# Experimental Study on the Mechanical Properties of Woven Jute Fiber/Human Hair Reinforced Hybrid Composite

**Md Shahriar Ali, Masuka Mahnur Oishy, Md Shariful Islam and Md Arifuzzaman**
Department of Mechanical Engineering
Khulna University of Engineering and Technology (KUET)
Khulna, Bangladesh
mdshahriarali1705106@gmail.com, masukamahnuroishy@gmail.com,
msislam@me.kuet.ac.bd, arif48@me.kuet.ac.bd

## Abstract

Research in composite materials is done in search of alternatives to existing materials. Composite materials provide plausible inexpensive, affordable, environment-friendly, and appropriately sustainable replacements for existing materials. In this paper, the mechanical properties of jute fiber composite and jute fiber-human hair reinforced hybrid composites are compared for a better understanding of the effects of human hair as reinforcements for natural fiber composites. The objective of this study is to test the appropriateness and limits of human hair as a reinforcement material when it comes to further reinforcing natural fiber composites. Towards that, woven jute fiber composite and woven jute fiber-human hair reinforced hybrid composite were manufactured using a hand lay-up process and then compared for their mechanical properties. Tensile, flexural, and impact tests are conducted on the fabricated composite to investigate their mechanical properties. The introduction of human hair in hybrid composites results in variations in tensile and flexural strengths compared to jute-only fiber composites. The tensile and bending toughness of the hybrid composite were 76% and 209% higher than the jute composite, respectively. The composite with human hair exhibits enhanced impact energy absorption and elongation at break, making them a promising alternative for scenarios demanding impact resistance and deformation accommodation. The hybrid composite has an energy absorption of 12.14 J, which is 15% higher than the jute composite's 10.59 J. This study explored the potential of human hair as a low-cost and widely available material to reinforce natural fiber-reinforced composites. Further studies are needed to bolster this analysis.

## Keywords
Human Hair, Fiber Reinforced Hybrid Polymer Composite, Woven Characteristics, Mechanical Properties and Composite Materials.

## 1. Introduction
Natural fibers with good mechanical properties, such as jute, bananas, hemp, etc., have biodegradability, and non-toxicity qualities, while also offering more strength at a cheaper cost and a lighter weight. These elements considerably increase cost reductions (Manik et al. 2019). Natural fibers are also widely accessible in nature, which is a significant advantage. Composites are materials that offers enhanced properties compared to its constituent parts. The concept spans several centuries. Natural composites' use can be traced back to ancient civilizations, such as "papyrus-reinforced clay" in ancient Egypt, which was used to make boats and various objects. The 20th century's Industrial Revolution noted a significant turning point in composite development as engineers and scientists began experimenting with reinforcing composites with natural fibers.

Numerous researchers have looked at cutting-edge methods of composite material synthesis and production. Researchers looked at using 3D printing to create polymer matrix composites with improved mechanical characteristics (Park et al. 2022). Similar to this, another study on electro spun carbon nanofibers and their reinforced composites was done (Yang et al. 2023) . A review was done on the estimated application of carbon nanotubes as reinforcing composite materials (Garg et al. 2021). The mechanical characteristics of composite materials are strongly influenced by the choice of reinforcing materials, a conclusion reached by studying the mechanical behavior of jute fiber-reinforced polymer composites while focusing on the impact of fiber orientation on strength and stiffness

(Gopinath et al. 2014). The use of natural fibers like jute and hemp as sustainable options for composite reinforcement was also looked at (Sanivada et al. 2020).

Research has focused on ways to improve the relationship between the materials used for reinforcing and the matrix. In order to increase the mechanical as well as thermal characteristics of natural jute fiber composite, the impact of adding nanoparticles to polymer matrices was investigated (Ejaz et al. 2022). Another study analyzed the mechanical properties of the inclusion of Human hair with natural fiber for the unidirectional arrangements of the fibers. It demonstrated the addition of human hair offered a unique synergy of properties that can be suitable for various applications where strength, flexibility, and impact resistance are crucial (Oishy et al. 2023). Methods for interface engineering to reduce delamination and enhance durability in fiber-reinforced composites were researched (Zhu et al. 2021). Incorporating nano-additives into jute composites to improve their mechanical performance was the main goal of another work (Rehman et al.2019). The study examined the impacts of adding nanoparticles in the jute-polymer matrix system and found that both tensile strength and impact resistance had significantly improved. According to the study, jute fibers and nanoparticles worked together synergistically to improve the weight transmission mechanisms in the composite. The study also emphasized how useful these hybrid composites may be for lightweight structural applications.

