ICMIEE20-075

Characterization and Environmental Impacts on Mechanical Properties of Woven Jute/Carbon Fiber Reinforced Epoxy Composites

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ABSTRACT
As natural fiber is environment friendly and low cost as well as lightweight material, the development of natural fiber composites and its application are increasing day by day. Many researchers are doing research on jute fiber composites using twill type jute fiber mat. However, in this study, unidirectional jute fiber mat using jute yarn was used. The mat was fabricated by specially designed manual handloom and the composites and hybrid were fabricated by hand layout with cold press process. Unidirectional carbon/carbon fiber mat was incorporated to fabricate the hybrid composites. A series of composites and hybrids were introduced for the characterization of the composites and hybrid. Environmental impacts on mechanical properties were also investigated. Improved mechanical properties were found where jute fiber mats were placed separately in the case of hybrid composites.

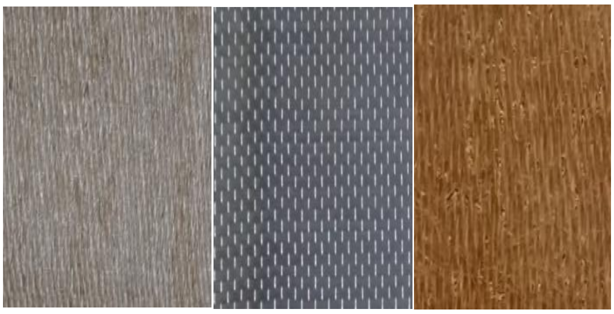
Keywords: Hybrid composites, Manual hand loom, Hand layout with cold press process.

1. Introduction

Materials are likely more deep-seated in our modern era. Communication, amusement, transportation, lodging, clothing, and nourishment production—virtually each portion of our regular lives is impacted to one degree or another by materials. Composite material is one of the best choices to meet the demand of present era. The goal of a composite is to realize a combination of properties that is not displayed by any single fabric, additionally to join the excellent characteristics of each of the component materials [1]. Reinforcement and matrix are the two basic portion of having the fabricated composites. Fabrics are of two types, continuous and discontinuous [2]. Different types of fiber such as hemp, jute straw, wood, rice husk, wheat, grain, oats, rye, cane (sugar and bamboo), grass, reeds, kenaf, ramie, oil palm purge natural product bunch, sisal, coir, water, hyacinth, pennywort, kapok, paper mulberry, raphia, banana fiber, pineapple leaf fiber and papyrus etc. [3]. are used nowadays to fabricate composites. Twill type jute cloth were used by some researchers to fabricate the composite. Due to the lack of interfacial bonding between the fibers and matrix, also for the orientation of the fibers in the composites causes less strength to the composite materials [4, 7]. In this study, unidirectional jute cloth were used, and the cloth were made of jute yarn. The jute yarn was collected from the local market. A manual hand loom was designed to prepare the unidirectional cloth by jute yarn [5, 6]. Also, environmental impacts on mechanical properties such as the moisture present in the air is taken into consideration [6].

2. Fabrication Procedure

A simple type special manual tool called handloom was used to woven the jute mat using jute yarn. Unidirectional carbon-carbon cloth of 317 grams per square inch (GSM) was collected from Lab Cast Co. Ltd. Japan to fabricate the composites and hybrids. The solution of epoxy crystal resin and hardener are used to as a matrix. The ratio of epoxy resin and hardener was 11:1 by weight.



(a) (b) (c)

Fig. 1 (a) Unidirectional jute mat, (b) Unidirectional carbon cloth, (c) Fabricated composites

Jute yarn of 0.8 mm to 1.0 mm diameter was used to fabricate the jute mat by manual handloom process [5]. Unidirectional woven jute mat of thickness 1.0 mm to 1.2 mm are used to fabricate the composite. Unidirectional jute mat produced by jute yarn are shown in figure 1(a). 317 GSM Carbon fiber cloth from Lab Cast Co. Ltd. is shown in figure 1(b), and fabricated jute-carbon fiber composite was shown in figure 1(c). Figure 2 shows the schematic representation of the fabricated composites and hybrids.

