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Effects of the Fiber Orientation on Mechanical Properties of Jute Fiber Reinforced Epoxy Composites

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ABSTRACT

Among all the natural fiber epoxy composites jute turns to be a leading one reinforcement because of it's strong bonding with matrix and also the easiest one to fabricate. Three types of jute fiber woven mat was prepared using a manual handloom to fabricate the composites by land layout with cold press process. It was discussed that mechanical properties of the composites depend on the volume and orientation of reinforcement in a certain amount of matrix and SEM and XRD were carried out to comprehend more precisely that the fiber quantity and orientation into the matrix is a key factor. In addition, the effects of the moisture on physical properties were also investigated. Higher mechanical properties were found where unidirectional mat using yarn was used to fabricate the composites. In this study, the orientation of the fiber reinforcement was varied to investigate the mechanical properties of the composites.

Keywords: Jute fiber, Fiber orientation, Mechanical properties, Physical properties, XRD.

1. Introduction

Composite material is the constitution of two materials which are not same inherited but forms a new single structure to achieve different physical and mechanical properties which is not possible to possess for any component material alone. Research on composite materials are increasing day by day and the main reason behind it is different permutation and combination of reinforcement material which forms new composites possessing some advantages like high strength, better fatigue performance and damage tolerance, low thermal expansion, non-magnetic properties, corrosion resistance, low energy consumption during fabrication [1]. For example, carbon fiber reinforced composite is one fifth of the weight of 1020 grade steel but still it can be five times stronger than the steel [2]. The weight of Aluminum 6061 grade is close to carbon fiber composites but it is seven times weaker than carbon fiber composite [2]. Fiber orientation is one of the factors, which has a great effect on the performance level of composites [3]. These composites consists of matrix and reinforcement. Matrix works as a barrier from contradictory environment due to high temperature and humidity to protect the periphery of the composites. As most of the natural fibers are thermally unstable above 200˚C [4], thermosets can be used as matrix to keep the fibers in intended orientation and to make a dynamic bond with the reinforcement [5, 6]. As per demand for the ecology, the recent researches are driving towards natural fiber reinforcement replacing synthetic fiber for possessing recyclability, bio-degradability, renewability and low cost. Besides the use of bio-composite material enhances the flexural and impact properties [7]. Among all the natural fibers, jute is the second most important vegetable fiber after cotton in terms of global production [8]. Besides, it has the mixing capability with other fibers and makes durable and strong composites, which are easy to handle. As jute is a bast fiber like wood, it can be a replacement of wood for indoor applications in housing. One has high insulating properties, it may find applications in automotive doors, ceiling panels and panel separating the engine and passenger compartments [9]. In this study, both unidirectional and bidirectional fiber mats produced from jute yarn and unidirectional fiber mats produced from jute fiber have been used for the fabrication of composites. The purpose of this research is to investigate the effect of the fiber orientation on various mechanical and physical properties of the composites.

2. Experimental Procedure

2.1 Reinforcement material

Jute yarn, fiber and twill type jute mat were used as reinforcement for the composites. They were collected from a local market. Diameter of the yarn is 0.65 to 0.75 mm.

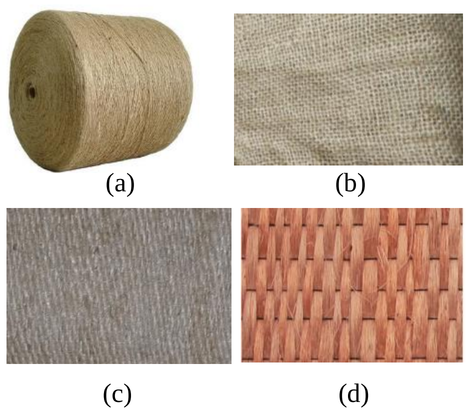

Fig. 1 Reinforcement material (a) Jute yarn (b) Twill type jute mat, (c) Unidirectional mat made by jute yarn, (d) Unidirectional mat by jute fiber.

2.2 Preparation of epoxy resin-hardener mixture

As a matrix, epoxy resin (LY 556) and hardener (HY 951) were used. After mixing the resin and

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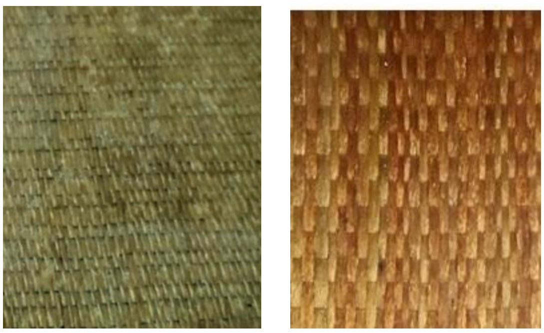
hardener in different ratios, it was found that the ratio of 11:1 is best suited according to the trial and error method. Prior to the fabrication process, many combinations were applied to determine the appropriate ratio between epoxy resin and hardener The.y were well mingled for 5 to 10 minutes.

