Impact of Fiber Orientation on the Mechanical Properties of Rice Straw-Glass Fiber Reinforced Polymer Composites

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Abstract

Polymer composite, presently one of the most promising and innovative fields of research, and the importance of using biodegradable fibers as reinforcement in polymer composite material is growing rapidly. In this era of excessive depletion of petroleum resources and for new green environmental regulations, natural fiber-based composites can be crucial for the environment. In this study, a composite has been produced using reinforcement of glass fiber and rice straw and a matrix of epoxy resin. Mechanical properties of the composite such as impact and flexural properties have been investigated. The fiber orientation has a great impact on the mechanical properties of these composites. Impact and flexural strength both were found to be higher at 0° fiber orientation. Flexural strength rapidly decreased as the orientation angle of fiber increased from 0° to 90°. On the other hand, impact strength decreased up to 45° and then it again increased until the orientation angle reaches 90°.

Keywords
Rice Straw, Polymer Composite, Impact Test, Flexural Test and Fiber Orientation.

1. Introduction
Presently composite materials have vanquished a major segment of research of materials science. Composites are one of the most useful materials because of their adaptability to various requirements and the comparative clarity of mixing with various materials. Moreover, cost optimization has become a great factor in today's manufacturing. Using composites instead of wood not only reduces the cost but also gives more accurate and qualified product.

A polymer composite fabric can be characterized as a combination of more than one materials. It comes about in superior nature than those utilizing only one material. These are different from a metal-alloy. These have different physical and chemical nature. By combining materials of distinctive nature, it can be improved to a wanted constraint. The fundamental sides of interest of polymer-based composites adheres to their high performance and firmness. They often have the behavior of much thickness, in comparison with bulk items, permitting for a weight reduction in the enfolded up portion.

William D. Callister, Jr. defined composites as an object of many phase that is normally made, as opposed to those that occurs or forms naturally. Moreover, the structural phases should be chemically different and detached by a specific interface (Callister 2006).

Normally composite materials can be classified into different types (Callister 2006). These types are given below in figure 1. From the below classification of composites, it is noticed that composites are normally three types. Among them, one of the most important type is particle-reinforced composite which has one or more material particles in binding matrix. On the other hand, fiber-reinforced composites uses materials as reinforcement. In addition, structural composites are normally made from carbon fibers, plastic, wood or glass fibers.

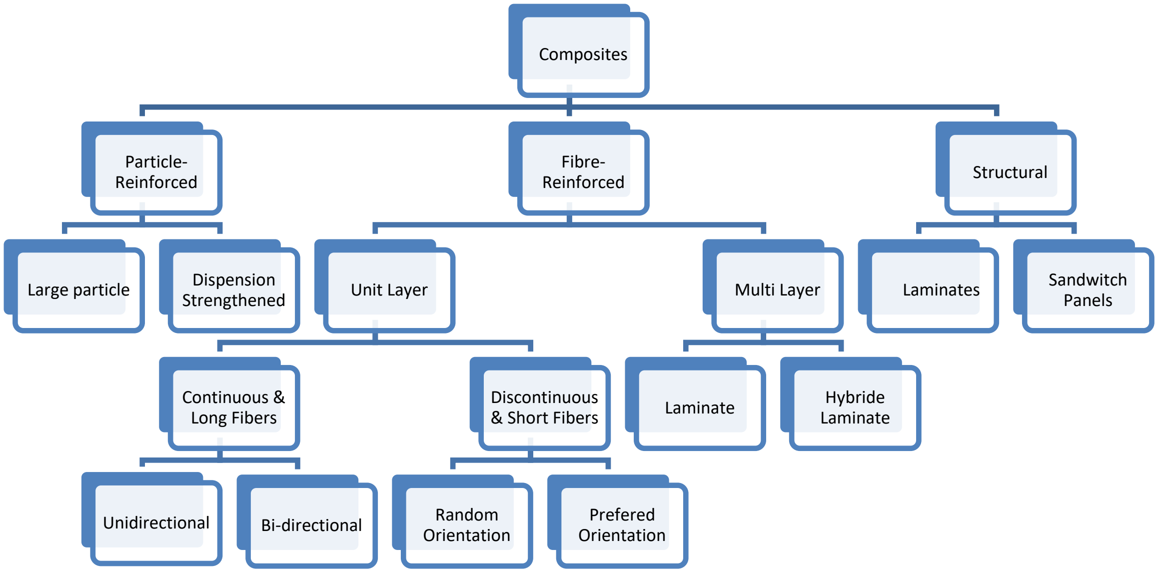

Figure 1. Classifications of Composites (Callister2006)