Table 1. Orientation of composites and hybrids

Types	Arrangement of materials
A	J + J + J + J

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B	J + C + C + J
C	C + J + J + C
D	J + C + J + C
E	C + C + C + C

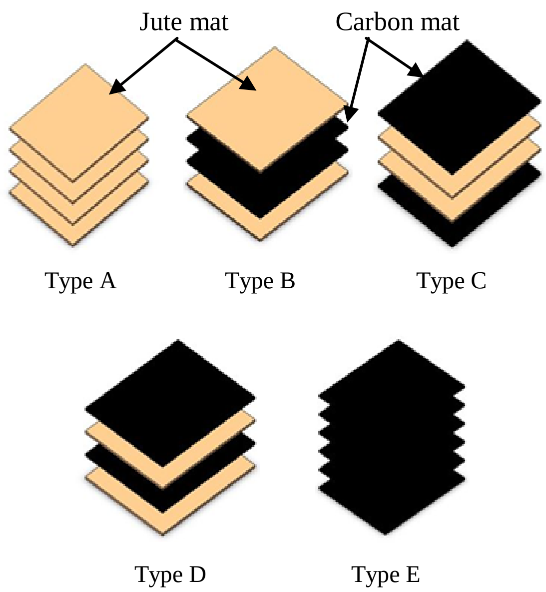


Fig. 2 Types of fabricated jute composites and hybrids

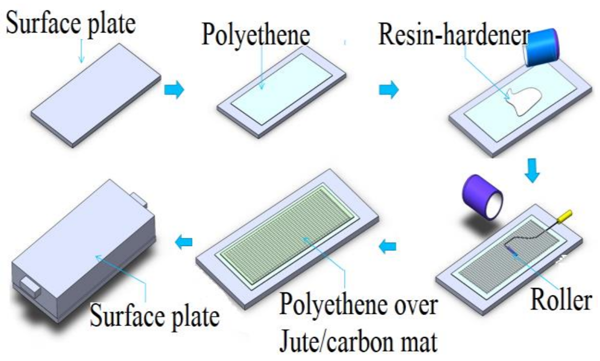


Fig. 3 Schematic diagram of sequential fabrication process

Aranno et. al describe the preparation of unidirectional jute mat using jute yarn prepared by manual hand loom, and the composites fabrication procedure by hand layout with cold press process [1]. Figure 3 shown the procedure of fabrication process. Carbon fiber mat of 317 grams per square meter (GSM) was incorporated with the woven jute mat of 500 grams per square meter (GSM) to fabricate jute hybrid composites.

3. Experimental results and discussion

3.1 Physical properties

The physical properties of a composite and hybrid material system are important mechanical properties in accomplishing the possibility for a particular application. Therefore, some physical properties of the fabricated composites and hybrids were examined, and the measurements were done at the room temperature. Table 2 shows the results of physical properties of the fabricated composites and hybrids. The maximum density was found in the case of *E* type specimen where all carbon cloth were used to fabricate the composites, and lowest specific gravity was found in the case of *D* type hybrid composites.

Table 2. Physical properties of fabricated composites and hybrids

Type	Density (kg/m^3)	Specific Gravity
A	1133.90	1.20
B	1164.31	1.22
C	1181.12	1.25
D	1100.65	1.19
E	1340.82	1.39

