Influence of Fiber Orientation on the Tensile and Flexural Properties of Jute Fiber Reinforced Polymer Composites

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Abstract

The incorporation of natural fibers in replacement of synthetic fiber is one of the ongoing concerns for the environmentalists. Sheets or panels made of natural fiber reinforced composites cover a wide range of applications including roof tiles, automobile body structures, marine and aerospace structure etc. The strength of the sheets may vary with the orientation of fiber with respect to loading direction. In this research, jute fiber reinforced sheets were fabricated maintaining three different orientations using epoxy and characterization was done for tension and flexural properties. Results of the investigation showed that the sheets prepared with 0°-0°-0° orientation showed the highest tensile strength and tensile modulus but this orientation showed a lowest failure strain. The range of tensile strength and tensile modulus were 26.21 - 30.54 MPa and 35.21 - 36.60 MPa respectively. In the case of flexure properties, the maximum flexural strength and modulus were found to be 64.29 MPa and 42.64 MPa respectively for the sample oriented as 0°-90°-0°. However, the deflection at failure is the maximum for 0°-0°-0° orientation. Failure investigation showed that the composite failure is brittle in nature irrespective of the fiber orientation.

Keywords
Jute Fiber, Composite, Tensile Strength, Flexural Strength, Fiber Orientation.

1. Introduction
The implementation of natural fibers as an eco-friendly substance is growing rapidly. Researchers are introducing jute, kevlar, wood, coir fibers in order to reduce weight of structures and to improve strength. Considering the availability and the cost-effective phenomena the jute fibers are mostly used. Raghavendra et. al [1] reported that jute fiber reinforcement into epoxy exhibits better properties than the resin alone. Kumar et. al [2] found that JFRP sheets are very much suitable for partition wall boards, door frames, roof tiles and so on. Hossain et. al [3] introduced four layers of jute with varying orientations and suggested that the tensile strength of the sheet is mainly dependent on the strength and quality of jute fiber. Kumaresan et. al [4] experimented the mechanical properties of sisal fiber under three different orientations. Ramesh et. al also [5] concluded that fiber content and fiber orientation might play a great role in improving strength from the research outcome of sisal-jute-glass fiber reinforced polyester composites. Dalbehera et. al [6] checked the stacking sequences of glass-jute epoxy composites to investigate the tensile and shear properties. Maharana et. al [7] incorporated four different orientations of Kevlar and jute to investigate the mechanical properties. The best results for tensile and flexural strength were observed in 30° and 45° orientation respectively according to their [7] research.

1.1 Objectives
In this research jute fiber mat made of yarn is used to fabricate JFRP sheets using epoxy resin under three different orientations (0°-0°-0°, 0°-90°-0° and 0°-45°-0). The objectives of this work are to investigate the effect of fiber/yarn orientation of jute mat on the tensile and flexural properties of jute fiber reinforced epoxy composite and to understand the failure behavior under tension and bending load.

2. Materials and Methodology

2.1 Materials

- Jute Fiber Mat

Jute fiber mat was bought from Sonali Jute Mills Ltd., Mirerdanga I/A, Daulatpur, Khulna- 9206, Bangladesh. The mats were cut maintaining a size of 300 mm × 300 mm for the reinforcement purpose. A total of 18 mats were cut to prepare six sheets having three different orientations (0°-0°-0°, 0°-90°-0° and 0°-45°-0°) where each sheet contained three layers of mat. The measured GSM of the fiber mat was 320-321 g/m^2.