2.3 Fabrication process

Unidirectional woven mat was produced by manual handloom [10, 11]. The thickness of the woven jute mat is approximately 0.75 mm, Gram per square meter (GSM) of this woven mat is about 550. Twill type woven mat of same GSM was collected. Hand layout with cold press process was applied to fabricate the composites as it is a cost effective, and swift in manufacturing. A thin layer of polyethylene sheet and grease were put on the surface plate to avoid the stickiness of epoxy resin to the surface plate. After that the resin–hardener solution was applied on that polyethylene surface with a roller. Then a layer of woven jute fiber mat was laid down and resin-hardener mixture was poured and distributed evenly. This process was performed repeatedly until four layers were obtained. Another plastic was placed on the top of the laminate. The air gaps formed by between layers were gently squeezed out by cold pressing. Finally, the surface plate of 150kg weight was put on the top after completing the fabrication process. Then it was kept for 24 hours in the room temperature and allowed to cure and harden.

2.4 Fabricated composites



(a) (b)

Fig. 2 Composite fabricated by: (a) Jute yarn, (b) Jute fiber.

Table 1. Various types of jute composites.

<table>
<tr><th>Types of composites</th><th>Fiber orientation</th></tr>
<tr><td>A and X</td><td>| + | + | + |</td></tr>
<tr><td>B</td><td>— + — + — + —</td></tr>
<tr><td>C and Y</td><td>| + — + | + —</td></tr>
<tr><td>D</td><td>| + / + | + /</td></tr>
<tr><td>E</td><td>+ + + + + + +</td></tr>
</table>

Where, | = Unidirectional mat with loading direction, — = Unidirectional mat with perpendicular to loading direction, / = Unidirectional mat with 45 degree angular direction, + = Twill type mat.

2.5 Specimen geometry

Test specimens were cut from composite plates according to ASTM standard to investigate various mechanical and physical properties of the fabricated composites.

2.5.1 Tensile test

Tensile test was conducted by cutting the specimen according to ASTM D638-01 [12] using a universal testing machine (Testometric). The test speed was 20 mm/min. The load was applied until the failure occurred. 3 samples from each types of composites were tested and average value has been used for the experiment. Figure 3 shows the specimen geometry of the tensile test specimen.

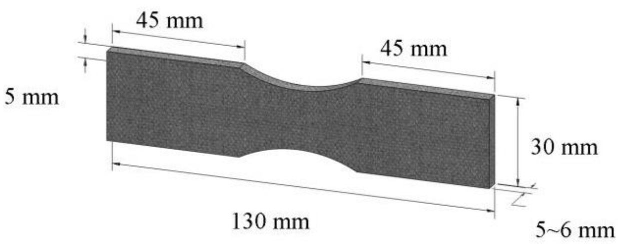


Fig. 3 Geometry of the specimen for tensile test.

2.5.2 Flexural test

Three point bending machine was used to conduct the test as per ASTM D790 [13]. The specimen geometry is shown in figure 4. The cross head speed of the machine was 0.5 mm/min. 3 samples from each types were tested and average value has been used for the experiment.

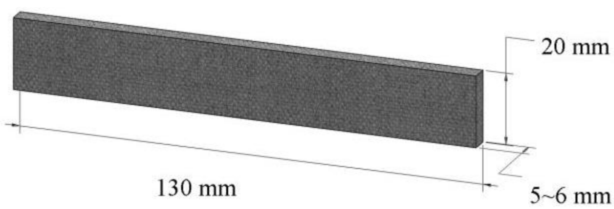


Fig. 4 Geometry of the specimen for flexural test.

2.5.3 Impact testing

ASTM D6110 [14] standard was followed for conducting charpy impact test using Impact Testing Machine (Model JB-300B). The dimension of the specimen was 100mm ×10mm × 5~6 mm with a V-notch of 45˚. The geometry is shown in figure 5.

