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Enhancing Strength and Sustainability of Hybrid Composites with E-Glass and Jute Fibres

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Abstract

A number of other materials, including natural composites with a combination of natural and synthetic fibres, are replacing them. Hybrid composites containing E-glass fibre have industrial importance due to their excellent strength-to-weight ratio, high modulus, low cost, partial biodegradability, and eco-friendliness. Natural fibres possess many advantages with regard to abundant availability, renewability, low cost, and eco-friendliness. Hybridization is normally adopted to retain the required strength properties without the disadvantage of high density and cost. The following research work is based on investigations regarding the content of natural fibre combined with E-glass fibre and epoxy on composite mechanical properties. Composite samples were fabricated using the hand lay-up technique with different weight proportions among epoxy, glass and jute fibre. The specimens after curing were moulded to ASTM standards and subjected to tensile, flexural, impact and hardness tests. The results were further validated through experiments. Whereas, for the properties of hybrid composites, an increase of approximately 65% in tensile strength, and 32% and 11% respectively for flexural and impact strengths over natural composites were determined.

Major Findings: *The study demonstrates the enhanced mechanical properties of hybrid composites made from E-glass and jute fibres, highlighting their potential for sustainable applications. Notably, the composites exhibited superior tensile strength and improved impact resistance compared to traditional materials, making them viable for use in eco-friendly engineering solutions.*

Keywords: Composite Characterization, E-Glass Fiber, Flexural Strength, Hand Lay-Up Technique, Hybrid Composite, Impact Strength, Jute Fiber, Natural Fiber Composite, Tensile Strength

1.0 Introduction

The demand for composite materials is increasing due to their superior properties, which support their indispensable role in various industries[1,2,3]. Composites are admired for their low density, ease of manufacturability, and the versatility of any number of combinations of matrix and reinforcement materials[4,5]. Their versatility allows composites to meet the specific requirements of diverse end uses. Consequently, composites are now widely applied in the manufacturing of sports equipment, automotive and railway components, and even in the construction of aircraft, rockets, and satellite structures[6,7,8].

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Among all types of composites, significant attention has been focused on hybrid composites, which contain two or more reinforcement materials[9]. By combining the best attributes of different materials, they perform exceptionally well across commercial, industrial, and scientific applications[10,11]. In composite manufacturing, the selection of matrix and reinforcement materials plays a crucial role since the performance and applicability of the final product depend on these choices[12,13]. Moreover, composites offer a longer service life and resistance to harsh environmental conditions with minimal environmental impact. Research and development efforts worldwide are actively focused on developing novel composites to compete with metals and alloys[14,15]. However, it should be noted that the unique properties of composites are often preserved only when they are used without cutting or mechanical processing. Environmental factors, such as temperature and moisture, can also reduce the service life of composites[16].

Additionally, certain applications, such as manufacturing railway wagon panels, aircraft bodies, and automotive components, require cutting, trimming, and drilling. In these cases, it is essential for the composites to maintain their properties with minimal defects, such as the absence of air voids or fiber debonding[17-19].

Although many studies have reported the effects of reinforcement on the properties of various fiber-reinforced epoxies[20], to the best of our knowledge, no systematic research has investigated the mechanical properties of natural fibers (like jute) and synthetic fibers (like E-glass) in different stacking sequences as reinforcement materials.

In this study, hybrid composite fibers were fabricated using the hand lay-up technique, incorporating natural fibers (jute) and synthetic fibers (E-glass) in different stacking sequences. Epoxy resin served as the binding agent for these composites. Three sets of composites were fabricated, with one set featuring chemically treated fibers while maintaining similar stacking sequences. The composites were subjected to mechanical testing to evaluate their impact, flexural, and tensile strengths. This research aims to enhance understanding of the mechanical properties of hybrid composites, especially those made from a combination of natural and synthetic fibers. The investigation highlights the potential of hybrid fiber composites reinforced with jute and E-glass as a promising choice for structural and automotive applications.