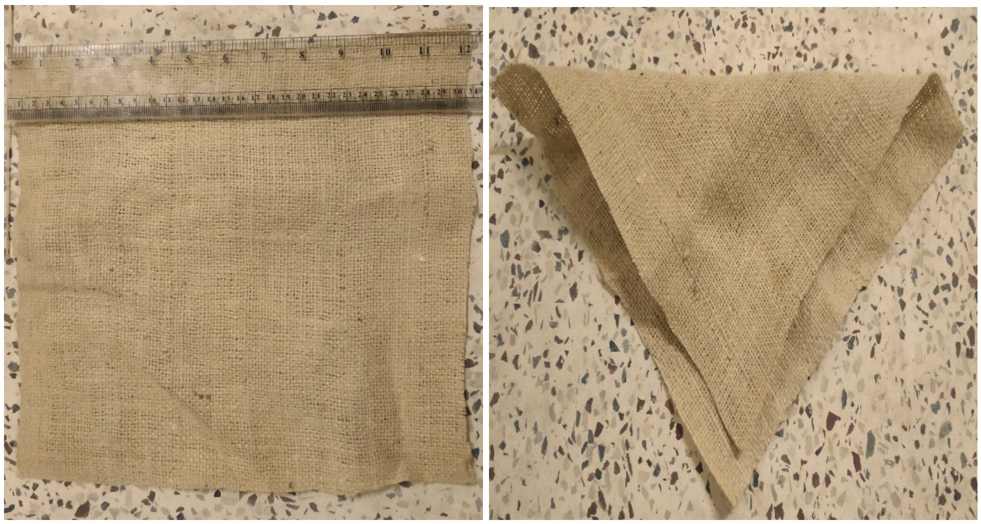


Figure 1. Jute Fiber Mat

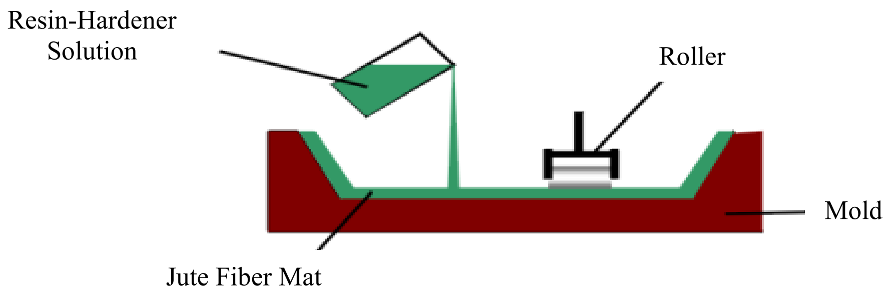
- Solution (Epoxy Resin, Hardener)

Epoxy resin (LY 556) and hardener (HY 951) was purchased from Joypara Chemical, Old Mogaltoli, Dhaka. A resin to hardener ratio of 10:1 was used for composite fabrication.

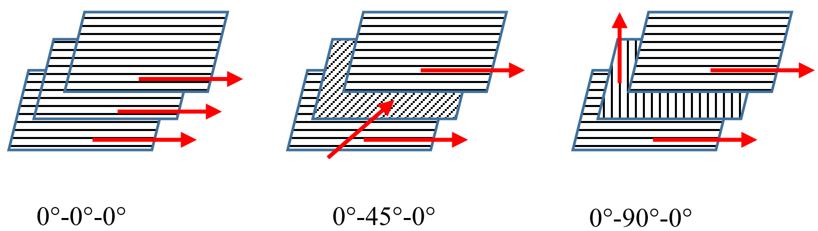
2.2 Methodology

- Sample Preparation

To manufacture jute fiber reinforced polymer (JFRP) composite sheets the hand lay-up method was used. Firstly, the resin and hardener were mixed thoroughly to prepare the solution maintaining 10:1 ratio by weight. The mold surface was then covered with a thin polyethylene. A square mark of size 300 mm × 300 mm was drawn on to the polythene surface for the proper positioning of the mat using a permanent marker. A layer of epoxy resin was then spread in the polyethylene surface and the first layer of jute fiber mat was placed on top of the epoxy layer in the mold. Three layers of mat were used to manufacture each sheet. The hand rollers were used for maintaining equal distribution and to prevent the void formation. Then, the panel was kept under the pressure of 100 kg load in the atmospheric temperature for 24 hours for curing. The hand lay-up method for the fabrication of JFRP is shown in Fig. 1(a) and the orientations (0°-0°-0°, 0°-90°-0° and 0°-45°-0°) of the fibers are shown in Fig. 1(b).