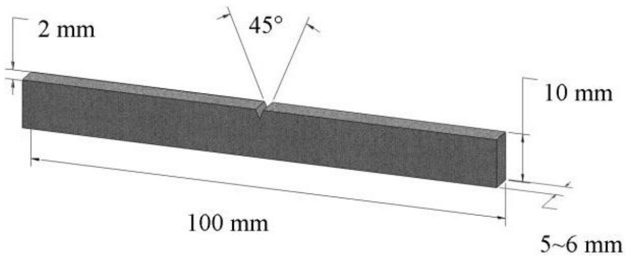


Fig. 5 Geometry of the specimen for impact test.

3. Results and discussion

3.1 Density measurement

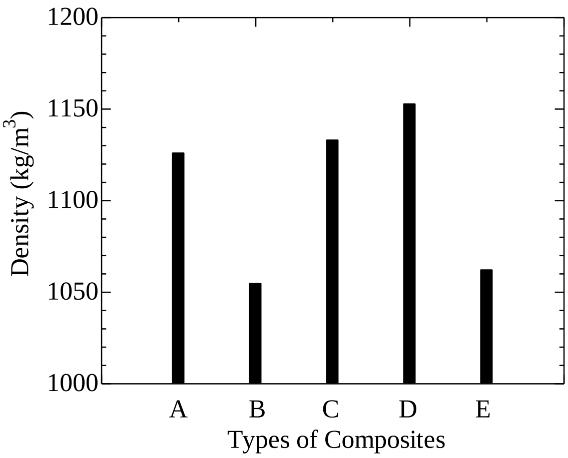


Fig. 6 Density of fabricated composites.

Density plays a vital role in the application of a material. Density was calculated using Eq. 1.

$$\rho(t)=m/V \quad (1)$$

Here, ρ *(t)* = Density of composite in each time, *m* = Mass of the specimen in each time, *V* = Volume of the specimen in each time. The mass was measured by digital weight machine and the volume was calculated by measuring length, width and thickness of the specimen measured by digital Vernier calipers. Figure 6 shows the density of the fabricated composites.

3.2 Tensile strength

Figure 7 shows the tensile strength of different types of composites. Maximum strength has been found in *A* type composites when the all the layers are in loading direction. Minimum strength has been found for type *B* where all the layers are perpendicular to the loading direction. Downward trend has been found in other types as fibers with perpendicular to the loading direction gives lowest tensile strength. *B, C, D* types of specimen contains fiber mat with perpendicular to the loading direction. Type *X* and *Y* are similar to the type *A* and *C* respectively, according to the orientation of the fiber direction. However, the difference is *X* and *Y* are made from independent jute fiber instead of jute yarn [9, 5]. As yarn is a bundle of individual jute fiber (Fig. 1(a)), the strength of yarn is greater than that of individual jute fiber. Therefore, the strength of type *X* (51.1 MPa), and *Y* (35.9 MPa) are less than the strength of type *A* and *B* respectively.

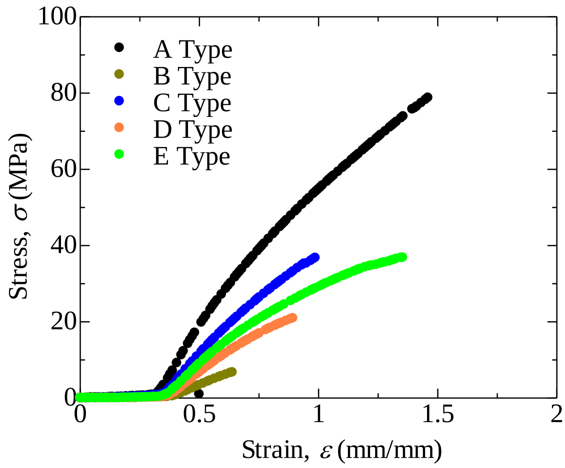


Fig. 7 Tensile strength of composites.

Table 2. Results of tensile test of fabricated composites.

Types	Break Elongation (mm)	Young's Modulus (GPa)	Peak Elongation (mm)	Break Stress (MPa)
A	1.375	11.59	1.374	71.511
B	0.629	4.2	0.629	8.468
C	1.081	9.15	1.081	44.957
D	0.718	6.27	0.718	18.747
E	1.21	7.53	1.21	35.555

3.3 Flexural strength

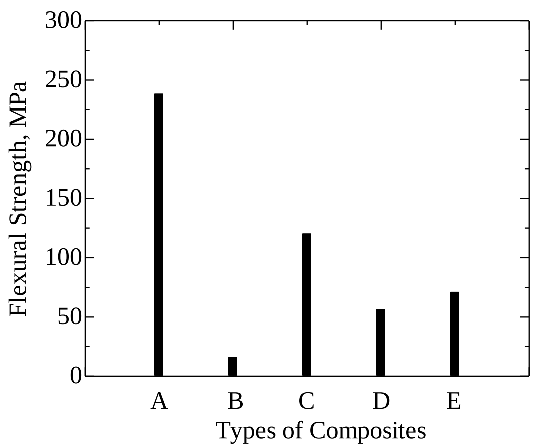


Fig. 8 Flexural strength of fabricated composites.

