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The Influence of Stacking Sequence on the Mechanical Properties of Woven Bamboo and Jute Fiber Reinforced Epoxy Hybrid Composites

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Abstract

Composites are materials that satisfy the demands of modern technology. Research on herbal fibers as reinforcements for polymer composites is becoming prevalent. They are non-poisonous, inexpensive, easily processed, eco-friendly, lightweight, plentiful, and readily available. They also require few energy inputs. This work focuses on how some mechanical qualities are affected by stacking series. Epoxy composites reinforced with bamboo and jute fibers were tested for their tensile and flexural properties. 30% reinforcement and 70% matrix are employed to create composite samples. The hybrid composite laminates were made using the hand layup technique. The ASTM specifications were followed in the preparation and testing of the specimen. According to the findings, hybrid composites' tensile and flexural characteristics are more significantly impacted when bamboo fiber and jute fiber are combined. Using 0.1N NaOH solution treatment on Bamboo and Jute fibers demonstrates a notable enhancement in the adhesion between the fiber and matrix. Flexural and tensile characteristics Plots for various stacking configurations showed that the hybrid composite's tensile and flexural strengths increased with the amount of woven Jute fiber laminate. These fibers have great appeal for structural packaging and might eventually replace synthetic fibers. They might be employed in producing skateboards, electric-powered switchboards, helmets, dashboards, parcel shelves, and car doors.

Keywords: *Bamboo, Epoxy, Flexural, Jute, SEM, Stacking Sequence, Tensile*

1.0 Introduction

Post-mining land use for industrial crop production presents a promising opportunity to mitigate mine closure's negative environmental and socioeconomic impacts. This approach not only helps to restore the disturbed land but also facilitates post-mining economic growth. There exists a possibility to evaluate the practicality of converting post-mining areas into fertile land and constructing robust communities via the creation of diverse-value chains using fibre-enriched plants, such as kenaf, hemp, jute, or bamboo.

Natural fibers are abundantly available in nature[1]. These fibers are frequently used for high-end objects to create wall hangings, wallets, purses, ropes, and mats. The natural fiber composites mainly comprise cellulose, lignin, pectin, and hemicelluloses. These fibers are commonly used for producing yarns, ropes, mats, handbags, purses,

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and wall hangings for fancy articles[2,3]. Hybrid structures, i.e., combining two or more fibers in the matrix phase, made engineers design new materials with appreciable properties for specific applications[4]. The fiber's surface is hydrophilic and poorly suitable for use in hydrophobic polymers[5]. Natural fibers' cost and processing methods offer an advantage over synthetic fibers. However, these natural fibers have lower mechanical properties than synthetic fibers. Another disadvantage of natural fiber composites is their poor moisture absorption[6]. In Asia and South America, bamboo fiber is found in abundance. Bamboo evolved as the backbone of society's socio-economic status. It is used as a living facility. It shows a high strength-to-weight ratio[7,8]. Natural fibers were initially used between 1920 and 1930[9]. Bamboo and jute fiber are considered for the composite fabrication in this study. One of the contemporary natural fiber materials, jute, is widely used as reinforcement in hybrid composites[10]. These fibers' weaving patterns are warp 0^0 and weft 90^0 [11]. These woven textiles are stored in a 0.1 N sodium hydroxide (NaOH) solution. It is done to strengthen the adhesive property of polymers with natural fibers, increasing the composite material's strength.

1.1 Constituent Materials of the Composite

1.1.1 Bamboo Fiber

Bamboo fiber (BF) consists of cellulose 60-73.83 %, 10-15 % lignin, and 12-46 % hemicelluloses. Bamboo belongs to the Bambusoideae family[12]. Bamboo fibers are known for their tall and persistent growth, with heights ranging from 10 cm to 40m. Bamboo plants are divided into more than 70 kinds and are grown in a variety of conditions across the world[13]. Bamboo has many advantages, like high mechanical strength, stiffness, low cost, low density, and high growth rate, as well as the ability to fix carbon dioxide. Bamboo was traditionally used in construction and also for the production of everyday tools[14]. Extraction methods include chemical, mechanical, and steam explosions. China is known as the "Kingdom of Bamboo" because it grows over 400 distinct bamboo species[15].