(a)



(b)

Figure 2. (a) Hand lay-up process for JFRP and (b) Fiber orientations (Weft direction of yarns are shown as arrow)

- Tension Test

Tension test was performed on the JFRP sheets using the Universal Testing Machine (Shimadzu AGX-300kN). Two specimens from each of the manufactured sheet (a total of four for each orientation) were cut to a size of 250 mm × 25 mm × 3.5 mm to perform the tensile test. From the tensile test, the tensile strength and the tensile modulus of elasticity were calculated using ASTM D3039/D3039M standard.

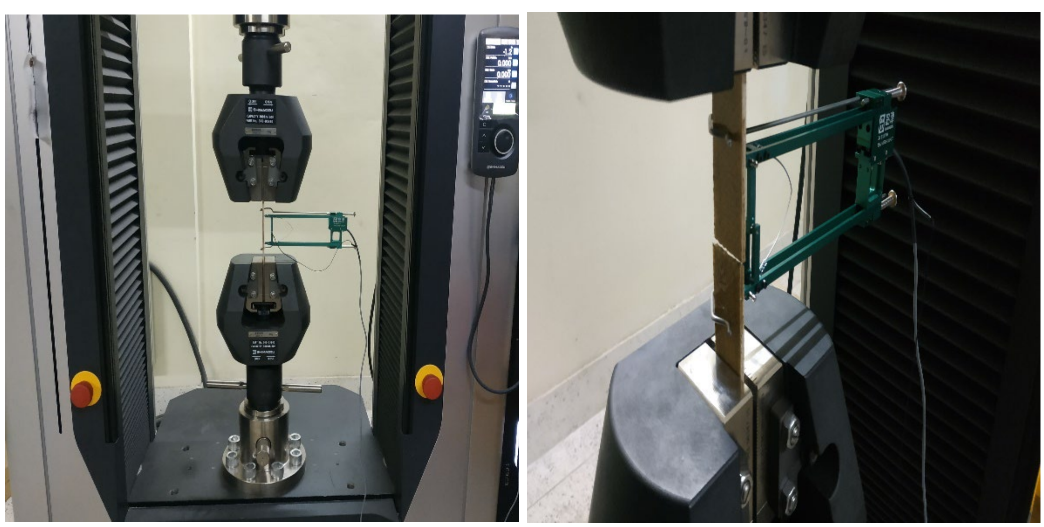


Figure 3. Tension test setup

- Flexure Test

Flexural test was also performed on the JFRP sheets using the Universal Testing Machine (Shimadzu AGX-300kN). Two specimens from each of the manufactured sheet (a total of four for each orientation) were cut to a size of 130 mm × 13 mm × 3.5 mm to perform the flexural test. From the flexural test, the flexural strength and flexural modulus of elasticity were calculated using ASTM D7264/D7264M standard.