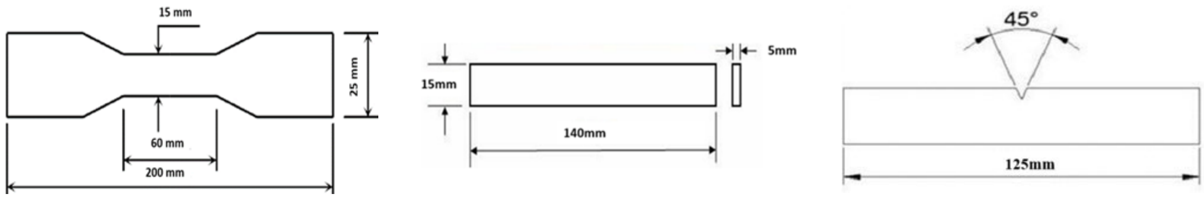
The application of hair fiber composites in sustainable packaging materials was investigated (Abdul Khalil et al., 2016). To develop ecologically friendly packaging solutions, the study investigated the viability of employing hair fibers as reinforcement in biodegradable polymer matrices. According to the results, hair fiber composites had the right mechanical characteristics for packing applications and had the extra advantage of reducing waste because they were made from discarded hair. The study focused on the potential of hair composites to address problems with material performance and sustainability. In another study nano-coatings were used to increase the fire resistance of hair fiber composites (Carlier et al., 2001). The work concentrated on coating hair fibers with fire-retardant nanoparticles before putting them into polymer matrices. According to the results, the composites of nano-coated hair fibers showed improved flame retardancy without sacrificing their mechanical qualities. This study demonstrated how hair fiber composites might be customized for certain uses, such as fire-resistant materials for the building and automobile sectors.

## 2. Methods

### 2.1 Materials
Woven fabric of jute and human hair were used as reinforcement in this study. Jute fabric was purchased from the local manufacturer with a yarn count of 20 per inch along the weft direction and 18 per inch along the warp direction with an aerial density of 200 gsm. Human hair was collected from the wig manufacturer. Epoxy resin LY 556 with HY 951 hardener was used as a matrix.

### 2.2 Composite Fabrication
A hand lay-up process was used to fabricate both composites which is an easy and low-cost process for fabricating composite (Chakrabarti et al., 2020), (Asif et al. 2020). Two steel plates of 18 inches by 20 inches were used as mold plates. Mold release was used on the surface of the mold plates which aided in the composite removal after curing. Epoxy resin and hardener were mixed with a 10:1 ratio by mass as recommended by the manufacturer. The first layer of the jute was placed on top of a mold plate and then the resin-hardener mixture was applied with a brush. Then the layer was rolled using a roller which helps to distribute the resin-hardener mixture throughout the fabric layer uniformly and removes any air bubbles formed during the mixing. The successive layers of jute were placed on top of each other and the procedure was repeated. Finally, the fabricated specimens were cured at room temperature for 24 hours.

For the jute-human hair composite, after the first layer of jute composite, a layer of unidirectional human hair was placed. Then resin was applied evenly over the whole human hair layer. On the very top, after laying the human hair layer, a second bidirectional jute fiber layer was placed. Basically, one human hair layer was sandwiched between two jute layers. Other than placing one human hair layer in between, other procedures were the same as the jute-only composite fabrication process.