1.1.2 Jute Fiber

Jute Fiber (JF) is indigenous to India, Bangladesh, and Nepal and is one of the most often used stem-type herbal fibers[16]. Bast fibers are currently employed in the car industry for seat backs, interior door panels, trunk liners, and other applications[17,18]. The jute plant has a base stem diameter of 25 mm and may reach a height of 2.5 m[19]. JF is derived from two plants: white Corchoruscapsularis (white jute), which is planted in Asian nations, and Corchorusolitorius (Tossa jute), which is growing in African regions. Next to cotton fiber, jute fiber is the 2nd largest natural fiber producer.

1.1.3 Epoxy Matrix

In the plastics sector, the epoxy matrix is known as a thermosetting resin[20]. Initially, it was used for structural applications and later implemented in composite materials. It is also used in paint industries as convertible coatings. The following are the characteristics of epoxy resin:

- It has good physical properties like abrasion resistance, toughness, and flexibility.
- It offers excellent adhesiveness to various substrates.
- Its low shrinkage during cooling results in good dimensional accuracy.
- It is very chemical resistant.
- It acts as good electrical insulation.
- Epoxy as a matrix performs better than thermoplastics at elevated temperatures.
- Ease of fabrication and low cost.
- The present investigation uses a Lapox L12 and K6 hardener.

1.1.4 Rule of Mixture

The following equation[21] is the analytical formula used to construct composites with different matrix and fiber volume fraction combinations.

$$Vf + Vm = Vc \quad (1)$$

Vf = Fiber Component Volume Fraction
Vm = Matrix Volume
Vc = Composite Volume

1.2 Fabrication Process and Methodology

1.2.1 Fabrication of Mold

A metallic mold made of mild steel measuring 300mm x 300 mm x 3.2 mm is fabricated to prepare the required specimens. The details are shown in Figure 1.

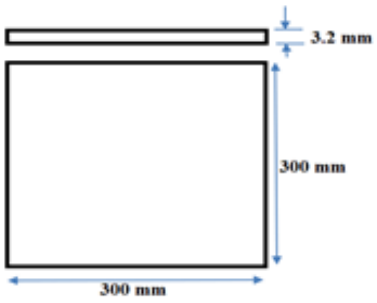


Figure 1. Mold box for the fabrication process.

1.3 Hand Layup Method

During fabrication, this open molding method requires minimal tooling and is easy and quick to use[22]. That method is done to place reinforcements and matrices with various orientations. The specimen preparation details are shown below.

1.4 Specimen Preparation

Natural fibers, like bamboo and jute fibers, and Matrix and Lepox 12 are reinforced. The orientation of the layers is bidirectional, which proved to produce more strength.

- In order to stop specimens from adhering to the mold surface, a gel coat is put on it.
- A single layer of Jute is placed along the x-direction (0^0) over the mold surface.
- In the semi-liquid form, the epoxy resin is applied over the Jute surface, and then another layer of bamboo is added to the surface in the y-direction (90^0).
- Repeating steps two and three to get the necessary fiber quantities and thickness.
- The details of fabricated specimens (laminates) with different stacking sequences are shown in Table 1. Woven Jute fiber is indicated with J, and Woven Bamboo fiber with B.

2.0 Experimental Details

2.1 Tensile Test

Tensile test specimens were prepared to the required dimensions, as shown in Figure 2 as per ASTM D3039[23]. The test is conducted using Computerized UTM with a capacity of 100 KN. The specimen is firmly held in a tensile fixture, and load is applied at a rate of 5mm/min at

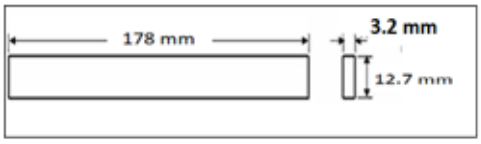


Figure 2. Tensile test specimen.