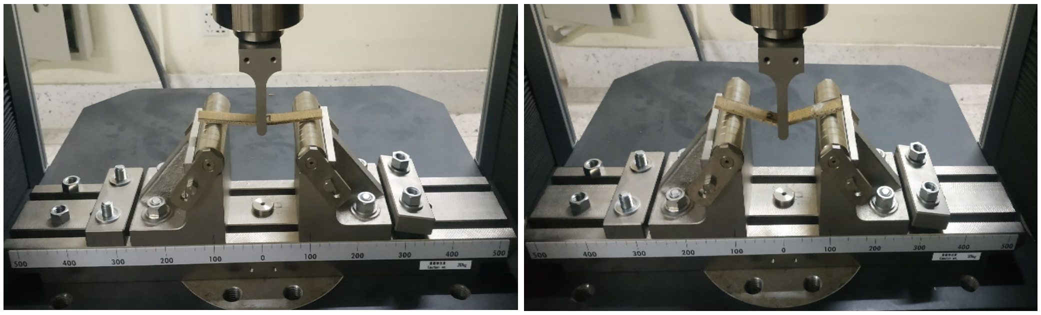


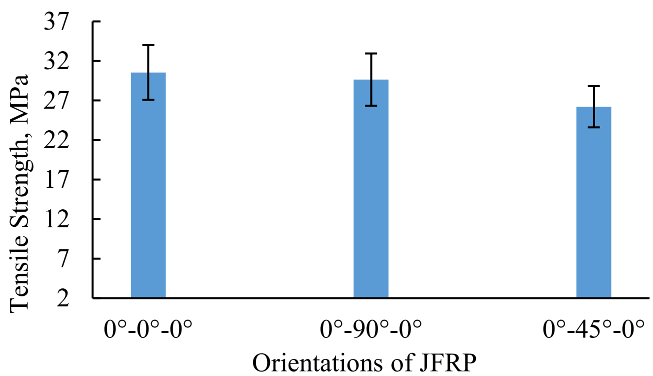
Figure 4. Flexure test setup

3. Results and Discussion

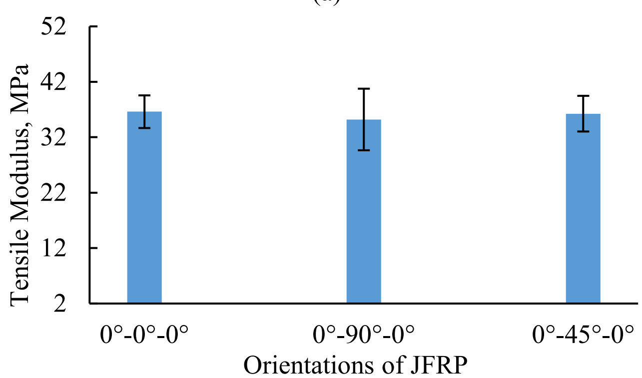
3.1 Density

The average density of the prepared JFRP sheets are within 1.168-1.184 g/cm^3.

3.2 Tension Test Results



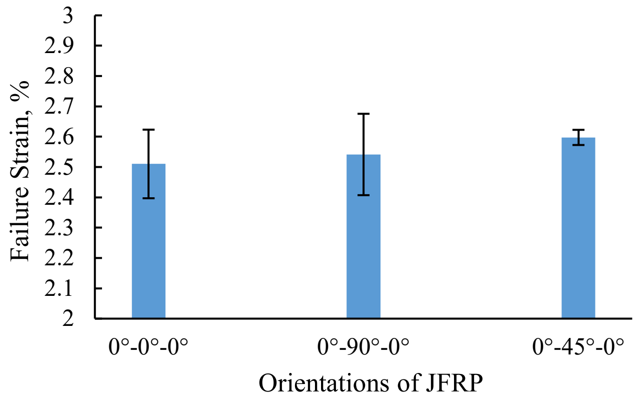
(a)



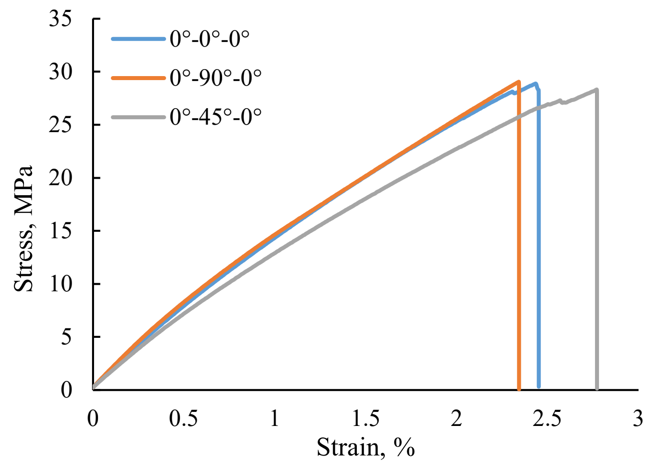
(b)