At the present era, the demand for using natural fiber has increased. Moreover, it brings a lot of benefit for the environment to use natural fibers. Natural fiber as reinforcement is not only cheap to use but also ecofriendly for the environment. It is biodegradable and has not dangerous impact on nature. Impact and flexural strength can be improved by using natural fibers. But it can less improve the tensile strength. Many efforts are taken to improve the mechanical properties of the composites like improving the interface, newer methods of fabricating the composites. It will be better to understand about the natural fibers, if the classification is clear. Thus, the classification of natural fiber is given below in figure 2.

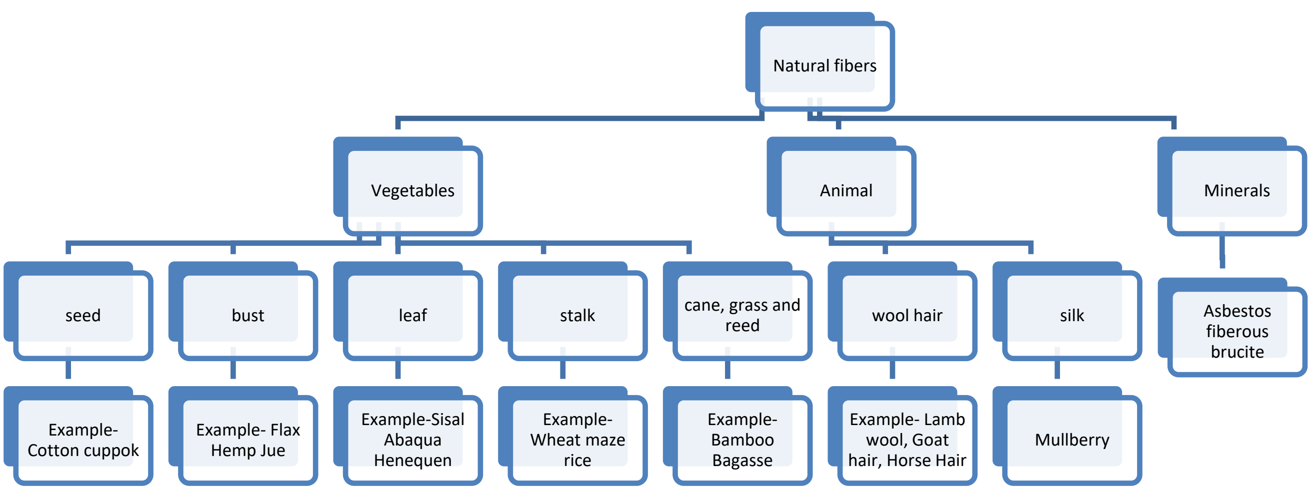

Figure 2. Classification of natural fibers (Bongarde and Shinde 2014)

Thus, research on natural fibers has great impact for the present time. Moreover, rice straw is an agricultural by-product which is dramatically cheap in Bangladesh. In many areas, it is one kind of wastes. Therefore, if it is possible to make a reliable composite using rice straw, it will be very cost effective and ecofriendly. For, increasing

the strength, glass fiber is used as reinforcement in the current research. Therefore, in this study mechanical property of rice straw and glass fiber based composite has been investigated.
The core objectives of this study are too fabricate rice straw-glass fiber polymer composite and to evaluate the mechanical behavior like impact and flexural properties of these composites. To investigate the impact of fiber orientation on the mechanical properties of these composites is the most important aim of the study.