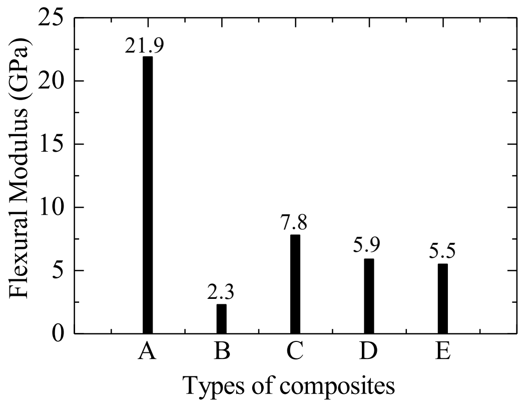


Fig. 9 Flexural modulus of fabricated composites.

Figure 8-9 show the flexural strength and flexural modulus of the fabricated composites, respectively. Highest flexural modulus has been found in type *A* and lowest has been found in type *B*. As twill type jute fiber mat contains both directional fibers, the flexural strength and flexural modulus lower than that of *A* type specimen.

3.4 Impact Strength

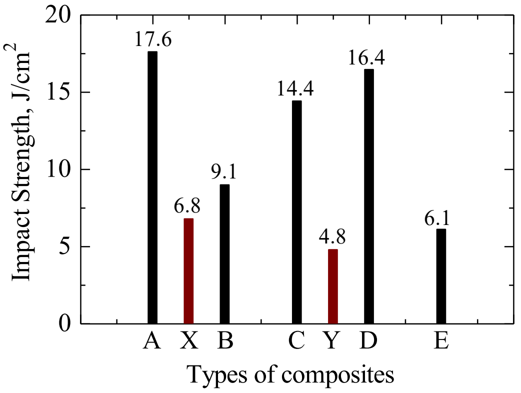


Fig. 10 Impact strength of composites.

Charpy test was carried out for measuring the impact strength. Figure 10 shows the result of the impact strength of fabricated jute fiber woven composites. In this experiment, maximum impact strength was found in type *A* where vertical unidirectional mat was used. The lowest impact strength was found in type *E* specimen where twill type mat was used. There is a downfall in other types for their alternative direction of woven mat with respect to the impact force. Because of containing fiber instead of yarn, the impact strength of type *X* and *Y* are less than that of *A* and *C*, respectively.

3.5 Microstructural analysis by *SEM*

Figure 11 shows the microstructure of *A, E, and X* type composites. Scanning electron microscope was used to analyze the microstructure. The images of fig. (a) and fig. (b) were taken from the cross-section of the fabricated composites. Figure (c) shows the tensile fracture surface. From the figure, it was clearly shown that some voids developed during the fabrication process, which causes poor mechanical properties. In figure 11(c), it was found that random independent jute fibers are scattered. Voids between the matrix and fiber is also clearly visible. The fiber orientations of *A* type *X* type specimens are same but in *A* type specimen jute yarn is used to fabricate the woven jute mat. On the other hand, independent jute fibers was used to fabricate the woven jute mat for specimen *X*. Therefore, the main reason of the improved mechanical properties in the case of *A* type specimen is the nature of interfacial bonding between the fibers and matrix.