2.0 Experimental Details

2.1 Material Selection

The composite utilized in this research is a hybrid composite reinforced with jute, E-glass fiber, and epoxy resin. To enhance the mechanical properties of hybrid composites, careful consideration was given to the selection of weight proportions of the constituent materials (epoxy, E-glass, and jute fibres). The choice of weight proportions was based on several factors aimed at optimizing the balance between strength, flexibility, and cost-effectiveness.

Epoxy Resin: The epoxy resin was selected as the matrix material due to its excellent adhesive properties, high strength, and good thermal stability. It is widely used in composite fabrication for its superior bonding strength with fibre reinforcements. The resin content was optimized to ensure sufficient matrix-fibre interaction while maintaining the lightweight nature of the composite.

E-glass Fibres: E-glass fibres were incorporated due to their high tensile strength, durability, and relatively low cost. These fibres are known for their excellent mechanical properties, including strength and stiffness, which provide reinforcement to the composite structure. The weight proportion of E-glass was selected to improve the overall tensile strength and flexural performance of the composite.

Jute Fibres: Jute fibres were selected for their eco-friendliness, low cost, and biodegradable nature, making them an attractive alternative to synthetic fibres. The inclusion of jute fibres aims to enhance the sustainability of the composite material while also contributing to the overall mechanical properties. The weight proportion of jute was varied to study its impact on the hybrid composite's performance, particularly in terms of impact resistance and flexibility.

Jute, a natural fiber, was selected for its biodegradability and availability, while E-glass fiber was chosen for its superior mechanical properties. Epoxy resin (LY556) was employed as the matrix and binder, combined with a hardener (HY 951) in a 10:2 ratio. The

Table 1. Mechanical properties of the reinforcements and matrix element

Properties	Jute Fiber	E glass fiber	Epoxy LY556
Young's modulus in GPa	240	12	3.5
Tensile strength in MPa	3800	400	83
Ultimate elongation in %	1.6	3	4.2
Density in g/cm3	1.8	1.5	1.15
Weave type	Plain	Plain	-

jute fibers were collected from a nearby processing unit and dried under direct sunlight for three days to remove moisture. The dried fibers were then cut into mats measuring 250 mm in length and 150 mm in width. The selected weight proportions were designed to maintain a balance between the performance characteristics of the hybrid composites, ensuring that the final product was both mechanically robust and environmentally friendly. The variations in the proportions were chosen to explore the synergistic effects of E-glass and jute fibres on the overall composite properties. Additionally, different fibre ratios were tested to understand the optimum mix for achieving superior mechanical properties while retaining the natural advantages of both fibres. The mechanical properties of the reinforcement materials are presented in Table 1.

2.2 Chemical Treatment of Natural Fibers

Chemical treatment was done on the jute fibers to enhance the bondability between the natural and synthetic fibers. The jute fibers were treated to reduce hygroscopy, a characteristic of naturally occurring fibers, that, if not treated, may interfere with their bonding to the matrix material and affect the mechanical properties of the composite.

2.3 Stacking Sequence Selection

Three different stacking sequences are selected for hybrid composites:

1. Jute fibre in four layers.
2. Four-layer E-glass fiber.
3. Two layers of jute fiber and two layers of E-glass fiber.

Specific investigations of the mechanical properties of this hybrid composite due to the order of its stacking were carried out with these stacking sequences. Each set of composites was prepared in view of the above-mentioned stacking configurations, and the samples were fabricated for mechanical testing. Such variation in stacking sequence allows comparative research on how the arrangement of fibers affects the overall performance of a composite.

2.4 Fabrication of Composite Sheets

In this work, a few composite sheets were prepared by using a wooden die frame. The whole frame was fully greased in order to take the composite out easily after curing. The layers of fibers were carefully set inside the frame and separated by each layer with a coating of epoxy resin. Then, the epoxy resin in which the appropriate ratio of hardener had previously been added is poured quickly over each fiber layer and evenly spread with the use of a roller or brush in order for proper impregnation to occur. The process was repeated in this manner for the rest of the three layers, correctly assembled with an even amount of resin.