Table 1. Composition of composites with stacking sequence

Matrix Volume %	Fiber Volume%		Stacking sequence	Specimen
	Bamboo(B)	Jute(J)		
70	10	20	JBJBJBJ	S1
	15	15	BJBJBJB	S2
	20	10	BBJBBJBB	S3
	30	-	BBBBBBBB	S4
	-	30	JJJJJ	S5

room temperature of 25^{0}C. Readings were recorded, and tensile properties were evaluated.

2.2 Flexural Test

Test samples are prepared to the required dimensions shown in Figure 3 as per ASTM D790[24]. The gauge length of the specimen was set at 50mm. This test is carried out by fixing the models in a fixture using three-point bending conditions. The cross-head speed for the test was kept at 2mm/min. Flexibility of the test samples is observed by measuring the force required to bend the specimen or the beam under specified loading conditions. Readings are tabulated, and flexural properties are evaluated.

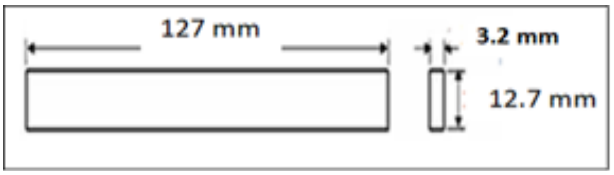


Figure 3. Standard test specimen for flexural test.

2.3 SEM Analysis

It is a powerful investigating tool. To study surface topology, the highly focused beam of electrons produces complex and large magnification images of the specimens. In this test, the Hitachi SU3500 SEM analyzing machine is used. It involves a low aberration objective lens. It offers a better bias function, providing a greater low-kV emissions current[25].

3.0 Results and Discussions

Bamboo and jute fibers are heterogeneous lingo-cellulosic polymers primarily composed of cellulose with a small amount of hemicellulose and lignin. Nature's natural fibers are hydrophilic. They include a large number of hydroxyl groups, making them incompatible with hydrophobic matrices such as epoxy. Alkali treatment of bamboo and jute fibers reduces hydroxyl groups and improves bamboo/jute fiber compatibility with the epoxy matrix. To improve interface adhesion to the epoxy matrix, the bamboo and jute fiber-based fabrics were treated with 0.1N NaOH solution.

3.1 Tension Test

Woven hybrid bamboo and jute fiber composites can achieve the following test results.

Table 2 presents the tensile properties of composite specimens with different stacking sequences. Figures 4 and 5 illustrate the variation of tensile strength and modulus of samples with respect to stacking sequences. The results indicate that the hybrid composites of specimens S1, S2, and S3 exhibit higher tensile strength and modulus values compared to the pure bamboo S4 and S5 jute specimens.

It's interesting to note that the S1 hybrid sample shows an increase in the value of tensile strength and modulus. It also improves ductility and toughness, which is likely due to the high percentage of Jute fibers in the sample. As the percentage of Jute fibers increases, the ductility of the composite material improves. SEM images also show a good bonding strength between the fibers of the S1

Table 2. Tensile Properties of composite specimens with different stacking sequence

Specimen	Load N	Deformation mm	Tensile strength (MPa)	Tensile modulus (MPa)	% of Elongation
S1	4208	4.99	47.411	695.44	9.99
S2	4007	4.82	44.68	650	9.08
S3	3553	4.625	35.63	556.56	9.02
S4	3241.5	4.34	34.5	540	8.76
S5	3850	4.69	34.805	596	9.38

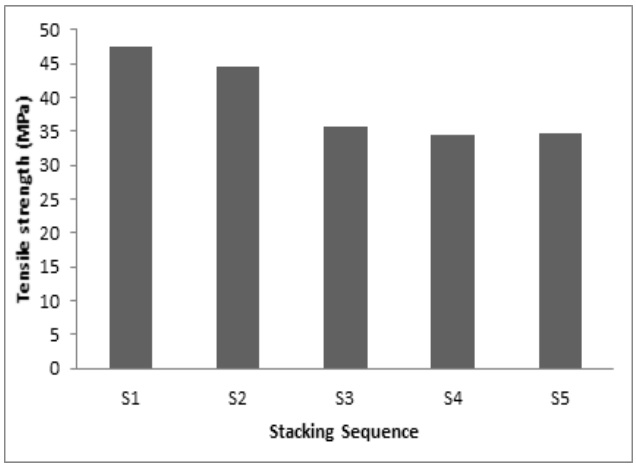


Figure 4. Variation of tensile strength of specimens concerning stacking sequence.