2. Literature Review

2.1 Study on Rice Straw Fiber

Rice *(Oryza sativa)*which is a very significant crop in all around the globe. According to the specialized agency of United Nations, Food and Agricultural Organization (FAO), it has become the third most cultivated corps all over the globe. Kadam et al. (2000) reported that the total yearly production of rice all around the world was 577 million metric tons in 1997-98. Asian farmers are responsible for 92% of this total production. Kadam et al. (2000) also reported that the agricultural byproduct, rice straw covers about 50% of the dried weight of rice herbs. However, this amount may significantly vary from 40% to 60% because of the producer and producing method. In order to harvest every ton of grain, 1.35 tons of rice straw is also produced. In addition, this agricultural byproduct is a high possible source of plant biomass because of the large yield of it per hectare. The amount of this waste can be recovered, depends on the technique of reaping and harvesting (physical or mechanical) and on the condition of the field (damp or dried) and crop (lodged or not). The average production of dried rice straw per hectare field is about 5.5-6.7 tons.

At the time of collecting, the rice straw has a moisture percentage of 60-70% on a weight measurement. But Dobie and Haq (1980) suggested that before starting harvesting and storing the water content should be below 25%. This drying process will occur naturally. Dobie and Haq (1980) studied that in California of United States, it takes 72 hours to reach a water percentage of 18-20%. Kadam et al. (2000) also studied the chemical composition of this agricultural byproduct. It is a fibrous plant material, which is normally an agricultural residue. However, it is significant from most of the other crop residues; it has a very high amount of silicon dioxide (SiO2). The percentage of ash in rice straw on a dried state basis are normally from 13 to 20. The contents of ash are normally1.3% CaO, 3% Fe_2O_3, 3% P_2O_5 , 10% K_2O, 75% SiO_2, , and a little amounts of Na, S and Mg.

Sudhakar (2014) and Yao (2008) also studied the effect of using rice straw as reinforcement in the composite. Yao (2008) suggested that the fiber of rice straw could work nice with both vHDPE and rHDPE polyethylene as reinforcing shim.

2.2 Study on Natural Fiber Based Polymer Composites:

The use of natural fiber in composite is growing very fast. Several significant features of natural fiber like biodegradability, flexibility, low density, availability, low cost are responsible for the using. A lot of research have enhanced the mechanical behaviors of composites, which are based on natural or biodegradable fiber. Joshi (2004) used life cycle evaluation to compare the natural superiority of biodegradable fiber and glass fiber. They reported that nonrenewable energy requirements for production of natural fibers are less than glass fiber. The energy requirement to produce one kg glass fiber is 54.7 and to produce china reed fiber, the amount is 3.64MJ. Joshi (2004) also studied the impact of biodegradable and glass fiber on the nature. It was also found from that research that environmental impact of using synthetic fiber is a lot more than using a biodegradable fiber. Natural fiber emits less amount of environment polluting agents like Co_2, CO, Nitrogen and Sulfur Oxides than synthetic fibers.

Defoirdt et al. (2010) studied the tensile properties of various fibers like jute, coir, bamboo and observed that the strength of all types of fiber strength decreases as the test fiber becomes larger. It occurs because in this case they used Weibull's distribution and larger fibers has more flaws. The chance of failure also increases. They suggested to use jute and bamboo fibers for reinforcement in finer and high-performance composites because of their significant tensile strength. It was observed in their research that bamboo fiber was two times stronger than jute fibers. On the other hand, coir fiber provide low strength but it is potentially make the composites tougher because it has high strain to failure. Thus, it has a high potentiality to be used for noise absorption purpose. Mohanty et al. (2004) observed the mechanical properties of kenaf and jute fiber and noticed that jute fiber is better than kenaf fiber in this case. Pavithran et al. (1987) observed the rapture strengths for various fiber strengthen polymer composites and explained that, instead of the coconut fiber; the more fiber toughness was increased, the more fracture breakage probability of the composites was increased.

2.3 Study on Hybrid Fiber Based Polymer Composites:

The composites which are found by combining more than one fiber within an unit matrix are defined as hybrid composites. Hybrid composites may be the incorporation of more than one natural fiber or it can be a mixture of natural and synthetic fibers. Ashmed et al. (2007) observed the elastic nature and notch sensitivity of unprocessed jute and jute-glass reinforced hybrid composites. They noticed that the notch sensitivity of jute composites are greater than jute-glass hybrid composites. Dixit et al. (20012) observed a significant improvement in the tensile and flexural behaviors of hybrid composites in comparison to the non-hybrid composites. It was also noticed that the hybrid composite gives more water absorption hindrance.