When all layers were set, the composite was covered by a wax-coated polyethylene sheet to avoid the resin sticking to the pressing plate. A flat wooden plate was laid on top to press the composite, applying even pressure across its surface to ensure that the resin was pushed through the layers uniformly.

The curing time was 72 hours, which allowed the resin to harden completely and bond the fibers together. After curing, the composite sheets were taken out of the die frame carefully and were prepared for moving on to do some mechanical tests to check their structural

properties. Figure 1. Fabrication process. Table 2. The nomenclature of fabricated sample.

Table 2. Nomenclature of fabricated sheet

Sample 1	Sample 2	Sample 3
EJEJEJEJE	EGEGEGEGE	EJEGEJEGE
Epoxy	Epoxy	Epoxy
Jute Fiber	E Glass fiber	Jute Fiber
Epoxy	Epoxy	Epoxy
Jute Fiber	E Glass fiber	E Glass fiber
Epoxy	Epoxy	Epoxy
Jute Fiber	E Glass fiber	Jute Fiber
Epoxy	Epoxy	Epoxy
Jute Fiber	E Glass fiber	E Glass fiber
Epoxy	Epoxy	Epoxy

The stacking sequences outlined in Table 2 were chosen to investigate the synergistic effects of natural and synthetic fibers. The "EJEJEJEJE" sequence ensures a uniform alternation of jute and E-glass fibers, which helps to balance tensile strength and flexibility.

The "EGEGEGEGE" sequence serves as a baseline to evaluate the performance of purely synthetic composites, characterized by superior tensile and flexural properties. The "EJEGEJEGE" hybrid sequence optimally combines two natural and two synthetic layers to study their interaction and bonding under mechanical stress.

The step-by-step process shown in Figure 1 highlights critical aspects of the hand lay-up method, such as uniform resin application and the importance of pressure distribution. These factors directly influence fiber-resin bonding and minimize void formation, as validated in earlier studies[21].

2.5 Mechanical Property Testing

Various mechanical properties of the fabricated composites were examined, which included tensile, flexural, and impact strength. In order to investigate different stacking sequences and the influence of the chemical treatment on the mechanical properties of hybrid composites, these tests were conducted. Comparison and correlation between the results obtained will feature the development of an optimal configuration. The tensile properties were measured according to the ASTM D638 test method that included the preparation of dog bone-shaped specimens shown in Figure 2. The dog-bone-shaped specimens,

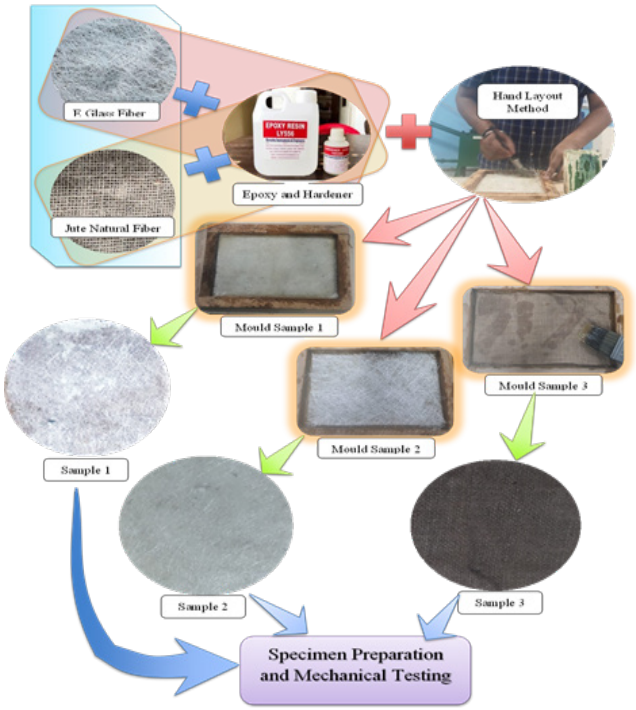


Figure 1. Fabrication process of hybrid fiber composites.