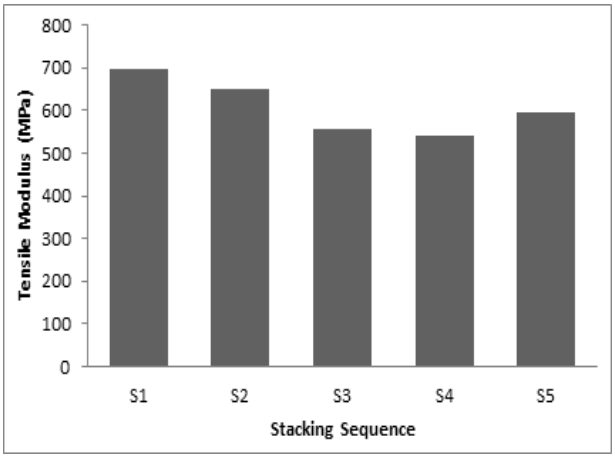


Figure 5. Variation of tensile Modules of specimens concerning stacking sequence.

Table 3. Investigating the flexural properties of composite specimens with varying stacking sequences

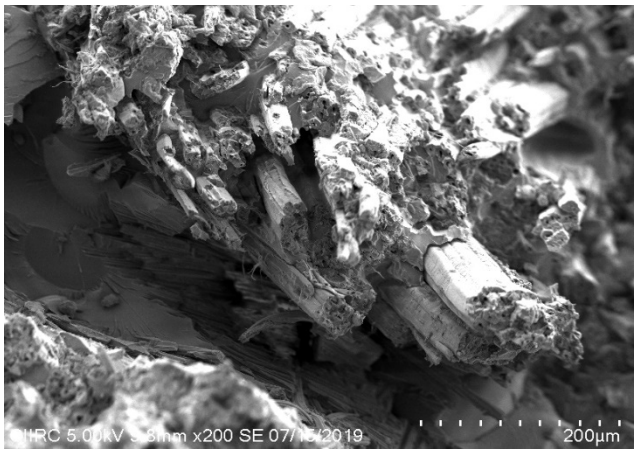
Specimen	Load N	Deformation mm	Flexural strength (MPa)	% of Elongation	Flexural modulus (GPa)
S1	181	2.585	80.25	4.455	9.065
S2	172.56	2.01	76.25	3.256	8.756
S3	166.76	1.25	64	2.155	8.367
S4	123.36	1.585	58.19	2.33	8.507
S5	103	3.34	59.75	6.69	6.7245

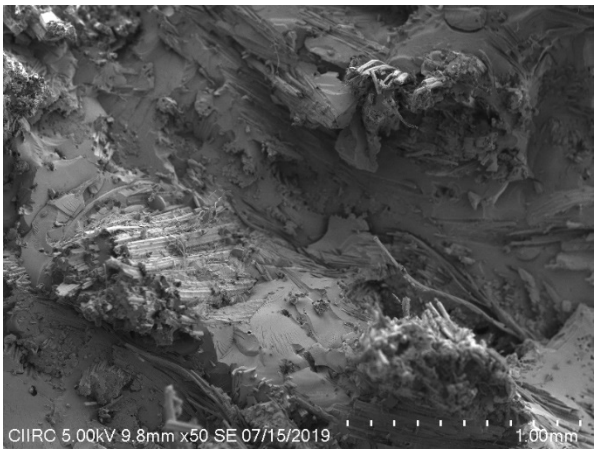
Sample. The S1 sample offers the highest values of tensile strength (47.411 MPa) and tensile modulus (695.44 MPa) among all the composites, which is likely due to the alternative arrangements or positioning of the Jute and Bamboo fibers.