3.2 Impact Strength

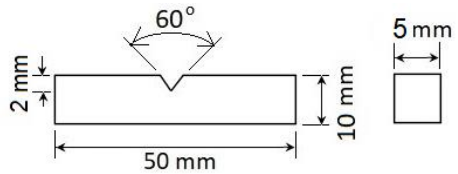


Fig. 4 Impact specimen specification

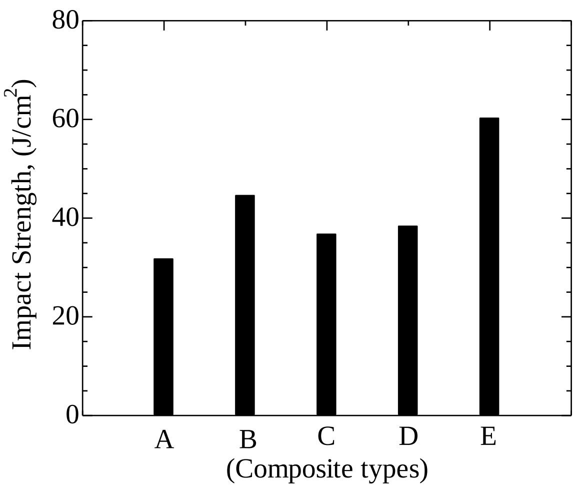


Fig. 5 Graphical representation of impact strength vs. composites and hybrids.

Charpy impact tests was carried out by a Pendulum Impact Tester to investigate the impact strength of the fabricated composites and hybrids. Figure 4 shows the geometry of the specimen to conduct charpy test. The length of the specimens were 50mm, width was 10mm, and thickness was 5mm. There was a 2mm depth notch of 60° angle at the center of the specimen. Figure 5 shows the results of impact strength. The maximum impact strength was found where all the carbon fiber was used to fabricate the composites (*E* type specimen). In the case of hybrid composite, *B* types shows moderate results. Figure 6 shows the fracture pattern after charpy test.

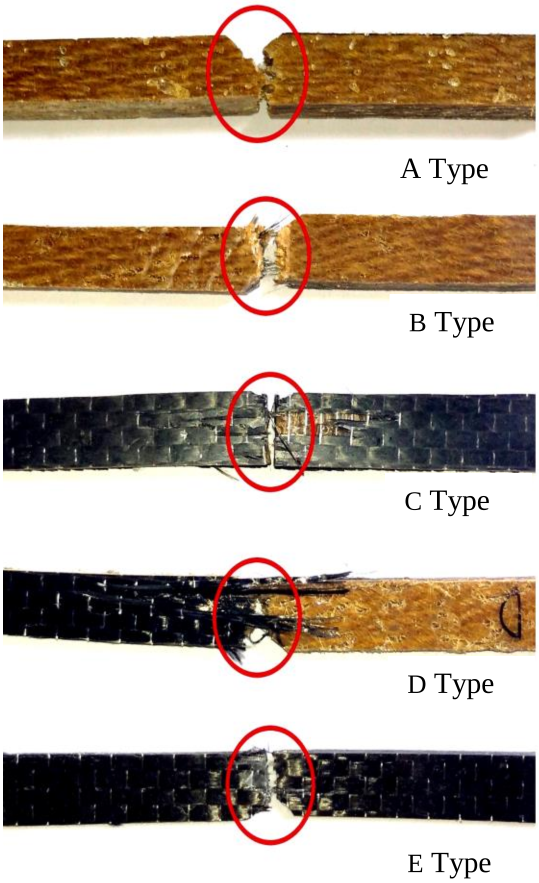


Fig. 6 Specimen after Impact test

3.3 Tensile Strength

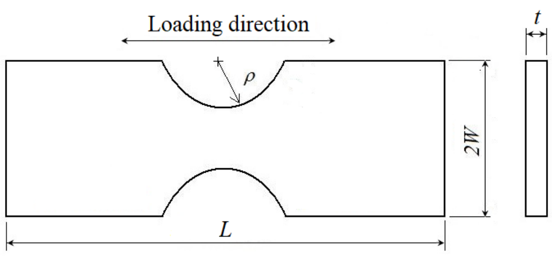


Fig. 7 Tensile specimen specification

To investigate the tensile strength of the fabricated composites, a series of tensile test were carried out. Dumble type specimen was used to carry out the test. Figure 7 shows the specimen geometry of the specimen. The length of the specimen was 130 mm, width was 30 mm. ASTM D638-01 standard was used to prepare the specimen. A universal testing machine (UTM) was used to investigate the tensile strength of the composites.