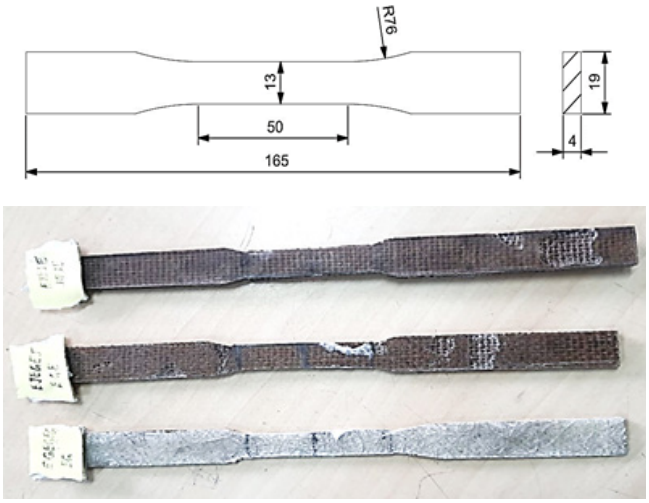


Figure 2. Tensile test specimens as per ASTM D638.

prepared per ASTM D638 standards, are designed to focus stress on the central region, ensuring failure occurs away from the grips. This standardized geometry enables consistent comparisons across different materials. Tests are performed on a Universal Testing Machine where the specimens undergo increased tensile load till failure in a gradual manner. From the obtained data, tensile strength and Young's modulus for specimens were calculated.

3.0 Results and Discussion

The mechanical properties of the composites were analyzed according to the stacking sequence and the chemical treatment effects. The analysis presented results on the quality improvement of the composite and the application possibility of the developed materials.

Standard tests were conducted to ascertain the mechanical properties of the hybrid composites with respect to their suitability for various design applications. Such tests were essential in the determination of the fundamental qualities of the composites, which include the tensile and flexural characteristics, impact, and hardness. For this purpose, the cutting of the specimens was necessary for each test from the composite materials with a water jet machine to accurate dimensions according to ASTM.

3.1 Tensile Test

Tensile properties were measured using the ASTM D638 test method, and dog-bone-shaped specimens were prepared shown in Figure 2. Each specimen was subjected to a gradually increased tensile load in the Universal Testing Machine until the failure of the test. The variation of tensile strength and Young's modulus was determined based on the data.

Table 3. Tensile test results

Configuration	Tensile strength (MPa)	Young Modulus (MPa)
EJEJEJEJE	66.2	9.9
EGEGEGEGE	87.5	12.6
EJEGEJEGE	109.2	14.3

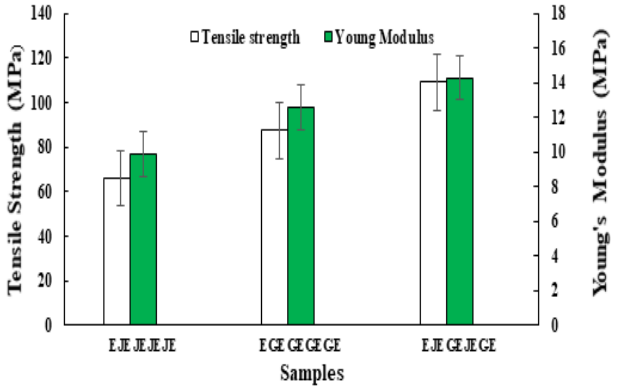


Figure 3. Tensile strength and Young's modulus of the composites.