Figure 5. (a) Tensile strength and (b) Tensile modulus for different fiber orientations (Standard deviations are shown as error bars)

In Figure 5, the tensile strength and modulus for three different fiber orientations is shown as bar chart with standard deviations. The range of tensile strength lies within 26.21-30.54 MPa. It is clearly seen from the figure that the tensile strength is maximum for the sample oriented unidirectional. The modulus of elasticity does not differ that much and the range of values (35.21-36.60 MPa) is almost similar for all the samples.



(a)



(b)

Figure 6. (a) Failure strain during tension test and (b) Typical stress vs strain curves during tension test for different fiber orientations

The failure strain is plotted in Figure 6(a). It is seen that the failure strain was found to be highest for 0°-45°-0° orientation of fibers and it is minimum for 0°-0°-0° orientation. The representative stress vs strain curves during tension test are presented in Figure 6 (b). The stress increases linearly with increasing strain until a peak where the sudden failure takes place. So, the failure nature of all composites is undoubtedly brittle because there is no energy absorption after failure.

5.3 Flexural Test Results

In Figure 7, the flexural strength under three different fiber orientations is shown. The range of flexural strength lies within 60.66-64.29 MPa. It is clearly seen from the figure that flexural strength is maximum in case of 0°-90°-0° sample. The flexural modulus of elasticity for three differently oriented JFRP sheets is shown in Figure 8. In case of flexure test, the deviation in modulus of elasticity is not so severe and the range of values (39-42.63 MPa) is almost closer for all the samples.

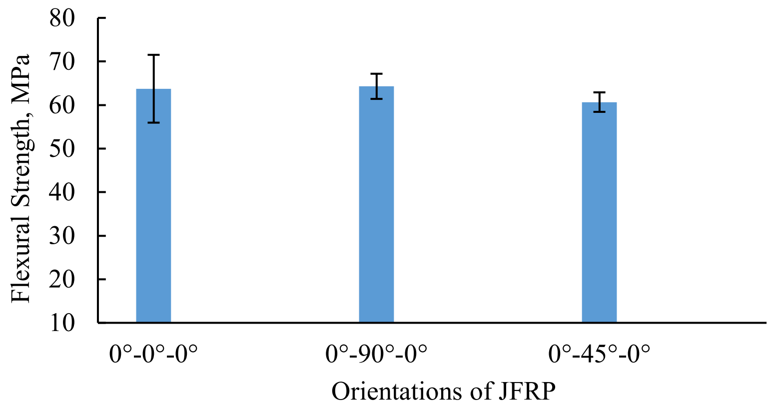


Figure 7. Flexural strength for different fiber orientations (Standard deviations are shown as error bars)

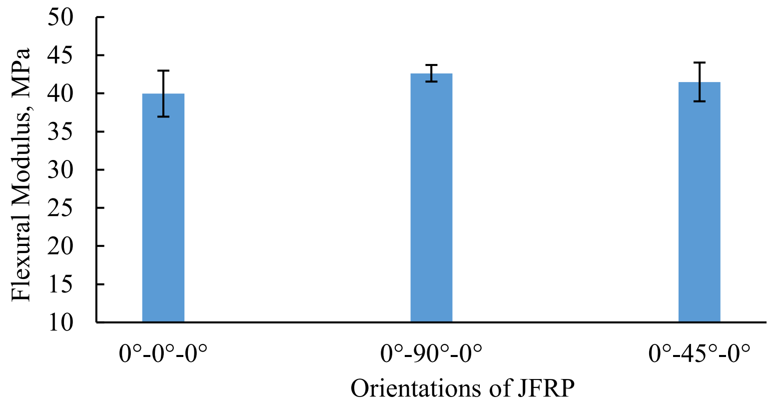


Figure 8. Flexural modulus for different fiber orientations (Standard deviations are shown as error bars)

