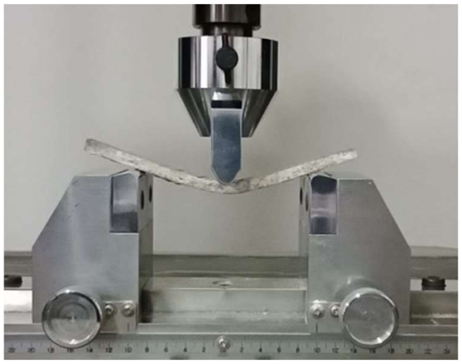

Figure 3. The three point bending testing [18]

The collected data were systematically analyzed using the Analysis of Variance (ANOVA) method, following a series of detailed steps to ensure rigorous statistical evaluation. Initially, the flexural strength data were meticulously compiled based on the various laminate configurations and their replicates. From this data, both the total data (TDK) and the average data (RDK) were calculated for each configuration, providing a foundational dataset for further analysis. In the ANOVA calculations, several key statistical measures were computed. The total sum of squares (SST) was calculated to capture the overall variability in the data. Subsequently, the sum of squares for treatments (SSTreatment) was determined to quantify the variability attributed to different laminate configurations. The sum of squares for error (SSE) was also calculated to account for the variability within the groups. Degrees of freedom for treatments (DoFTreatment) and error (DoFE) were then established to facilitate further calculations. Using these degrees of freedom, the mean squares for treatments (MSTreatment) and error (MSE) were computed, which are essential for understanding the variance within and between the groups. The F-value (F0) was subsequently calculated by dividing MSTreatment by MSE. This calculated F-value was then compared with the critical value from the F-distribution table at a 5% significance level, enabling the determination of whether the laminate configuration had a statistically significant effect on flexural strength. The results of the flexural strength tests, along with the detailed ANOVA analysis, were compiled and presented in comprehensive tables and graphs. These visual representations provided a clear and concise understanding of the impact of different laminate configurations on the flexural strength of hybrid jute/E-glass/epoxy composites, highlighting significant trends and differences

3. RESULTS AND DISCUSSION

The flexural strength results for the hybrid jute/E-glass/epoxy composite laminates are summarized in Table 2. The configurations tested were JJG, JGJ, GJG, JJJG, JGJG, and GJGJ, each with three specimens. The total data (TDK) and average data (RDK) for each configuration were calculated to provide a comprehensive understanding of the mechanical performance.

Table 2. Flexural strength results (TDK and RDK)

Configuration	Flexural Strength (MPa)	Total (MPa)	Average (MPa)
JJG	26.84, 39.90, 29.79	96.53	32.18
JGJ	47.47, 32.39, 39.84	119.69	39.90
GJG	24.87, 28.95, 25.18	79.00	26.33
JJJG	33.72, 41.64, 33.18	108.53	36.18

JGJG	41.85, 37.40, 32.56	111.81	37.27
GJGJ	74.85, 92.51, 46.25	213.60	71.20

The results show significant variability in the flexural strength across different configurations. The highest average flexural strength was observed in the GJGJ configuration (71.20 MPa), while the lowest was in the GJG configuration (26.33 MPa). This suggests that the arrangement of jute and E-glass layers significantly influences the mechanical performance of the composites.

The ANOVA analysis was conducted to determine the statistical significance of the differences in flexural strength among the various configurations. The sum of squares for treatments (SSTreatment), sum of squares for error (SSE), and total sum of squares (SST) were calculated, as shown in Table 3 and Table 4.

Table 3. ANOVA sum of squares calculation

Configuration	Sum of Squares $(y - \bar{y})^2$	Sub Total
JJG	186.95, 0.37, 114.90	302.22
JGJ	48.42, 65.95, 0.45	114.82
GJG	244.53, 133.72, 235.02	613.27
JJJG	46.08, 1.27, 53.78	101.13
JGJG	1.80, 9.64, 63.25	74.69
GJGJ	1178.96, 2703.84, 32.95	3915.75
	Total	5122.00

Table 4. ANOVA sum of squares for treatments (sstreatment) calculation

Configuration	Flexural Strength (MPa)	R	$(R - RDK)^2$
JJG	26.84, 39.90, 29.79	32.18	69.451
JGJ	47.47, 32.39, 39.84	39.9	0.373
GJG	24.87, 28.95, 25.18	26.33	200.994
JJJG	33.72, 41.64, 33.18	36.18	18.758
JGJG	41.85, 37.40, 32.56	37.27	10.487
GJGJ	74.85, 92.51, 46.25	71.2	941.963
	Total		1242.028
	SSTreatment		3726

Table 5. ANOVA summary

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Variation	5	3726	745.2	6.41	0.004
Error	12	1396	116.3		
Total	17	5122			

The ANOVA results Table 5 indicate a significant effect of laminate configuration on flexural strength ($F = 6.41$, $p = 0.004$). This statistical significance confirms that the arrangement of jute and E-glass layers plays a crucial role in determining the mechanical properties of the composite material.

The observed differences in flexural strength can be attributed to the unique mechanical contributions of jute and E-glass fibers. Jute fibers provide flexibility and toughness, while E-glass fibers contribute high tensile strength and stiffness. The hybrid configurations leverage these properties to achieve improved performance. The GJGJ configuration, which exhibited the highest flexural strength, suggests that alternating layers of jute and E-glass can effectively distribute stress and enhance load-bearing capacity. In contrast, the GJG configuration's lower performance highlights the importance of strategic layer arrangement to maximize composite strength. These findings align with previous studies that emphasize the potential of hybrid composites to offer superior mechanical properties compared to single-fiber composites. The results also underscore the necessity for further research to optimize the stacking sequence and volume fraction of fibers in hybrid composites. In conclusion, the study demonstrates that the flexural strength of jute/E-glass/epoxy hybrid composites is significantly influenced by laminate configuration. The ANOVA analysis provides a robust statistical validation of these differences, guiding future material design and application strategies. The GJGJ configuration, in particular, shows promise for applications requiring high flexural strength, indicating the potential for hybrid composites in advanced engineering applications.

4. CONCLUSION

This study investigated the flexural strength of hybrid jute/E-glass/epoxy composite laminates, employing the ANOVA method to evaluate the impact of different laminate configurations on mechanical performance. The primary objective was to identify the most effective laminate combinations for optimizing flexural strength. The experimental results demonstrated significant variability in flexural strength among the tested configurations. The GJGJ configuration exhibited the highest average flexural strength at 71.20 MPa, while the GJG configuration showed the lowest at 26.33 MPa. These findings underscore the critical role of laminate arrangement in enhancing composite performance. The ANOVA analysis confirmed that laminate configuration significantly affects the flexural strength of hybrid composites, with an F-value of 6.41 and a p-value of 0.004, indicating a statistically significant influence. This statistical validation supports the hypothesis that strategic layer arrangement can maximize the mechanical properties of hybrid composites. The GJGJ configuration's superior performance suggests that alternating layers of jute and E-glass fibers can effectively distribute stress and improve load-bearing capacity. In contrast, configurations with less optimal layering sequences, such as GJG, demonstrated lower flexural strength, highlighting the importance of carefully designed laminate structures. These results align with existing literature that emphasizes the advantages of hybrid composites in achieving superior mechanical properties. The study's findings provide valuable insights for the development of high-performance, sustainable composite materials tailored for specific engineering applications. Future research should focus on further optimizing the stacking sequences and exploring the effects of varying the volume fractions of jute and E-glass fibers. Additionally, investigating other mechanical properties, such as tensile and impact strength, will provide a more comprehensive understanding of the potential applications for these hybrid composites

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