Thus, natural fiber has become a significant area of research. Mechanical properties of natural fiber based composites has shown great improvements. Moreover, rice straw is dramatically cheap agricultural byproduct in Bangladesh. Few researches has been done about this fiber. That is why, rice straw-glass fiber reinforced polymer composites are to be made in this research and mechanical properties will be checked.

3. Methods

3.1 Materials:

The main goal of the research is to fabricate and analyze the mechanical properties of rice straw-glass fiber composite to obtain maximum impact and flexural strength. The unprocessed rice straw was collected from local farmers and glass fiber and epoxy resin was collected from local market. For composite fabrication, various combination of fiber weight percentage and fiber-loading directions have been made. Orientation angle and loading direction is shown in figure 3. Fiber orientation and fiber Wt% is shown in table 1.

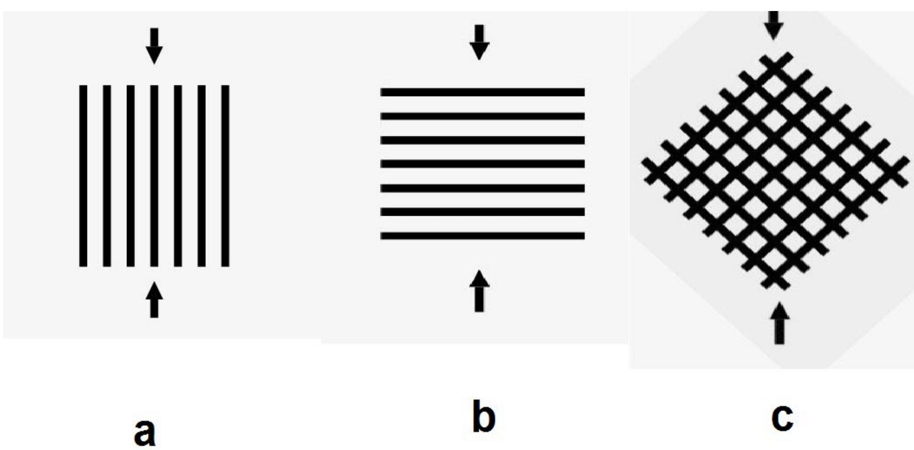

Figure 3. Stacking sequence and fiber loading direction (a) 0° (b) 90º (c) 45º

Table 1. Designs for fabrication and mechanical test

Experiment	Weight% of rice straw	Glass fiber weight %	Orientation angle
1	10	10	45°
2	10	20	0°
3	10	30	90°
4	20	10	0°
5	20	20	90°
6	20	30	45°
7	30	10	90°
8	30	20	45°
9	30	30	0°

The raw materials such as rice straw, glass fiber, epoxy resin and hardener for composite fabrication are shown in figure 4. The rice straw fibers were cleaned and cut uniformly of a length of 160mm. A mixture of resin and hardener in 3:1was employed to achieve prime matrix constitution.

Figure 4. Raw materials (Rice straw, Glass fiber, Epoxy Resin and Hardener)

3.2 Fabrication Procedure

In this study, the conventional hand lay-up techniques were used to fabricate the composites. At first, rice straw fibers and glass fiber were cleaned and dried and then cut uniformly for a length of 150 mm. A mixture of resin and hardener in 3:1was prepared for composite fabrication. At the very beginning, a release coating and resin were used to the molding surface. Then a covering of the rice straw fiber and glass fiber was used, followed by an amount of liquid epoxy resin streamed onto it. To remove any kind of voids in the composite and to ensure the flow of resin equally all over the fibers, brushes and simple hand rollers were used. This process was done up to the defined number of layers was achieved. At the last moment of the process, the specimens were given the required pressure with the help of presses to remove the air gap in the fibers and resin. Then these were kept for several days to solidify and get precise specimens. The completely systematic and step-by-step fabrication procedure is shown in figure 5. When the composite was solidified and hardened fully, it was taken out from the press and extra rough edges were carefully removed with the help of a cutting machine to get the required dimensions. The composite laminate specimens were healed by keeping it to normal atmospheric temperature.