(a) (b) (c)

Figure 1. Test specimens with dimension, (a) tensile test, (b) flexural test, and (c) impact test

## 3. Mechanical Testing

Tension, bending, and Charpy impact tests were performed on the fabricated composites. Universal Testing Machine (UTM) (Shimadzu AGXV-300kN) was used for the tensile test and the specimens were cut following the ASTM D3039 standard (International, 2007b) The specimen dimensions are shown in Figure 1(a) and the test setup in the UTM is shown in Figure 2(a). The stress-strain responses were recorded during the testing and using this response the tensile strength, modulus of elasticity, and tensile toughness were calculated. The tensile strength is the maximum stress of the stress-strain diagram. Tensile toughness is measured by determining the area under the stress-strain curve.

Three-point bending (flexural) tests were also performed using the same UTM (refer to figure 2(b)) and in this case, the load-displacement response was recorded. The specimens were prepared according to ASTM D790 (International, 2007a) as shown in Figure 1(b). The stress and strain were calculated using the load-displacement response. The stress during the bending test can be expressed as

$$\sigma_f = \frac{3PL}{2bd^2} \qquad (1)$$

Where $\sigma_f$ is the flexural stress, *P* is the load, *b* is the specimen width, and *d* is the specimen thickness.

(a) (b) (c)

Figure 2. Test set up (a) tension test, (b) flexural test, and (c) impact test

For the Charpy impact test, the specimens were prepared following the ASTM D6110 standard. The specimens were notched in accordance with ASTM D6110 standards to create a stress concentration point for fracture initiation (International, 2018). The specimen dimensions are shown in Figure 1(c) and the test setup is shown in Figure 2(c) and the following equation was used to calculate the impact strength per unit area

$$E_{abs} = mg(H_1 - H_2) \qquad (2)$$

Where the energy absorbed is denoted by $E_{abs}$, *m* is the mass, *g* is the acceleration due to gravity, the initial height is $H_1$ and the final height is $H_2$.

## 4. Results and Discussions

### 4.1 Tensile Properties

Three samples of each specimen were subjected to tensile testing using the UTM machine for both hybrid and jute composites. Figure 3(a) shows the stress-strain diagrams for pure jute and hybrid composite. From this figure, it is observed that the maximum stress for pure jute fiber reinforced composite is much higher than that of hybrid composite. However, the elongation at break for hybrid composite is higher than pure jute fiber reinforced composites. The average tensile strength of pure jute fiber composite was 26.25 MPa as shown in Figure 3(b) while the average tensile strength of hybrid composite was 17.13 MPa which indicates a 34.74% reduction in tensile strength due to hybridization. On the other hand, the elongation at break for pure jute fiber composite is 0.8% while for hybrid composite it is 2.0% i.e., a 150% increase in the elongation at break was observed for hybrid composite. Although the modulus of elasticity of the hybrid composite was 16.28 MPa while the jute composite was 39.02 Mpa as indicated in Figure 3(c), the tensile toughness in Figure 3(d) showed a significant increase from 13.86 J/m3 in the jute composite to 24.49 J/m3 in the hybrid composite. The hybrid composite, incorporating flexible human hair and jute fibers, exhibits a higher elongation at the break due to the hair's ability to elongate significantly before failure. In contrast, reinforced with stiffer fibers, the jute composite showcases higher tensile strength and localized stress concentrations. The hybrid composite's higher strain capacity makes it suitable for impact-resistant applications, whereas the jute composite's higher tensile strength makes it suitable for load-bearing scenarios.