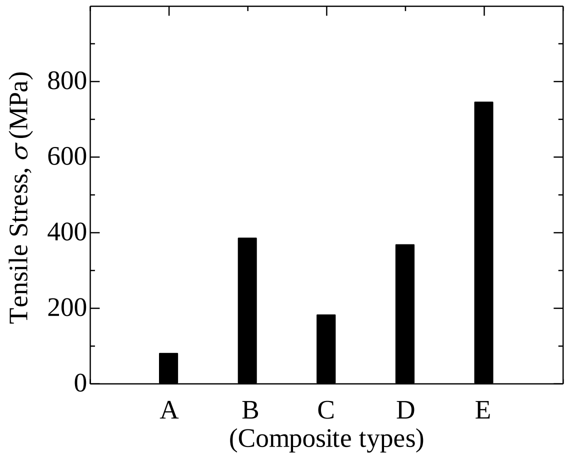


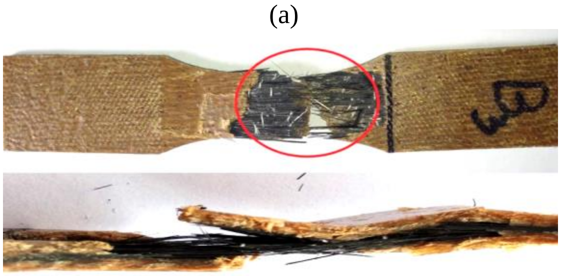
Fig. 8 Graphical representation of tensile stress

Table 3. Tensile test data

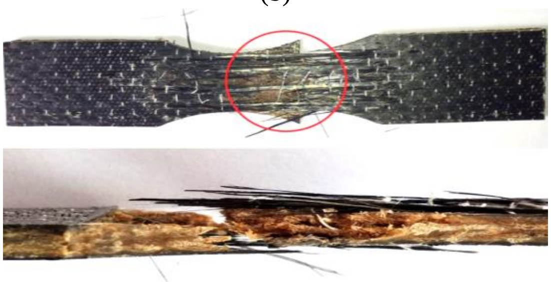
Types of Sp.	Peak Elongation (mm)	Break Stress (MPa)	Youngs Modulus (GPa)
A	1.836	80.3347	10.010
B	4.193	357.738	11.237
C	2.605	181.657	13.787
D	4.009	366.643	10.599
E	3.832	-4.043	22.445

Figure 8 shows the tensile strength of the composites and hybrids. Two specimens were used in each type of composites to get the appropriate results, and the fibers are in loading conditions in all the cases of the composites and hybrids. Minimum (80.33 MPa) tensile strength was found where all the jute fiber mat was used to fabricate the composites (*A* type specimen). Maximum result (745.17 MPa) was found where the carbon fiber cloths (*E* type specimen) fabricated the entire composites. Moderate results were found in the cases of *B* and *D* type hybrid composites. Table 3 shows some experimental parameters of tensile test. Peak elongation was observed in the cases of *B* and *D* type specimen, and minimum elongation was found for *A* type specimen. After the tensile test, fracture surfaces were analyzed. In all the cases, shear fracture has been observed. In most of the cases, 45° shear fracture has been occurred. Figure 9 shows the fracture surfaces after the tensile test.

(a)

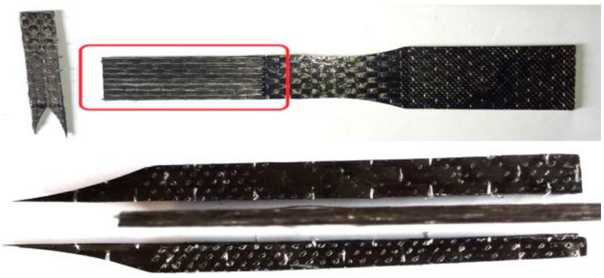


(b)



(c)

(d)



(e)

Fig. 9 (a) Type-*A* (b)Type-*B* (c) Type-*C* (d) Type-*D* (e) Type-*E*

3.4 Flexural Strength

The flexural strength was measured by three point bending test by Universal testing machine. A rectangular type specimen as shown in figure 10 was used to investigate the flexural strength. Figure 11 shows the experimental results of flexural strength of fabricated composites and hybrids. *D* type specimen shows the maximum and *A* type specimen shows the minimum flexural strength. Table 4 shows some experimental results of flexural test.

