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Experimental Investigation on Mechanical Characterization of Jute-Kevlar Hybrid Composites

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ABSTRACT
The use of composite materials is increasing day by day. The main objective of this study was to characterize the mechanical properties of Jute-Kevlar reinforced epoxy hybrid composites, and investigate the environmental impacts on the physical and mechanical properties of the hybrid composites. Unidirectional jute mat which is made of jute yarn was used, and the mat was prepared by special type of manual hand loom. Hand layout with cold press technique was used to fabricate the composites and hybrid. The internal bonding between the matrix and fiber reinforcement were examined in a scanning electron microscope (*SEM*) and analyzed. Tensile test was done in a universal testing machine. The result shows that Kevlar has an impacts on the mechanical properties of fabricated hybrid composites. Also, it has an influence of heat on change in length of fabricated composites and hybrid.

Keywords: Jute-Kevlar Hybrid composites, Unidirectional mat, Hand layout with cold press process, *XRD*, *SEM*.

1. Introduction

When two or more different kind of fibers are encapsulated in a matrix and produce a whole new material of different characteristics than those reinforcing fibers then this material is called composite materials. If two or more fibers work as reinforcement for the matrix then it is called hybrid composite. The function of the matrix is to transfer the load into the reinforced fibers and to protect the fibers from mechanical or environmental damage and to bind the composite. The reinforced fibers produce rigidity and required strength. Natural fiber are produced from nature growing on plants. Synthetic fibers are manmade fibers which are made in laboratory by chemical synthesis. Composites provide the potential of achieving a balanced pursuit of stiffness, ductility, as well as bending and membrane related mechanical properties with weight savings, reduced notch sensitivity, improved fracture toughness, longer fatigue life and excellent impact resistance [1].

Natural fibers are used in composite because of it's low density, high strength to weight ratio, These fibers are renewable, nonabrasive in nature, so little concern in terms of health and safety during handling of fiber products. In addition, they exhibit excellent mechanical properties and have low cost. This good environmental friendly feature makes the materials very popular in engineering markets such as the automotive industry [2-5], especially, on the interior part of the automobile industry. However, these natural fibers are relatively poor moisture resistance, fiber wetting, and its adhesion to the matrix, which affecting mechanical properties. Then, several chemical surface modifications in the natural fibers have been carried out to improve [6-8]. The more efficient way of solving this problem is to reinforce another fiber which is resistive to moisture and to make a hybrid composite. A synthetic fiber has the characteristics of moisture resistivity.

Among all the natural fibers, jute fibers are easily available and very cheap in Bangladesh. Jute fibers consists of cellulose, lignin and hemicelluloses. Furthermore, it has low content of lignin which made it low weather resistant. Jute fibers are biodegradable and recyclable. They are renewable resources and these materials are CO_2 neutral [9]. Kevlar is a synthetic fiber having high strength to weight ratio. Kevlar fiber can withstand high temperature and have negative thermal expansion coefficient. It also have high tensile strength but very poor compressive strength.

There are many processes to fabricate composites. Among all the fabrication processes, Vacuum assisted Resin Transfer Molding (*VaRTM*) process is comparatively expensive, hand layout with cold press process is used in this experiment. The main objectives of this study was to introduce new types of composites and hybrid having elevated mechanical properties with cost effective fabrication comparing with others.

2. Materials and Methodology:

Table1. Orientation of the layers of the specimen

Specimen Type	Specimen Layer Orientation			
Type *A*	*J*	*J*	*J*	*J*
Type *B*	*J*	*K*	*K*	*J*
Type *C*	*J*	*K*	*J*	*K*
Type *D*	*K*	*J*	*J*	*K*
Type *E*	*K*	*K*	*K*	*K*