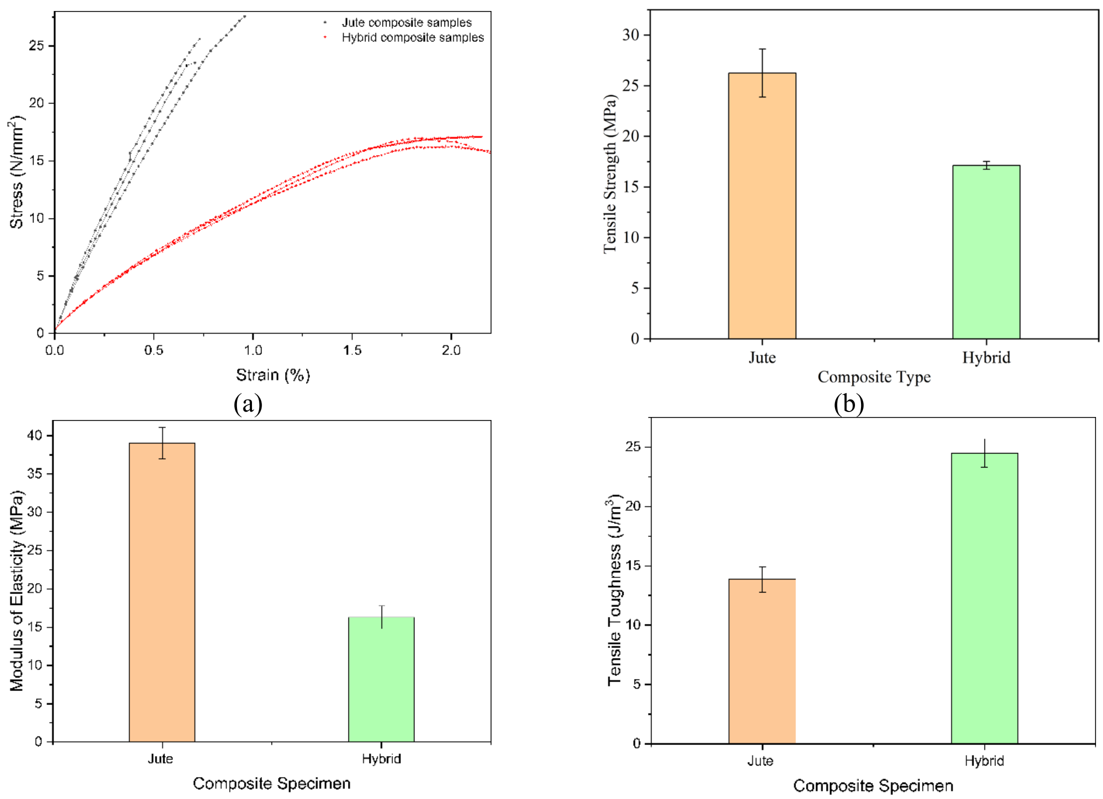



Figure 3. (a) Stress-strain diagram for pure jute and hybrid composite, (b) Tensile Strength, (c) Modulus of Elasticity, and (d) Toughness

### 4.2 Flexural Properties

The Flexural tests evaluate the ability of composites to withstand bending loads. The load-displacement diagram for pure jute and hybrid composites is shown in Figure 4(a). It is observed from this figure that the displacement before the rapture of the hybrid composite was greater than that of the jute composite. The maximum load for pure jute fiber reinforced composite is much higher than that of hybrid composite which is reflected in their flexural strength as shown in Figure 4(b). The average flexural strength of the jute fiber was 107.64 MPa and the average flexural strength of the hybrid composite was 52.67 MPa. The bending toughness of the hybrid composite made of human hair and woven jute fiber was significantly higher compared to the jute composite. According to Figure 4(d), the average bending toughness of the hybrid composite was 112.13 J/m$^3$, while the jute composite had an average bending toughness of 36.25 J/m$^3$.