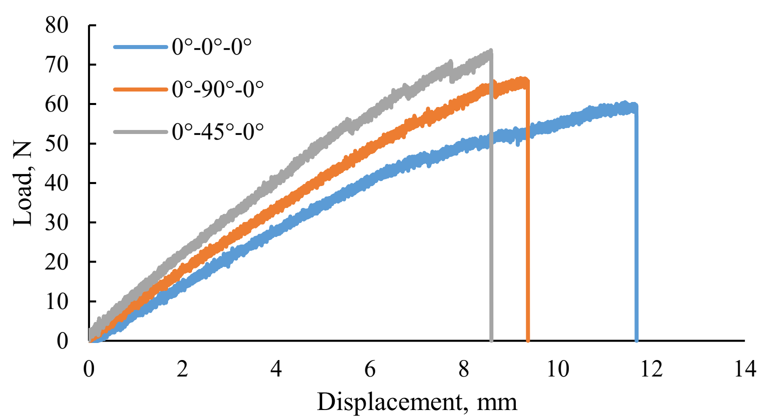


Figure 9. Load vs displacement curves during flexure test for different fiber orientations

The representative load vs displacement curves are given in Figure 9. A sudden drop occurs after reaching the peak value in all cases due to the initiation of crack in the sheets. The crack initiated at the tension side of the specimen and propagated towards the compression side although the failure occurred rapidly. It can also be seen from the Figure 9 that the failure in sample of 0°-0°-0° orientation was delayed that is the displacement at failure is higher even though the modulus of the same sample is the lowest.

4. Conclusion

This study is focused on the investigation of tensile and flexural properties of the JFRP sheets fabricated maintaining three different orientations. The density of the prepared sheets was 1.168-1.184 g/cm^3. Based on the tensile strength and tensile modulus the sheet oriented as 0°-0°-0° showed better result as compared to the samples having 0°-90°-0°

and 0°-45°-0° orientations. The highest observed tensile strength and tensile modulus are 30.54 MPa and 36.60 MPa respectively. The failure strain in tension is seen to be the highest for a sample with 0°-45°-0° orientation and the lowest for 0°-0°-0° orientation. In case of flexure test, the maximum flexural strength was found 64.29 MPa for the sample oriented 0°-90°-0°. In addition to this, a complete brittle failure was seen during both tension and flexural tests irrespective of the orientation of the jute fiber mats during manufacturing.

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Biographies

Pranto Karua is a Lecturer of Department of Mechanical Engineering at the Faculty of Mechanical Engineering, Khulna University of Engineering and Technology (KUET). He started his academic career in Khulna University of Engineering and Technology (CUET) in July, 2019 after receiving his undergraduate degree in Mechanical Engineering from the same university. He is now doing Masters in Mechanical Engineering at Department of Mechanical Engineering, KUET. He has published 4 research papers in several international conferences. He is also serving as a Testing Officer at the Consultancy Research & Testing Services (CRTS) in KUET. His current research is focused on building materials and sandwich structure of composite materials.

Md. Arifuzzaman is an experienced academic holding a Doctor of Philosophy (Ph.D.), focused on Construction Materials from The University of Newcastle, Australia with a proven history of working in the higher education industry since 2010. He is now working as Associate Professor at the Department of Mechanical Engineering, KUET, Khulna, Bangladesh. His research experiences include manufacturing, characterization, and developing structure-property relationships of construction materials; particulate composites; fiber-reinforced composites; lightweight sandwich structure; and materials property prediction and optimization. He is skillful in manufacturing composite materials, testing various mechanical and thermal properties, designing experimental setups, examining microstructure using SEM, writing the research grant application, writing research papers, etc. He has published 11 papers in reputed peer-reviewed journals and presented his work in 8 international conferences around the world. He has taught several courses at the undergraduate and postgraduate levels and supervised 18 students at the undergraduate and postgraduate levels. He has been awarded several prestigious awards and scholarships throughout his academic career.

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