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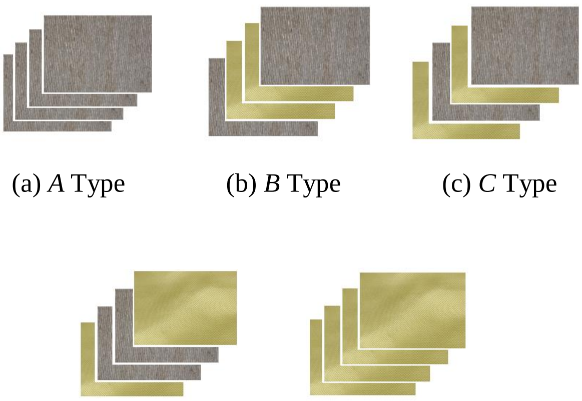
Clean and dry jute yarns of 0.65 mm to 0.75 mm diameter were used to fabricate the Jute-Kevlar hybrid composites. Firstly with the assist of hand loom jute yarns were used to make unidirectional woven jute clothes [10, 11]. Then Kevlar fiber was collected from Lab-Cast Company, Osaka, Japan. Epoxy resin and hardener were then mixed together to find out the suitable ratio. From the test, epoxy resin and hardener were mixed, and the ratio of the epoxy resin and hardener was 11:1 by weight to fabricate these composites. The solution was mixed homogeneously and then wait for 5 to 10 minutes. Then the fabrication process was started.

(a) (b)

Fig. 1 Woven mat: (a) With yarn type jute, (b) Kevlar



(a) *A* Type (b) *B* Type (c) *C* Type

(d) *D* Type (e) *E* Type

Fig. 2 Isometric view of Specimen Model

A layer of unidirectional woven jute fiber mat was laid down with resin, hardener solution onto it, and rolled the solution by hand roller putting on the hand gloves. The arrangement of layers were different for different specimens. In all the cases, the directions of the fibers were arranged in the loading direction because the composites having the fibers parallel to the loading directions gives the higher tensile strength than that of perpendicular to the loading direction [10, 12]. 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 [11]. Figure 3 shows the schematic diagram of the fabrication process of the composites and hybrid. Five type of specimens were fabricated following the same procedure.

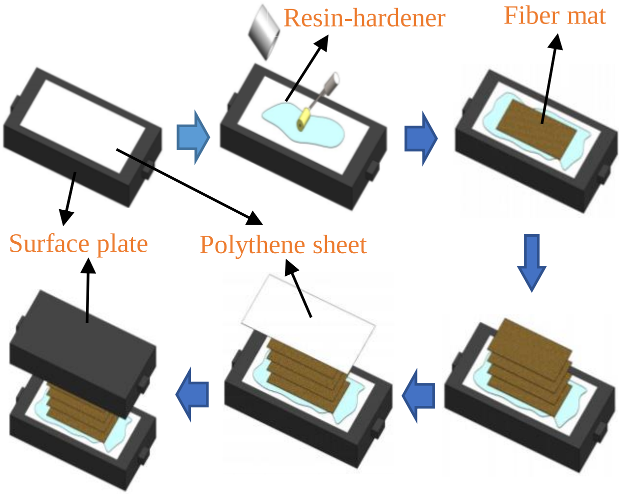


Fig. 3 Schematic diagram of hand layout with cold press fabrication process

3 Result and Discussion

3.1 Physical properties

The physical properties of the fabricated composites and hybrids were also investigated. Table 2 shows the experimental results.

Table 2. Physical properties of fabricated composites and hybrids

Type	Density (kg/m^3)	Specific Gravity
A	1133.96	1.387
B	1098.84	1.015
C	1144.74	1.203
D	1136.09	1.165
E	1102.99	1.167