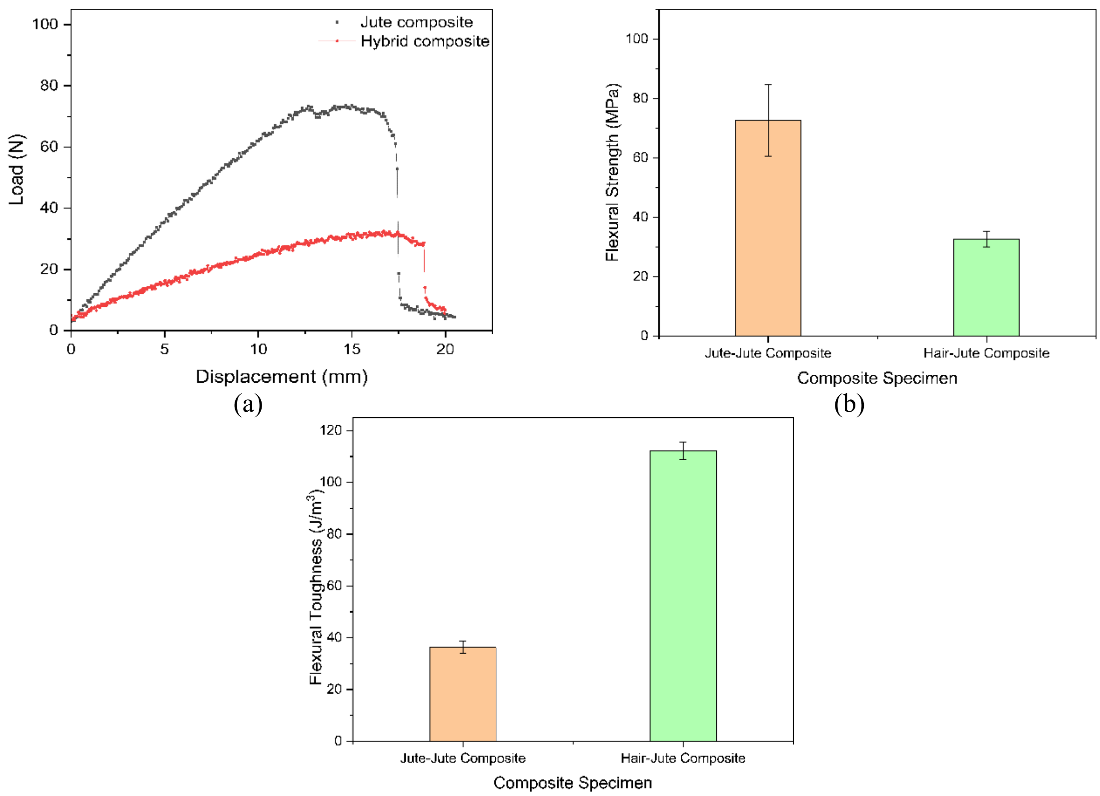



Figure 4. (a) Load-displacement response for pure jute and hybrid composite, (b) Flexural Strength, and (c) Bending Toughness

## 4.3 Impact Energy Absorption

The Charpy impact test was conducted to determine the impact strength of both types of composites. Figure 5 shows the average energy absorbed during the fracture of the composite specimens. Three specimens were tested for each type of composite. It is observed from Figure 5 that the average impact energy for hybrid composite is higher than that of pure jute fiber composite. The average impact energy for jute fiber reinforced composite was 10.59 J while it is 12.14 J for hybrid composite, indicating a 14.64% increase in the impact strength of the hybrid composite. So, it was found that the incorporation of human hair into jute fiber reinforced composite improved the impact performance of the composite.

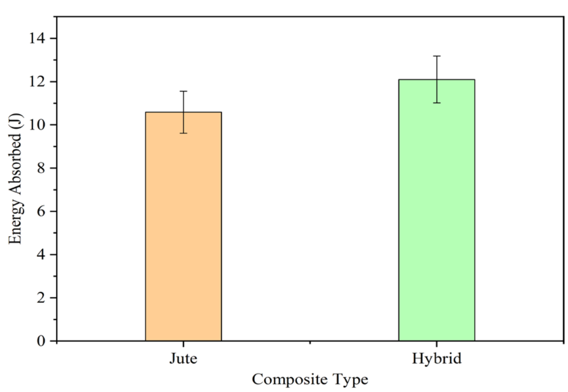



Figure 5. Energy absorbed in Charpy impact test

The combination of human hair's flexibility and the robustness of jute fibers results in improved energy absorption, as human hair can dissipate energy more effectively upon impact. Furthermore, because of the hybrid composite's greater elongation ability, which indicates improved toughness, it can deform significantly before fracturing, absorbing more energy during impact. This improved performance could be attributed to a synergistic interaction between the two materials, in which the flexibility of human hair reduces stress concentrations within the composite, thereby increasing its overall impact resistance.