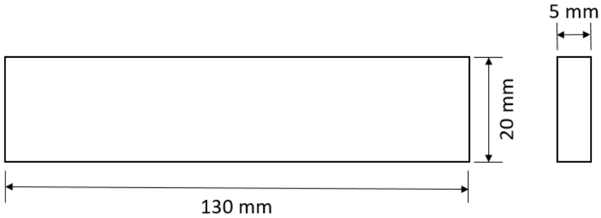


Fig. 10 Flexural specimen specification

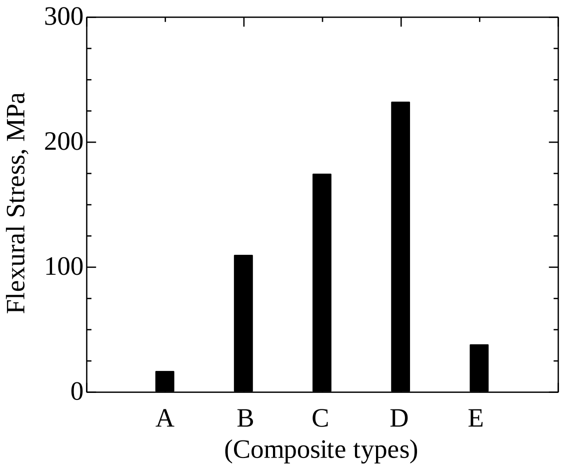


Fig. 11 Graphical representation of flexural stress

Table 4. Flexural test data

Types of Specimen	Max Deflection (mm)	Flexural Strain (mm/mm)	Flexural Modulus (GPa)
A	2.022848	0.00574826	2.88
B	14.50761	0.02714132	4.04
C	9.703349	0.017061722	10.19
D	5.815688	0.009547421	24.41
E	4.74105	0.004820068	7.87

3.5 Moisture Absorption

Water absorption analysis was done by immersing the test samples into the normal surface water. Five types of composites and hybrid specimens was immersed in the water for 10 weeks at room temperature. The specimens were withdrawn from the water and wiped dry to remove the surface water before the weight measurements. Then the samples were weighed periodically using an analytical precision scale accurate to 0.1 mg. After collecting data of weight of specimen after the withdrawn of the specimen from the water, the relative water absorption (W_A) was measured using Eq.1.

$$W_A(\mathrm{t}) = \frac{W_n - W_o}{W_o} \times \mathbf{100} \qquad \mathbf{(1)}$$

Where, WA(t)=% of water absorption at each time (t), Wn=specimen weight at each time, W_0 = initial specimen weight before the specimen submerge under water. The water absorption tests were stopped after 10 weeks. From the experimental results, it was found that *E* type specimen has very less tendency to absorb water. The water absorption after 10 weeks is within 0.5%. On the other hand, as jute fiber has hydrophilic properties, the percentages of water absorption is higher in hybrid composites.