The tensile strength values (66.2 MPa for EJEJEJEJE and 109.2 MPa for EJEGEJEGE) demonstrate the hybrid sequence's ability to leverage the high tensile strength of E-glass while compensating for the brittleness with jute's flexibility. Young's modulus trends further validate the improved stiffness of hybrid composites, with the EGEGEGEGE configuration showing intermediate values.

In an attempt to represent such dependence, the subsequent graph was plotted: dependence of tensile strength and Young's modulus on types of specimens (Figure 3). The graph highlights the incremental benefits of hybrid stacking. The peak values for EJEGEJEGE underline its optimized fiber-resin interaction and load transfer efficiency. The tensile test shown in Figure 4 evaluates the mechanical properties of composite materials fabricated in different stacking sequences. The test was conducted using a Universal Testing Machine (UTM), as per the ASTM D638 standard, which ensures uniform and comparable results.

Figure 4b shows the tensile strength (MPa) of each composite is represented by the blue bars in the graph.

- The EJEJEJEJE composite demonstrates the lowest tensile strength at 66.2 MPa, likely due to the lower inherent strength of jute fibers compared to E-glass.
- The EGEGEGEGE composite exhibits higher tensile strength at 87.5 MPa, which is attributed to the superior mechanical properties of synthetic E-glass fibers.
- The hybrid EJEGEJEGE composite achieves the highest tensile strength at 109.2 MPa, illustrating

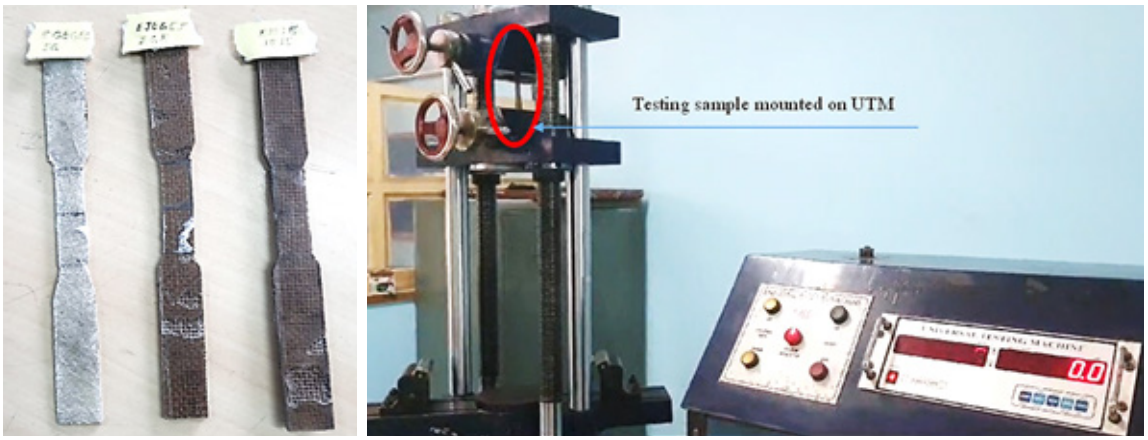


Figure 4(a). Tensile Test specimens as per ASTM D638 Standard and testing equipment.

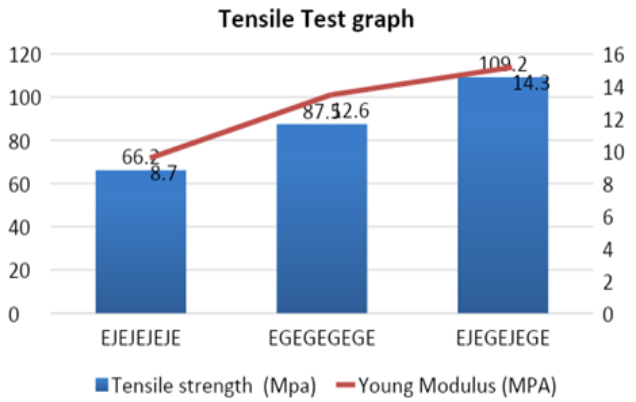


Figure 4(b). Test Results for Tensile Composites.

the optimized load transfer and synergy between natural and synthetic fibers.