It was found that the fiber and matrix interface played a crucial role in ensuring efficient and uniform stress transmission in the hybrid composite. The results showed that the hybrid composite S1 had 36% more tensile strength than the jute fibers. The fractures of fibers and voids created due to fiber pull-out after the test in the hybrid composites S1, S2, and S3 were also analyzed in Figure 6(a, b, c). Additionally, Table 2 showed that the lowest tensile strength of 34.5MPa and modulus of 540MPa were found in S4, a Pure Bamboo fiber composite. The reason for this was attributed to the lower strength of bamboo fiber and poor bonding with the polymer due to its higher cellulose content. The tensile strength and modulus of hybrid composite S2 and S3 were found to be next to hybrid composite S1 because jute fibers were present at the outer surfaces, allowing for effective load transfer.

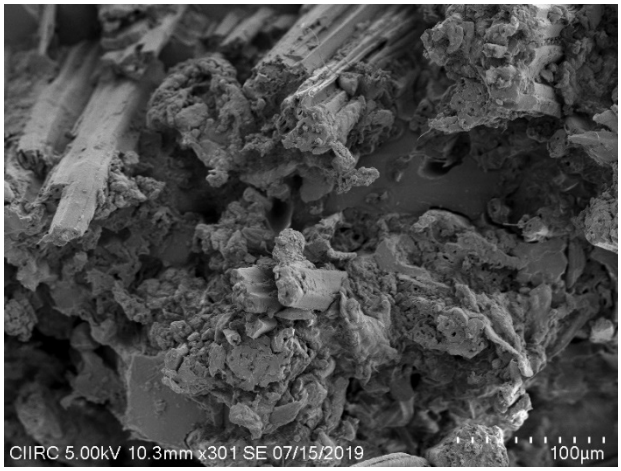
3.2 Flexural Test

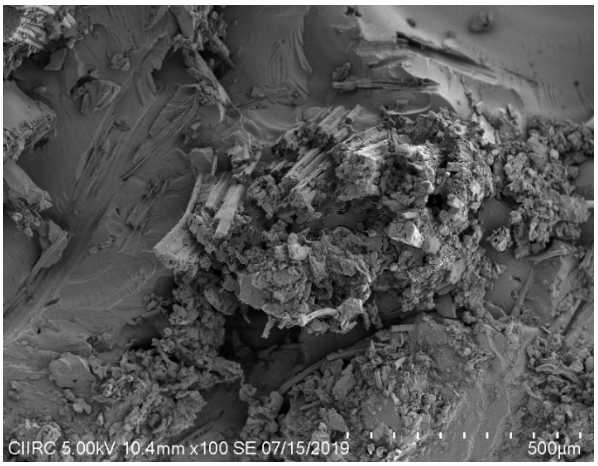
It seems that Table 3 demonstrates some interesting bending strength and modulus values of certain composites made from woven bamboo and jute hybrid