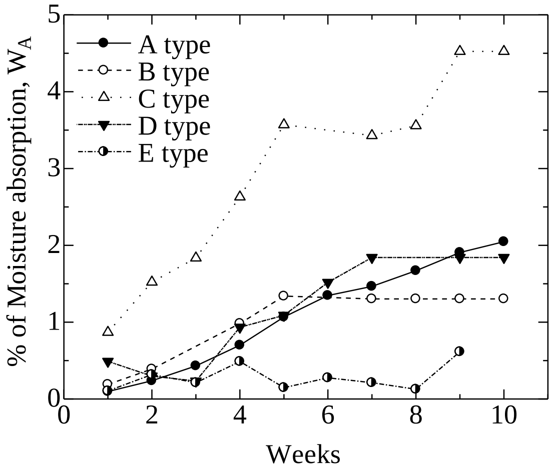


Fig. 12 % of Water absorption of fabricated composites

3.6 Swelling Thickness

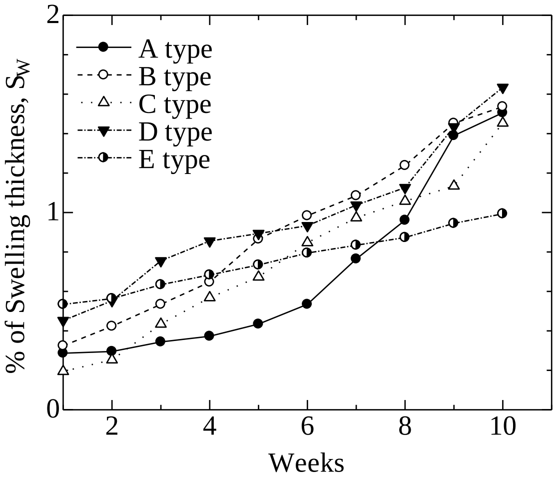


Fig. 13 % of Swelling thickness of fabricated composites

As the fabricated material's reinforcement is jute which contains cellulose. Cellulose has hydrophilic property so that the composites were swelled under submerged condition (*A-D* type specimen). The sample thickness was measured at three different position of the sample to have average value. Percent of thickness was measured by using Eq. (2).

$$S_w \, \mathrm{T}\,(\mathrm{t}) = \frac{T_n - T_0}{T_0} \times 100 \qquad (2)$$

Where, Sw T (t) = % of swelling thickness of the specimen at each time (t), Tn = specimen thickness at each time, To= initial specimen thickness before the specimen submerged under water. The Swelling Thickness tests were stopped after 10 weeks. From the experimental results, it was found that even though jute has a hydrophilic property, the percentages of swelling thickness is within 1.5% in most of the cases.

3.7 Heat Reversion Test

This test was carried out by examining the specimen at three different temperatures 100°C, 130°C, 150°C. Expansion or contraction was seen in the composites were quite different in value. Among the types, *D* type provides better result as the percentage of expansion or contraction is 0% in three different temperatures.

Table 5. Results of heat reversion test

Type	Heat reversion (%)		
	100° C	130° C	150° C
A	1.67	0	1.67
B	1.67	1.67	3.33
C	3.33	1.67	2.5
D	0	0	0
E	5	1.67	5

3.8 XRD analysis

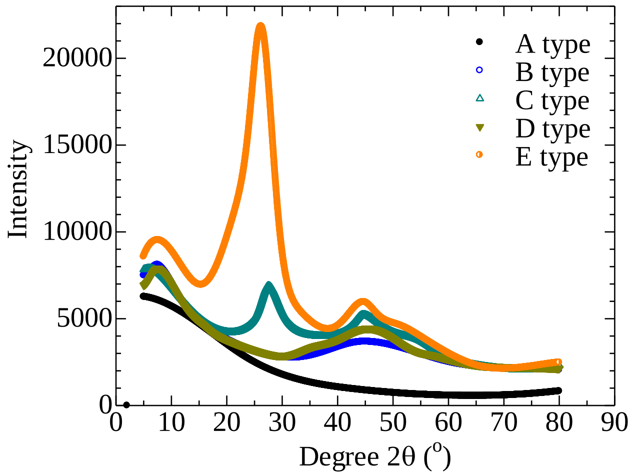


Fig. 14 *XRD* patterns of fabricated composites and hybrids

Figure 14 shows the experimental results of *XRD* of fabricated composites and hybrids. In the case of *C* and *E* type specimens, three peaks were observed, and the highest peak was observed at 2θ=26.2°. However, in the case of *A* type specimen, one peak has been observed at 2θ=5°. In *B* and *D* type specimens, two peaks were found. For *B* type specimen peak was observed at 2θ=7.48° and 44.9°.