### 4.4 Comparison of Mechanical Properties

A thorough comparison of the mechanical properties of the bidirectional hybrid composite and the bidirectional jute composite has been conducted and presented in Table 1. From the table, it is noteworthy that the tensile toughness and bending toughness of the hybrid composite are significantly higher, about 76.69% and 209.32% respectively, than those of the jute composite. However, the hybrid composite exhibits lower tensile and flexural strengths, with reductions of 34.74% and 55.02%, respectively, compared to the jute composite. Nonetheless, the hybrid composite outshines the jute composite in terms of impact resistance, displaying an almost 15% increase in impact energy. Due to the flexibility of human hair, the hybrid composite boasts a higher strain capacity, which is 150% greater than that of the jute composite. Additionally, its stress-strain behavior highlights its energy-absorbing plastic deformation, making it a reliable option for impact resistance.

Table 1. Comparison of mechanical properties

| Test Parameter | Jute Composite | Jute-Human hair hybrid composite | Percent Change |
|---|---|---|---|
| Tensile strength (MPa) | 26.25 | 17.13 | -34.74 |
| Toughness ($J/m^3$) | 13.86 | 24.49 | 76.69 |
| Strain (%) | 0.80 | 2.00 | 150.00 |
| Modulus of Elasticity (MPa) | 39.02 | 16.28 | -58.27 |
| Flexural strength (MPa) | 72.64 | 32.67 | -55.02 |
| Bending Toughness ($J/m^3$) | 36.25 | 112.13 | 209.32 |
| Energy absorbed in impact test (J) | 10.59 | 12.14 | 14.64 |

## 5. Conclusion

The key findings of this investigation can be summarized as follows:

(1) The tensile toughness of the hybrid composite is 76.69% higher than that of the jute fiber composite.
(2) The elongation at break of the hybrid composite is increased by 150% compared to pure jute fiber reinforced composite while the tensile strength and modulus of elasticity is decreased by 34.74% and 58.27%, respectively.
(3) The bending toughness of the hybrid composite has increased by 209.32% compared to that of the pure jute fiber composite.
(4) The flexural strength of the hybrid composite is reduced by 55.02% compared to the pure jute composite.
(5) The impact strength of the hybrid composite is increased by 14.64% than that of the jute fiber composite.

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## Biographies

**Md Shahriar Ali** received his Bachelor of Science degree in Mechanical Engineering at Khulna University of Engineering and Technology in 2023. His research interests include Composite Materials, Additive Manufacturing, Fiber Reinforced Composites, Polymer Matrix, and Mechanical Properties. He has hands-on experience working on various projects in the fields of Soid Mechanics, Material Science, and Robotics, and using different machines and testing methods.

**Masuka Mahnur Oishy** is a graduate from Khulna University of Engineering and Technology. She completed her BSc studies in the Mechanical Engineering field. Her research in the composite field is driven by the need to find better alternatives to existing materials.

**Dr. Md. Shariful Islam**, a professor at the Department of Mechanical Engineering at Khulna University of Engineering & Technology, holds a Ph.D. and M.Sc. in Mechanical Engineering from The University of Texas at El Paso, USA, and a B.Sc. in Mechanical Engineering from Khulna University of Engineering & Technology, Bangladesh. Dr. Islam's research focuses on Textile Composites, Natural Fiber Composites, and Multi-scale Material Modeling. His works in these areas have led to significant advancements in the field, particularly in the development of sustainable and high-performance composites. Dr. Islam's expertise in the design and evaluation of advanced materials has made him a valuable contributor to the field of Mechanical Engineering.

**Dr. Md. Arifuzzaman**, a professor at the Department of Mechanical Engineering at Khulna University of Engineering & Technology, has dedicated over a decade to researching and developing composite materials for the construction and building industries. His core area of expertise lies in the manufacturing and characterization of these materials. With a focus on developing innovative composites, he has also developed predictive models and identified failure mechanisms to improve the overall performance of these materials. His research has resulted in 20 published papers and several conference presentations, earning him numerous accolades for his contributions to the field. Dr. Arifuzzaman is committed to becoming a leading figure in the field of Construction Materials Engineering.