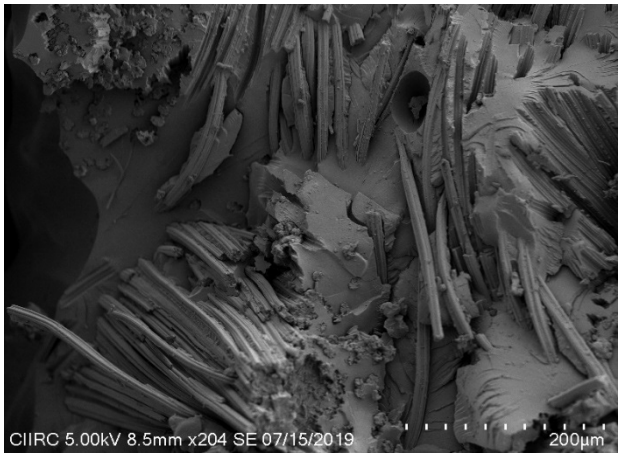


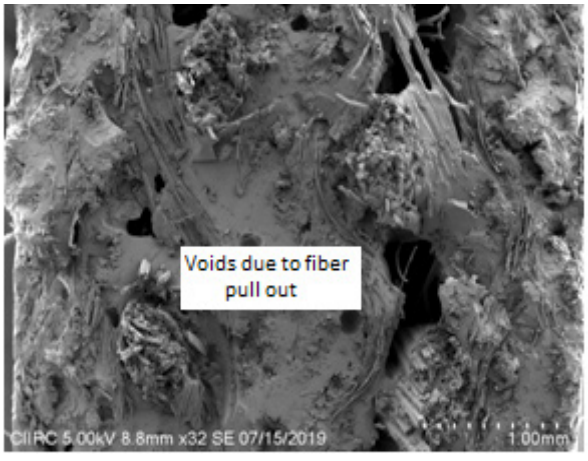
a. S1 10% Bamboo and 20% Jute.





b. S2 15% Bamboo and 15% Jute.





c. S3 20% Bamboo and 10% Jute.

Figure 6. Hybrid Bamboo/jute composites SEM tensile fracture pictures.

fiber epoxy. On top of that, Figures 7 and 8 provide a visual representation of how stacking sequence can affect the flexural strength and flexural modulus of said composites. Apparently, all hybrid composites showed a noticeable improvement in flexural strength and modulus compared to S4 and S5. It seems that the improvement is due to uniform load transfer to fibers, which is caused by good interfacial bonding that comes from incorporating a higher percentage of Jute fibers than bamboo fibers.

Based on the research findings, hybrid composite S1 has the highest flexural strength value of 80.25MPa and flexural modulus of 9.065 GPa. On the other hand, S4, which is made up of only bamboo fiber composites, has the lowest flexural strength values, at 58.19MPa and flexural modulus of 8.507 GPa, followed by S5 I, which is solely made up of jute fiber composites. It is interesting to note that the hybrid composite S1 has almost 36% more flexural strength than S4 and S5. This is because of the position of Jute fiber at the ends, as well as the increase in the percentage of Jute fiber which results in an increase in the flexural strength and flexural modulus. However, the percentage of bamboo fiber shouldn't be increased too much as that can lead to poor resistance to flexural load. Furthermore, in the Stacking sequence S5, there is an appreciable increase in the percentage of elongation, which indicates that the ductility of the material is greater compared to other materials. This is due to the only presence of Jute fiber in the composite material.

4.0 Conclusions

Fiber plants could be used to establish a fiber-based economy in regions that rely heavily on mining. It seems that natural fiber like bamboo and jute are the most promising fibers for post-mining land use due to their high biomass productivity, high fiber yield, and the fact that their fibers are already produced on a commercial scale. They hold great potential in creating a sustainable and productive post-mining economy. It seems like the research conducted by the study suggests that altering the stacking sequences of laminates in hybrid composites can enhance their mechanical properties. The study has drawn some conclusions based on its experimental investigation. Fiber-matrix adhesion in hybrid fibers treated with NaOH solution improves significantly.

- The tensile strength of composite with stacking sequence S1 exhibits highest value compared to S2, S3, S4 and S5 laminates.
- The maximum Modulus of elasticity in the S1 sample is 695.44 Mpa.
- Further, the bending strength of the S1 sequence specimen was higher compared to the other S2, S3, S4, and S5 laminates stacking sequences.
- The highest flexural modulus was 9.065 GPa in S1 laminate.