3.9 Microstructure by *SEM*

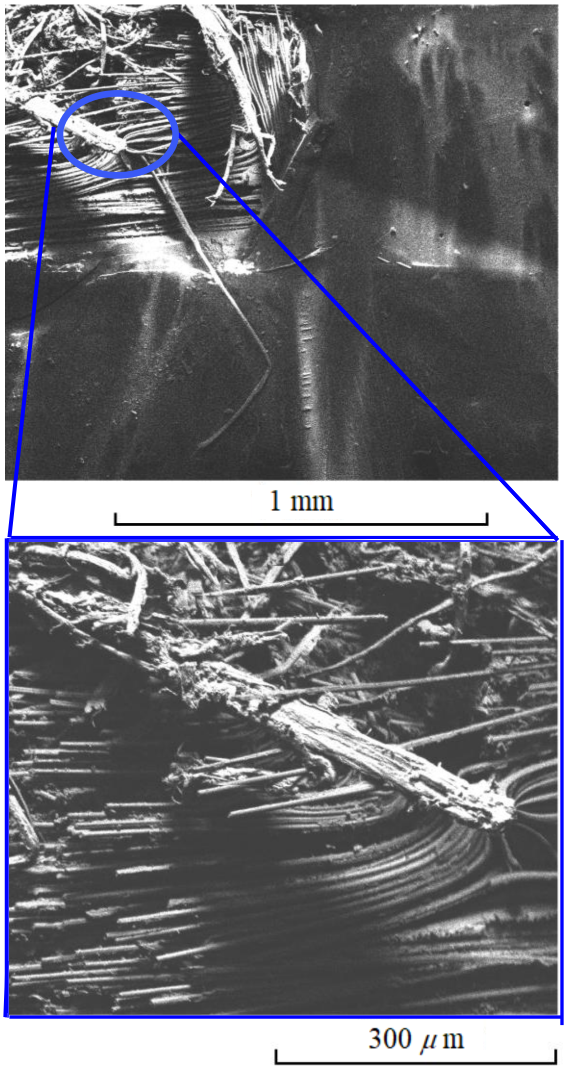


Fig. 15 Micrograph of fabricated hybrid composites (*D* type) by *SEM*

Figure 15 shows the microstructure of *D* type hybrid composites where jute and carbon fiber mat were used alternately during composite fabrication. Scanning electron microscope was used to analyze the micrograph of the composites. From the figure, the bonding between the matrix and fiber were visible clearly. Many voids founds in the composites, which causes the poor mechanical properties. By improving the fabrication quality and method, these voids could be eliminated.

4. Conclusions

The mechanical characterization of woven jute-carbon composites and hybrids were carried out in this study. At least three specimens were used for a single mechanical property test for each cases. The output were found as follows:

1) Enhanced mechanical properties were found when carbon fiber mate was incorporated with the jute mate, and shear fracture occurs in all the cases of composites and hybrids.
2) Hybrid composites shows better flexural strength than that of jute fiber composites and carbon fiber composites.
3) As jute fiber contains cellulose and has a hydrophilic property, *A-D* type composites absorb moisture from the environment. However, after 2 and half months it became saturated. Carbon composites does not have impact on moisture, and the swelling thickness is lies between 0 to 1.5%.
4) All the composites gives excellent result of heat reversion test within 130°C.
5) The interfacial bonding between fiber and matrix could be improved by modifying the fabrication process. From the *XRD* analysis, hybrid composites shows better results than that of jute composites.

5. References

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Acknowledgement

Authors are thankful to the Atomic Research Commission testing laboratory of Bangladesh for their enormous support throughout this experiment.

Nomenclature

W_A: Water Absorption
S_W: Swelling Thickness
SEM: Scanning Electron Microscope
XRD: X-Ray Diffraction
GSM: Gram per Square Meter