Figure 5. Fabrication Procedure

3.3 Testing mechanical Properties of the Composites

There are many types of mechanical tests to be employed on the prepared composites like impact test, water absorption test, bending test, hardness test and many more. Only impact test and flexural test are observed for nine different types of samples to clearly understand the strength variation of the composites. Three of each type of same sample was tested to find appropriate results. Each of the same sample was cut into 6 pieces by using grinding machine. In the cutting process, the fiber orientation angle (0°, 90° ,45°) was achieved by following proper measurement. Three of these pieces were used for impact test and three of them were used for the flexural test.

3.3.1 Impact test

Charpy impact test was performed on the samples. For impact test, the samples were cut following design. Figure 6 represents the sample work piece dimension for impact test. Composite specimens were placed in vertical position (Izod Test), the hammer was released to make an impact on specimen and CRT reader gives the reading of impact strength. Figure 7 and figure 8 consecutively present the impact testing machine and flexural testing machine.

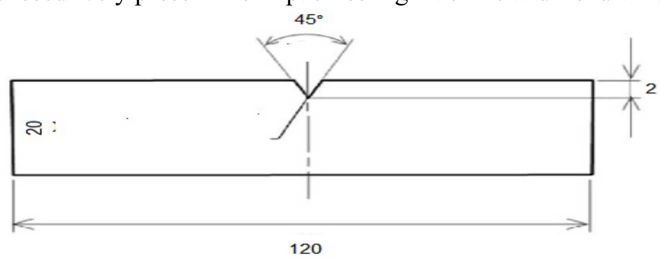

Figure 6. Work piece dimension for impact test

For impact strength, equation was followed by:

$$Impact\ strength = \frac{E}{A}$$
$$E = mg\ (h_1 - h_2)$$
$$A = b \times d$$

Where,
E = Impact energy
A = Cross section of impact surface
h_1 = 143 cm (constant for all work pieces)
d = thickness of the work piece
b = 20
m= mass of the hammer = 20kg
The figure of the impact and flexural testing machine is provided below.

Figure 7. Impact testing machine

Figure 8. Flexural testing machine

3.3.2 Flexural test

For flexural test 3-point, flexural test approach was followed. The work piece dimension for the flexural test is given in figure 9 and sample work specimen for mechanical tests has been shown in figure 10. They were achieved after cutting following the dimension in figure 9.

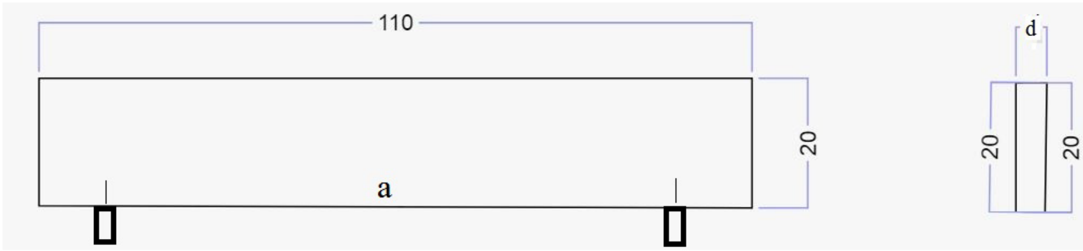

Figure 9. Work piece Dimensions for flexural test

The formula of flexural strength is followed by:

$$Flexural\ strength = \frac{Mc}{I}$$
$$M = P \times a$$
$$c = \frac{d}{2}$$
$$I = \frac{bd^3}{12}$$

Where,

The equations used for flexural strength calculation are given below:
M = Bending moment
P= Load
a = length of mid-span = 45 mm
d = Thickness of work piece
b = width of work piece = 20 mm