The Young's modulus (GPa) is represented by the red line in the graph:

- The EJEJEJEJE composite has the lowest modulus at 8.7 GPa, indicating greater flexibility, which can be attributed to the ductility of jute fibers.
- The EGEGEGEGE composite shows an intermediate modulus of 12.6 GPa, reflecting the stiffness of synthetic E-glass layers.
- The hybrid EJEGEJEGE composite reaches the highest modulus at 14.3 GPa, showing a balance between stiffness and flexibility due to its hybrid structure.

From Figure 4b the material performance can be observed as:

- EJEJEJEJE (Natural Fiber Dominant): The low tensile strength and modulus indicate that while this stacking sequence might not be ideal for high-stress applications, its flexibility and eco-friendliness make it suitable for non-critical applications.
- EGEGEGEGE (Synthetic Fiber Dominant): The purely synthetic stacking demonstrates significant strength and stiffness, making it ideal for structural applications where durability and mechanical performance are critical.
- EJEGEJEGE (Hybrid Configuration): The hybrid configuration outperforms the other two in both tensile strength and stiffness. This shows the complementary nature of natural and synthetic fibers, where the stiffness of E-glass is offset by the flexibility and energy absorption properties of jute, creating a superior composite material.

The hybrid configuration (EJEGEJEGE) is the most promising, achieving an optimal balance between eco-friendliness, mechanical performance, and cost. The natural fiber composite (EJEJEJEJE) is suitable for applications requiring flexibility and lower mechanical loads. The synthetic fiber composite (EGEGEGEGE) demonstrates the highest individual strength, suitable for high-performance applications.

3.2 Flexural Test

The flexural strength of the composites was determined using a three-point bending test in accordance with ASTM D790 specifications shown in Figure 5a. Tests were performed at ambient temperature with one millimeter per minute feed rate. The same bar-type specimens were

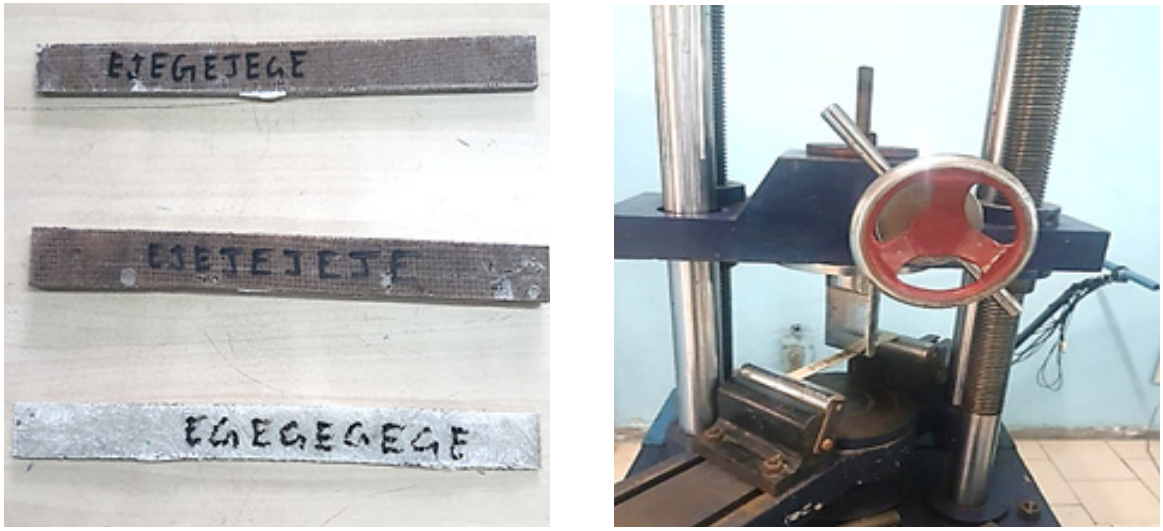


Figure 5(a). Flexural test as per ASTM D790 standard and testing setup.