3.2 Impact Test

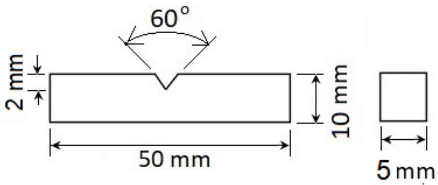


Fig. 4 Geometric Shape of Impact Specimen

Charpy test was applied to measure the impact strength of the fabricated composites and hybrid. Figure 4 shows the geometry of the charpy test specimen which follows according to the ASTM D6110 standard [13]. The geometry of the specimen is shown in Figure 4. From the Figure 5, it was found that impact strength was maximum when all the layers of the composite were Kevlar fibers. This is type *E*, reason behind this was the rigidity provided by Kevlar fiber. Type *A* was founded with the minimum impact strength. The impact strength was increased considerably due to the incorporation of Kevlar fibers with unidirectional woven jute cloth. From the experimental results, it was found that the layers orientation of jute and Kevlar fiber has a great impact on impact strength. This was found from the experimental data of type *B*, type *C*, type *D*.

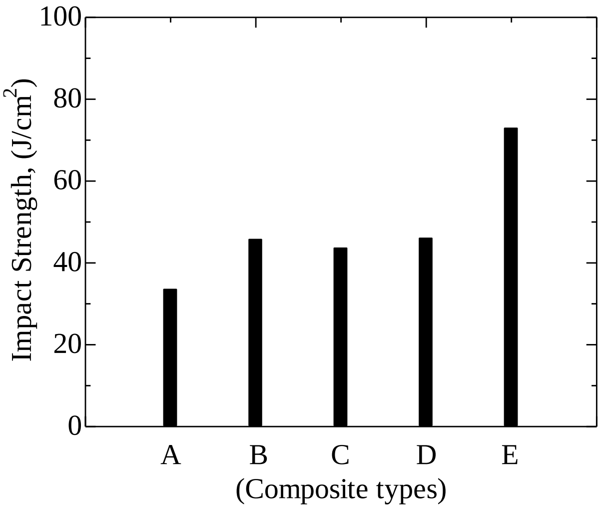


Fig. 5 Impact Test results

3.3 Tensile Test

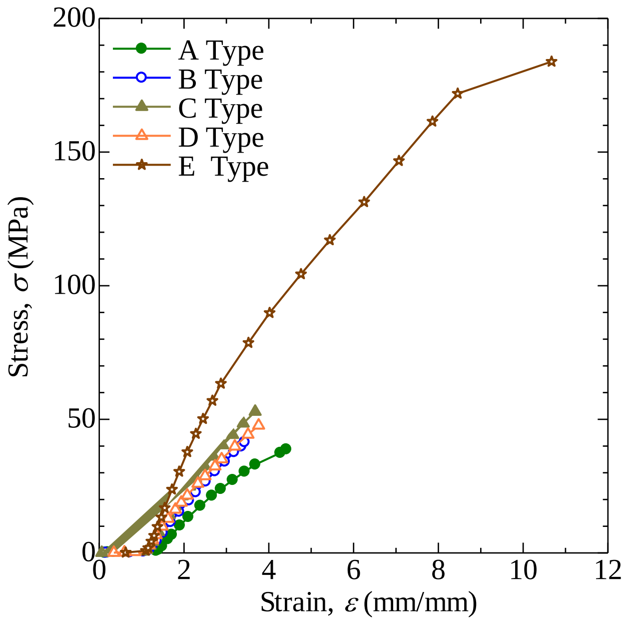


Fig. 6 Tensile Stress vs. Strain diagram

Tensile test was carried out in a universal testing machine and the specimen was cut according to the ASTM D638-01 standard [14]. A series of tests were done to find out the tensile strength of the hybrid composites. From the experimental result, it was found that type *A* which was composed with 4 layers of unidirectional jute fiber mat made of yarn got the minimum tensile strength among the 5 types of composites (38.77 MPa). But comparing with the traditional jute fiber composites (twill type), it was much more better in strength because of its unidirectional clothes which were at loading direction, and the clothes were made of jute yarn [11, 12]. With the incorporation of Kevlar fiber with jute fiber, the tensile strength increased, because of the rigidity of Kevlar fibers. Type *E* which were composed with 4 layers of Kevlar fibers showed the maximum tensile strength 9183.85 MPa). But among the hybrid composites, type *C* in which jute and Kevlar fiber layer was alternatively poised, was given comparatively higher tensile strength of 52.89 MPa among the hybrid. Figure 6 represents the stress vs. strain curve of the fabricated composites and hybrid. Figure 7 shows the calculated young's modulus of those composites, and table 3 shows the peak strain and peak elongation during the tensile test.