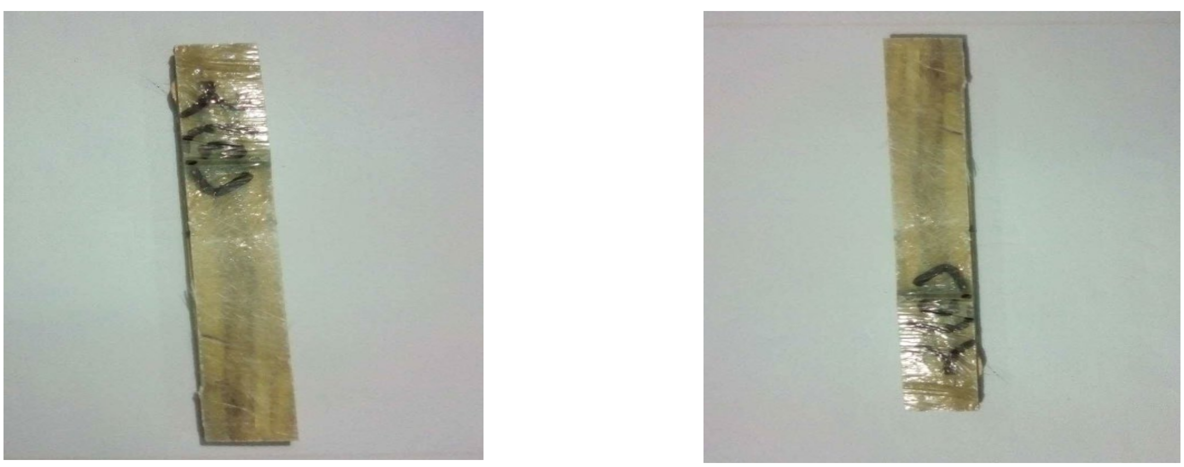

Figure 10. Sample work specimen for mechanical test

4. Results and Discussion
4.1 Impact Test
For analyzing the impact capability of the different specimens, an impact test is carried out by Charpy impact test. Impact strength of various samples is summarized in Table 2 and Figure 11. Lowest impact strength was found to be 95.52 kJ/m^2 of experiment no. 1 in where fiber orientation angle was 45°. On the other hand, the highest impact strength was found to be 232.82 kJ/m^2 of experiment no. 9 in where fiber orientation angle was 90°. Fiber orientation has a great impact on impact strength.

Table 2. Result of impact test

Experiment	Weight percentage of Rice Straw	Weight Percentage of Glass Fiber	Orientation Angle	Impact strength, kJ/m^2
1	10	10	45°	95.525
2	10	20	0°	153.105
3	10	30	90°	154.259
4	20	10	0°	109.977
5	20	20	90°	125.377
6	20	30	45°	112.848
7	30	10	90°	123.588
8	30	20	45°	113.442
9	30	30	0°	232.824

Due to the fiber loading direction, fracture takes place on matrix for 45° specimen whereas; fracture takes place on both matrix and fiber for 90° specimen. This might be the causes of low impact strength of 45° specimen. Moreover, fiber wt.% was also made a great effect on impact strength. When the maximum glass fiber content is incorporated with rice straw fiber, the impact strength found to be the highest (Experiment no.9).

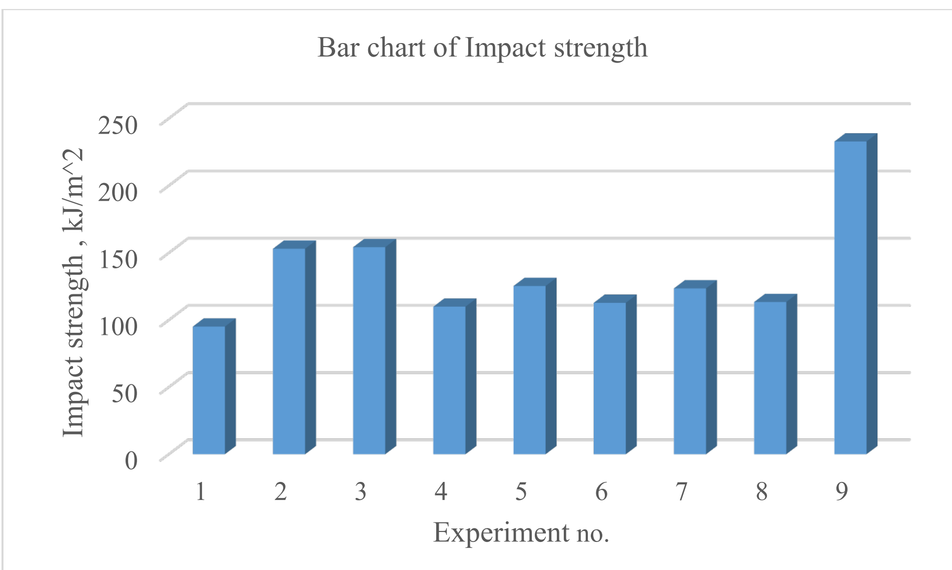

Figure 11. Bar chart of impact strength of different experiments

4.2 Flexural Test
The composite specimens are subjected to three-point bending loading and the results have been analyzed in this study. The flexural test results are shown in figure 12 and table 3.