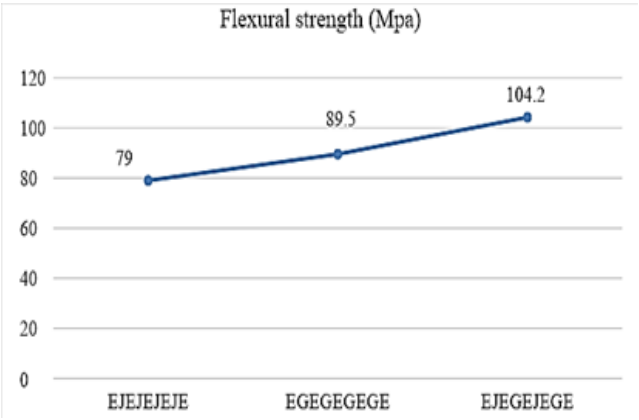


Figure 6(b). Flexural test as per ASTM D790 standard.

used with nominal dimensions of 127 × 16.5 × 2 mm and span length of 64 mm. The flexural strength was calculated by means of the following expressions:

$\sigma = (3FL) / (2bt^2)$

where, F = maximum load; L = span length; b = width; and t = thickness of specimen.

The graph depicting the flexural strength of the specimens is plotted as shown in Figure 5b. The flexural strength graph reveals that hybrid stacking (EJEGEJEGE) performs 16 % better than EGEGEGEGE, showing its potential for applications requiring high bending resistance. The failure modes observed during testing indicate better crack propagation resistance in hybrid composites due to jute fiber's energy absorption characteristics.

Table 4. Flexural test results

Configuration	Flexural Strength (MPa)	Flexural Modulus (GPa)
EJEJEJEJE	79	4.5
EGEGEGEGE	89.5	5.2
EJEGEJEGE	104.2	5.6

Table 4 shows the flexural strength and modulus values indicating that hybrid composites made from E-glass and jute fibres exhibit improved bending resistance compared to pure jute fibre composites. The combination of both fibres results in a higher modulus, indicating increased stiffness.

3.3 Impact Test

The Izod impact properties for determining the impact toughness of composites were performed according to ASTM A370. Toughness can be represented by the energy absorption during specimen fracture. V-notch specimens 5 mm inside, 2 mm in deep, and notch radius of 45° were used for testing with an impact hammer of 25 kg shown in Figure 6.



Figure 6. Impact Test **(a)** Impact testing Machine. **(b)** Sample after testing.

Table 5. Impact test results

Configuration	Impact Strength (KJ/m)
EJEJEJEJE	1.5
EGEGEGEGE	2
EJEGEJEGE	1.5

The impact strength shown in Table 5 shows that the hybrid composites, particularly those with both E-glass and jute fibres, have superior resistance to sudden forces. The increased impact resistance in the EJEGEJEGE configuration suggests a synergistic effect between the two fibre types. The energy absorbed during fracture is highest in EGEGEGEGE, attributable to E-glass fiber's inherent toughness. However, the hybrid configuration (EJEGEJEGE) shows only a marginal reduction in impact resistance, balancing toughness with eco-friendliness.

3.4 Hardness Test

The hardness of the composite specimens was measured by the Rockwell Hardness Tester. In this test, a harder material is pressed into the composite surface in order to assess the resistance of composites against permanent deformation. This test is highly useful in material selection, quality control, and comparison for a wide range of industries. Hardness test results were plotted to diagrammatically present the hardness values for the tested specimens shown in Table 6.