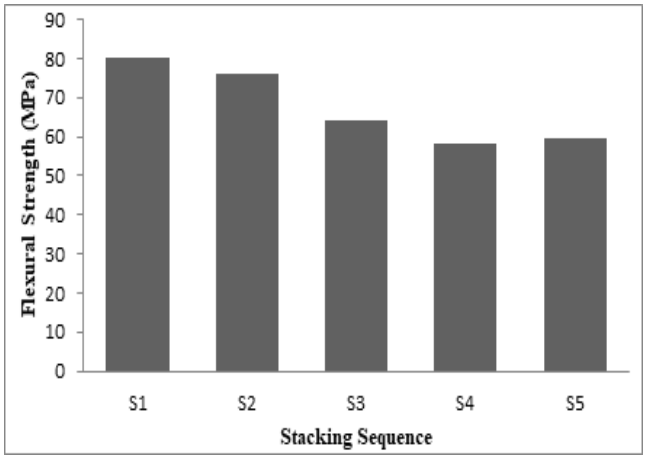


Figure 7. Variation of Flexural strength of specimens concerning stacking sequences.

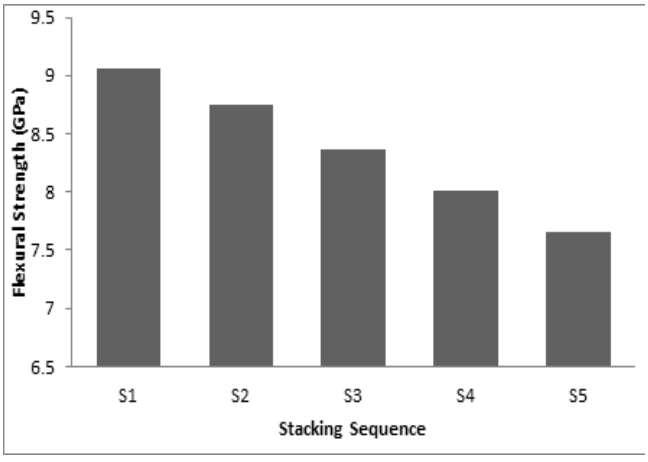


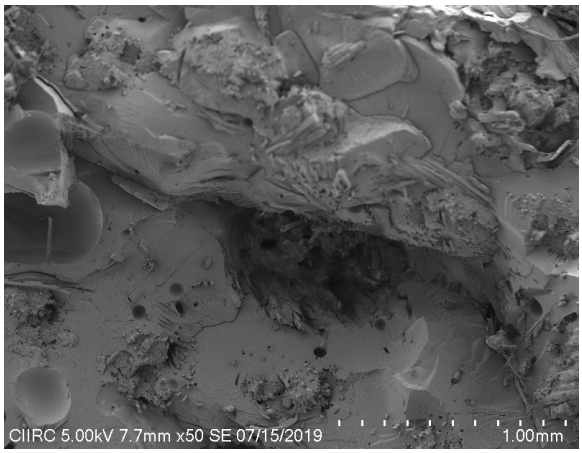
Figure 8. Variation of Flexural Modulus of specimens concerning stacking sequences.



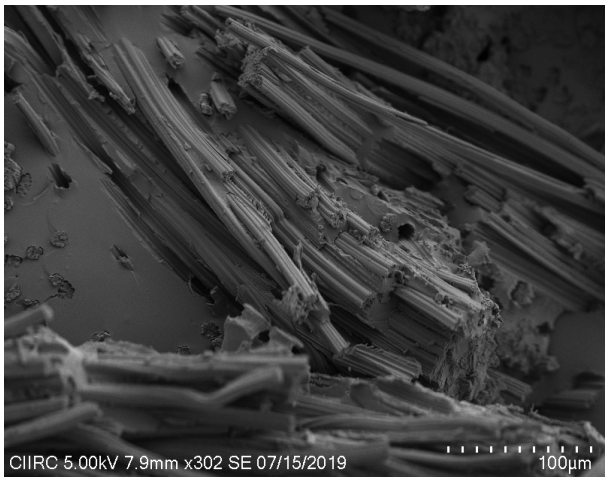


a. S1: 10% Bamboo and 20% Jute.





b. S2: 15% Bamboo and 15% Jute.





c. S3:20% Bamboo and 10% Jute.

Figure 9. Hybrid Bamboo/jute composites SEM bending fractures pictures.

- From SEM analysis, it is found that the failure of composites interface between the layers of the fabrics.

5.0 References

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