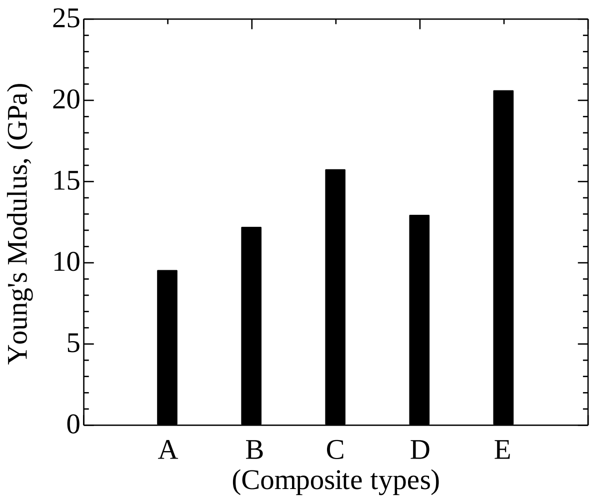


Fig. 7 Young's Modulus of fabricated composites

Table 3. Peak strain and peak elongation of fabricated composites and hybrid

Types	Peak Strain (%)	Peak Elongation (mm)
A	1.17	1.44
B	0.96	1.32
C	0.99	1.45
D	1.07	1.46
E	2.26	3.11

3.4 Environmental impact

Percentage of water absorption and percentage of swelling thickness were observed. The specimens were submerged in water for 7 weeks. Water absorption was measured by immersing the test samples into the normal water at room temperature. All 5 types of specimens were submerged under normal surface water. The specimens were taken out from the water and wiped by dry cloth to remove the surface water before the weight measurements. Then the samples were weighed periodically using an analytical precision scale with accuracy up to 0.001 mg. After measuring the specimen weight and immersion time data, the relative water absorption (*Wa*) was calculated using Equation (1):

$$Wa(t)=\frac{Wn-Wo}{Wo}\times 100 \quad (1)$$

Where, $Wa(t)$ = relative water absorption of the specimen at each time (t), Wn = specimen weight at each time, Wo = initial specimen weight.