Table 3. Result of the flexural test

Experiment	The weight percentage of Rice Straw	Weight Percentage of Glass Fiber	Orientation Angle	Flexural strength, MPa
1	10	10	45°	48.04
2	10	20	0°	89.2
3	10	30	90°	32.97
4	20	10	0°	84.77
5	20	20	90°	31.55
6	20	30	45°	65.67
7	30	10	90°	24
8	30	20	45°	50.95
9	30	30	0°	122.75

According to the results, the fiber orientation has a great effect on flexural strength of these composites. The highest flexural strength was found to be 122.75 MPa of experiment no. 9 in where fiber orientation angle was 0°. On the other hand, lowest flexural strength was found to be 24 MPa of experiment no. 7 in where fiber orientation angle was 90°. Flexural strength of all 0° orientation samples (exp no. 2, 4 and 9) are showing better performance followed by 45° (exp no. 1, 6 and 8) and 90° (exp no. 3, 5 and 7) orientation samples.

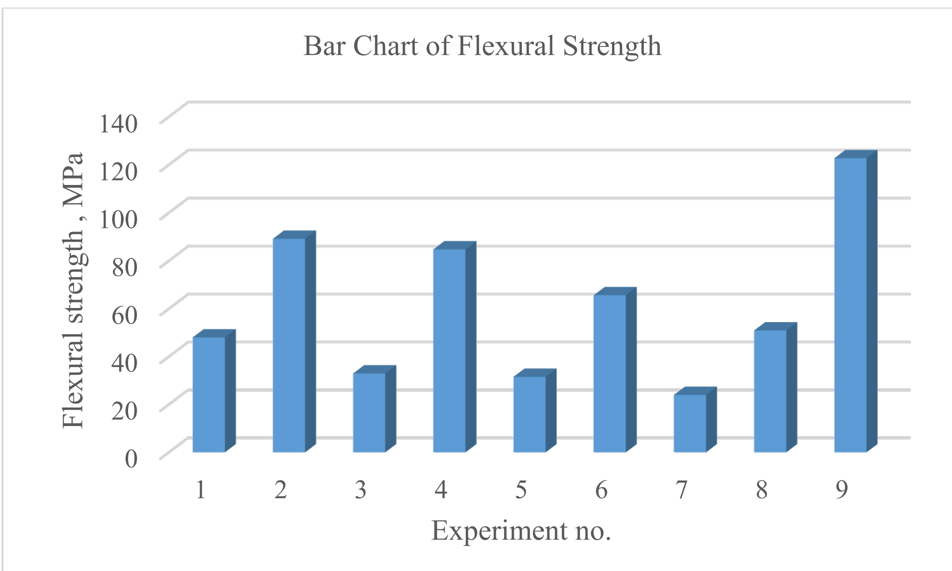

Figure 12. Bar chart of flexural strength of the different experiments

The reason behind this variation is that fracture take place on the both fiber and matrix of the 0° orientation samples. When orientation angle gradually increased (0° -45^0 -90°), the interfacial bonding between fiber and matrix might decrease as a result flexural strength became low. Also from this results it can be seen that fiber wt% have a great impact on the flexural strength of these composites. When the maximum glass fiber content is incorporated with rice straw fiber, the impact strength found to be highest (Experiment no.9).

5. Conclusion

In this study, mechanical behaviour of rice straw and glass fiber based polymer composites has been investigated. The key findings of this study are as follows.

Fiber orientation angle and fiber wt% has a great impact on both flexural and impact behaviour of theses composites. Both impact and flexural strength is found to be the highest (232.82 kJ/m^2 and 122.75 MPa) for 0° fiber orientation angle. And for impact strength, the minimum value of impact strength was found at 45°. On the other hand, for flexural strength, the minimum value was found at 90°. When the maximum glass fiber content is incorporated with rice straw fiber, both impact and flexural strength found to be highest.

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