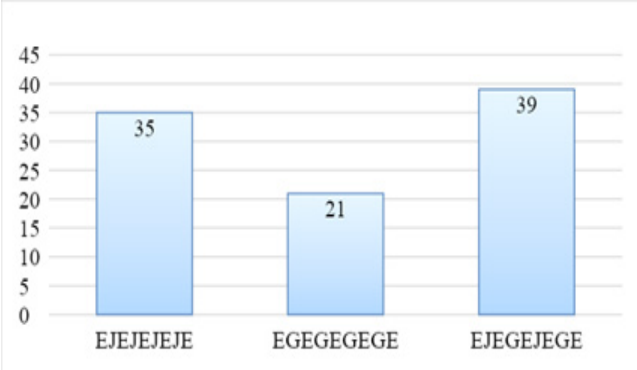


Figure 7. Hardness test.

Figure 7 shows the hybrid composite's hardness value in HRB, significantly higher than both jute and E-glass composites, demonstrating its suitability for surface wear resistance. This enhancement results from the interlocking mechanism between natural and synthetic fibres during fabrication.

4.0 Conclusion

The hybrid composite materials were developed and tested successfully with a hand layup process, manufactured from both natural fibers of jute and synthetic fibers in different sequences. It is unique because it concerns the synergistic action of combining such fibers with

epoxy resin LY556 and hardener HY 951 for developing a composite material that possesses far superior mechanical characteristics than their non-composite counterparts.

The tensile strength of the hybrid composite was 65 % higher compared to the pure jute fiber composite and 25 % improved than the pure E-glass fiber composite. Such large improvement in tensile strength by hybridization justifies the utility of the hybrid approach for applications requiring high tensile performance.

The flexural strength of the resultant hybrid composite was higher than that of the non-composite materials. It developed 32 % more flexural strength than the jute fiber composite and 16 % more than E-glass fiber. The ability to achieve such performance in flexure with the right combination of fibers points out the potential for this material in applications requiring strength and flexibility.

The toughness of the hybrid composite, in terms of impact resistance, was considerably improved. It provided an impact strength 33 % higher than that of the jute fiber composite. Although slightly lower than the E-glass fiber composite, the impact performance of this hybrid assures its suitability for applications requiring resilience against sudden forces.

The hardness of the hybrid composite was also noticeably enhanced, with a value about 11 % higher than that of the jute fiber composite and about 86 % higher compared with the E-glass fiber composite. Improved hardness means that this hybrid composite may possess better durability and resistance against wear in practical applications, where a tough surface is needed.

The overall properties of the hybrid composite system studied here provide a unique combination of tensile strength, flexural performance, resistance to impact, and hardness. These results broaden the possibility of application for such a composite in general engineering applications, particularly in those fields where the hybridization of natural and synthetic fibers leads to positive hybrid effects. While the study demonstrates the enhanced mechanical properties of hybrid composites reinforced with E-glass and jute fibres, certain limitations need to be acknowledged. One of the primary challenges lies in scaling up the fabrication process, particularly with regard to achieving uniform fibre distribution and optimal bonding in larger production settings. Additionally, environmental factors, such as temperature and humidity, may influence the composite's performance, necessitating further investigation into their impact. Environmental factors, such as humidity and temperature, can significantly influence the performance of hybrid composites. Humidity may lead to the absorption of moisture by the natural fibres, potentially affecting the bonding between the matrix and the fibres, which could reduce the mechanical properties like tensile and flexural strength. Temperature variations, on the other hand, can alter the matrix's curing process and affect the overall stability of the composite material. Therefore, future studies should explore the impact of these environmental factors to assess the composites' performance in real-world applications and optimize their durability under varying conditions.

Future research could focus on optimizing fibre proportions to achieve an ideal balance between mechanical strength and cost-effectiveness. Exploring other natural fibre combinations, such as kenaf or hemp, in hybrid composites could also provide valuable insights into enhancing the sustainability and mechanical properties of these materials. Additionally, investigating the environmental impact of these composites, including their biodegradability and recyclability, would further strengthen their potential for widespread industrial applications. This work contributes to an improved understanding of the design and development of advanced composite materials and their use in industries needing innovative materials with value-added performances.

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