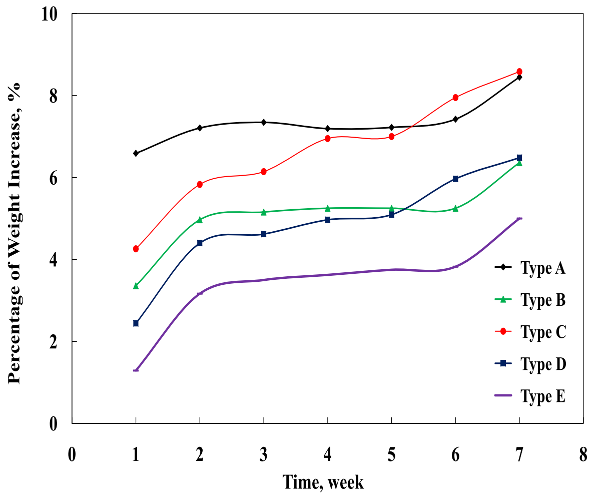


Fig. 8 Result of Weight Absorption Test

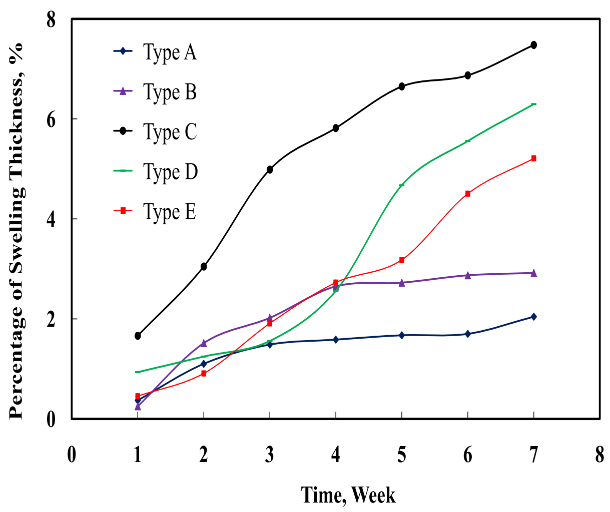


Fig. 9 Result of Swelling Thickness Test

On the other hand, the relative water absorption (*Ta*) was calculated using Equation (2):

$$Ta(t)=\frac{Tn-To}{To}\times 100 \quad (2)$$

Where, $Ta(t)$ = relative water absorption of the specimen at each time (t), Tn = specimen weight at each time, To = initial specimen weight [15]. After week 1 the weight and thickness of specimens were increased due to the absorbed water. Similarly, the weight and thickness were gradually increased with time. From Figure 8 we can say that type *E* (all layers of Kevlar fiber) had the minimum percentage of water absorption**.** When jute fibers were incorporated with Kevlar fiber, the weight and thickness were increased because jute fiber can absorbs more water than Kevlar fiber. Figure 9 shows the percentages of swelling thickness, and it shows that the rate is higher in the case of *C* type specimen. From Figure 9 we can point out that type *C* was the specimen with maximum swelling thickness and all other specimens swelling thickness were increased gradually with time.

3.5 Heat reversion Test

Heat reversion test were carried out in a furnace with three different temperatures. At first this test was carried out for 100°C temperature. The specimens were marked at a definite length. Then specimens were put in the furnace in a box where the specimen were submerged with petrol. After reaching the temperature of 100°C waiting 10 minutes the specimens were taken out from the furnace to check out if there was any change in the specific length. Similar tasks were also done at 130°C and 150°C temperature and the change in specified length was also noted down. The change in length was measured with a scale. From table 4, it can be found that there was no change in length in type *A* specimen at 100°C, 130°C and 150°C temperature. In type *B*, specified length was changed. Type *C* and type *D* had also influence on the heat reversion test. With the experimental analysis, it was proven that jute fiber composites does not have any influence on temperature effect on its length at 100°C, 130°C and 130°C temperature, respectively. However, Kevlar fiber has a little influence of heat on its length at 130°C and 150°C, respectively. Therefore, the hybrid composites also has a little influence of temperature on its length as it contains Kevlar fiber. The heat reversion was calculated by using equation (3):

$$\text{Heat reversion} = |(\Delta L)|/L_0 \times 100\% \quad (3)$$

Where, $|\Delta L| = L_0 - L$; L_0 is the distance between the marks in millimeters before test, and L is the distance between the marks in millimeters after the test.

Table 4. Results of heat reversion test

Type	Heat reversion (%)		
	100° C	130° C	150° C
A	0	0	0
B	0	0	1.58
C	0	1.58	1.58
D	0	0	1.61
E	0	1.67	1.67

3.6 *XRD* Analysis

Figure 10 shows the *X*-ray diffraction patterns of fabricated composites and hybrids at room temperature. According to the *XRD* chart two peaks for *A*, two peaks for *B*, six peaks for *C*, four peaks for *D* and three peaks for *E* were recognized. The peak is due to X-ray diffraction from the [100] plane. Among all the peaks, there were differences in the peak intensities which represent the fiber crystallinity changes. Peaks are visible at approximately 2θ = 7.6° and 46.7º for pattern *A*; 2θ = 7.02°and 44.12° for pattern *B*; 2θ = 8.02°, 24.36°, 26.82°, 29.94°, 39.76° and 80.76º for pattern *C*; 2θ = 7.46°, 24.22°, 29.74° and 41.24º for pattern *D*; 2θ = 8.06°, 23.54° and 29.44º for pattern *E*; arise with the intensity 7661 and 4049.006; 7921.496, and 5238.583 cps; 7942.553, 10240.65, 9112.086, 8892.014, 6711.354 and 2632.295 cps; 8099.917, 11072.1, 7243.101 and 5254.064 cps; 8094.183, 17553.9 and 7674.25 cps for *A; B; C; D; E* pattern, respectively.

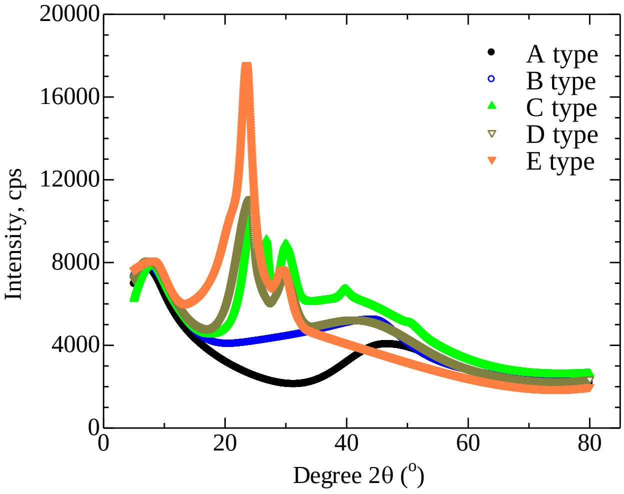
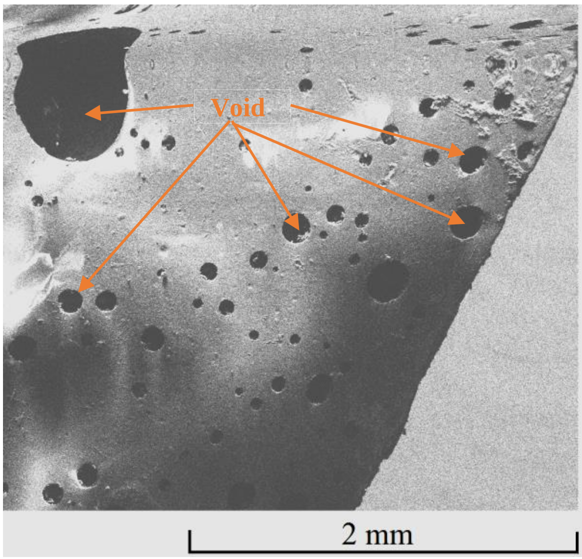


Fig. 10 *X*-ray diffraction pattern for the fabricated Composites and hybrids at room temperature

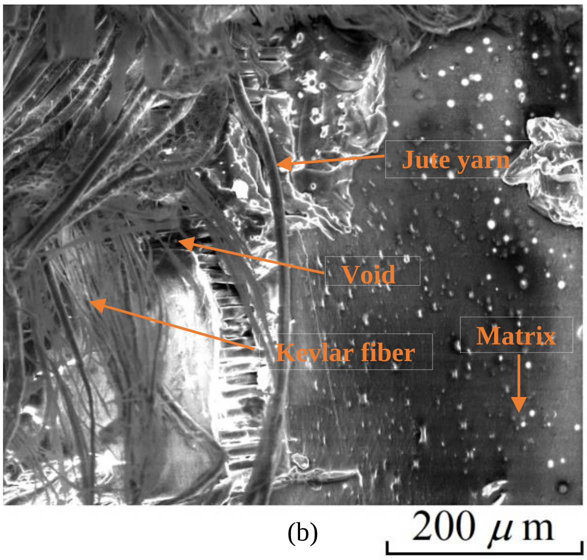
The increase in the peak intensity (I_{max}=17553.9 was found at 2θ = 23.54°) of pattern *E* indicates that the crystallinity has increased as the crystallinity of Kevlar fiber is higher. Furthermore, the increase in crystal size strength has increased. The results confirm the increase in the crystallinity of the composite fibers, which may contribute to its applications in polymer composites.

3.7 *SEM* analysis

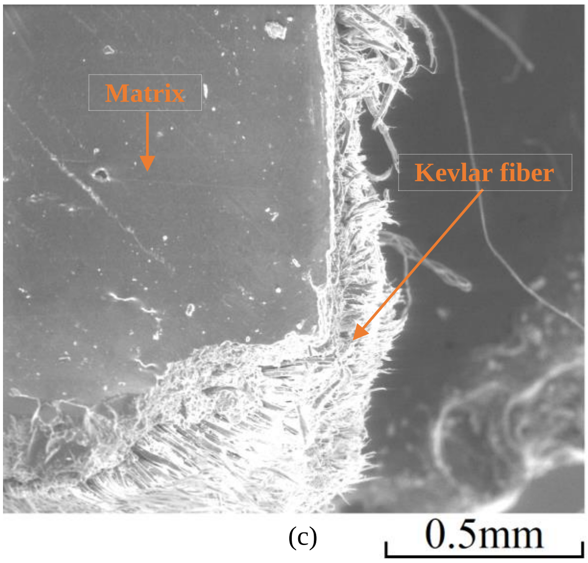
Figure 11 shows the microstructure of *B*, *D*, and *E* type specimen. The microstructure of *D* type specimen was taken from the cross-sectional area of the specimen, and the microstructure of *B* and *E* type specimens were taken from the side surface of the specimen without polishing the surface. From figure 11(b), the interfacial bonding between the Kevlar and jute fiber is visible clearly. The bonding are not so strong due to the formation of voids between the jute and Kevlar fiber. This is the main reason to having lower strength comparing with the tensile strength of *E* type specimen. Many voids can be easily observed which the causes of poor mechanical properties. The voids could be eliminated by improving the fabrication process. Figure 11(c) shows the micrograph of *E* type specimen. It is clearly visible that the bonding among the Kevlar fiber cloths are stronger than that of other hybrid composites. Therefore, the voids could be hardly be found in *E* type composite.



(a)



(b)



(c)

Fig. 11 Scanning Electron Micrograph of : (a) *B* type; (b) *D* type; (c) *E* type specimen at room temperature by *SEM*

4. Conclusions

The mechanical characterization of jute-kevlar hybrid composites were investigated in this study. Three samples were used in each cases to conduct the tests to evaluate the mechanical properties, and the deviation were found within ±3%. The following output were found:

1) Improved mechanical properties were obtained when kevlar fiber mat was incorporated with the jute fiber.
2) Hybrid composites shows improved tensile strength than that of jute fiber composites (*A* type) as the hybrid contains Kevlar fiber higher tensile strength.
3) As jute fiber contains cellulose and has a hydrophilic property, *A-D* type composites absorb moisture from the environment. Therefore, the thickness of jute fiber composites and hybrid are also increases. However, Kevlar fiber has a little impact of moisture. From the experimental result, swelling thickness was found 4.5%), and moisture absorption was about 2%.
4) All the composites gives excellent result of heat reversion test within 100°C. Jute fiber does not have any impact on heat reversion. As Kevlar fiber has an influence on heat over 100°C, the length was changes within 1.67% in the cases of hybrid and Kevlar fiber composites. But the result is within the limit of the international standard for composites and polymer materials.
5) The interfacial bonding between the jute fibers and Kevlar fibers are not strong. Therefore, many voids observed by the *SEM* analysis. So, the tensile strength of hybrid composites does not increase considerably. The bonding could be improved and the voids could be eliminated or reduced by modifying the fabrication process.
6) From the *XRD* analysis, it was found that the crystallinity increased of the composite fibers, which may contribute to its applications in polymer composites.

5. Acknowledgement

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NOMENCLATURE

W_A	: Water Absorption
$\boldsymbol{S}_W$	: Swelling Thickness
SEM	: Scanning Electron Microscope
XRD	: *X*-Ray Diffraction
VaRTM	: Vacuum assisted Resin Transfer Molding