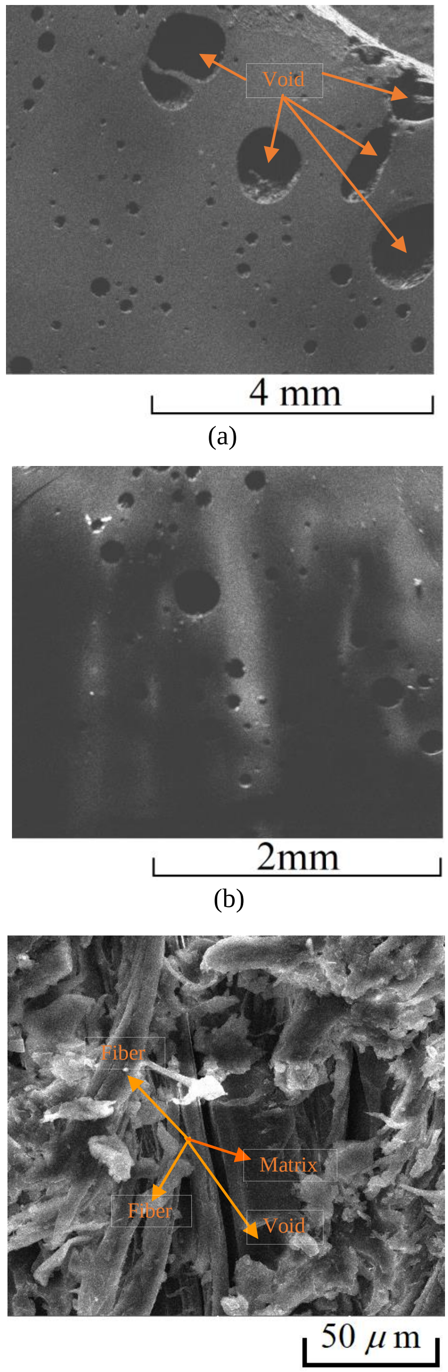


Fig. 11 Microstructure: (a) *A* type specimen fabricated by jute yarn, (b) *E* type specimen fabricated by jute yarn, (c) *X* type specimen fabricated by jute fiber.

3.6 *XRD* testing

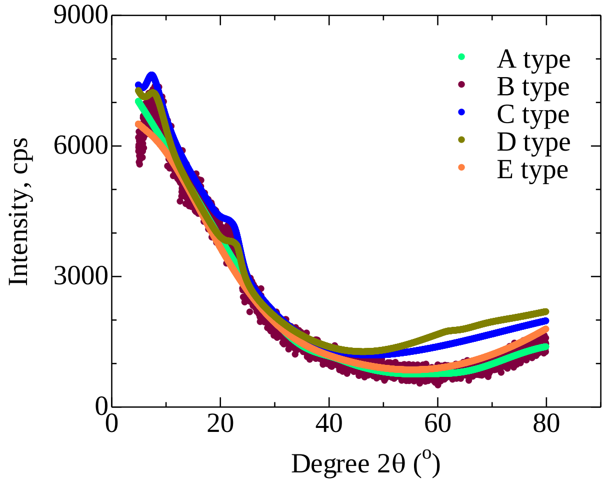


Fig. 12 *XRD* patterns for the fabricated composites at room temperature.

Figure 12 shows the experimental results of *XRD* of fabricated composites. From the figure, it was clearly found that there is no influence of fiber orientations on *XRD* of fabricated composites. The *XRD* characteristics are almost similar for all the composites.

3.7 Water absorption test

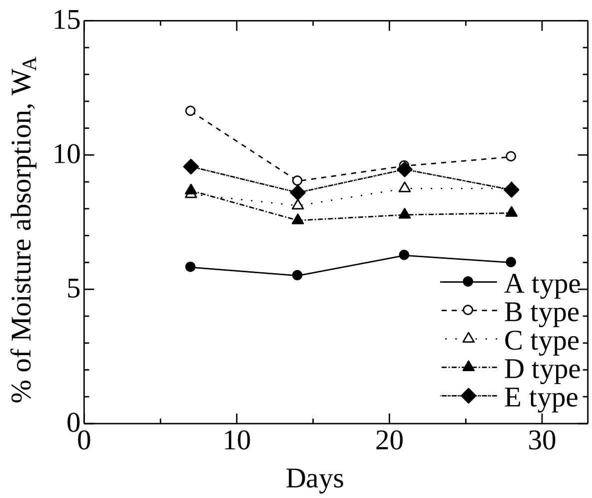


Fig. 13 Water absorption of jute composites.

The percentage of water absorption was investigated for 28 days. Test samples were submerged in normal water at room temperature. The reading was taken after every 7 days periodically. Before taking the measurement, the samples were withdrawn from the water and wiped with dry tissue to remove surface water. The samples were measured using a precision scale. The water absorption percentage was calculated using Eq. 2

$$W_A(t) = \frac{W_n - W_o}{W_o} \times 100 \qquad (2)$$

Here, $W_A(t)$ = Relative water absorption of the specimen at each time, t; W_n = Specimen weight at each time; W_o = Initial specimen weight.

Figure 13 shows that water has a great impact on these composites as jute has hydrophilic properties. It has been found that type *B* has the maximum, and type *A* has the minimum percentage of water absorption rate. This is because in the grinded area the bonding between matrix and mat is less strong in type *B* type than that of type *A* specimen. Therefore, water can easily penetrate into the specimen.

3.8 Swelling thickness test

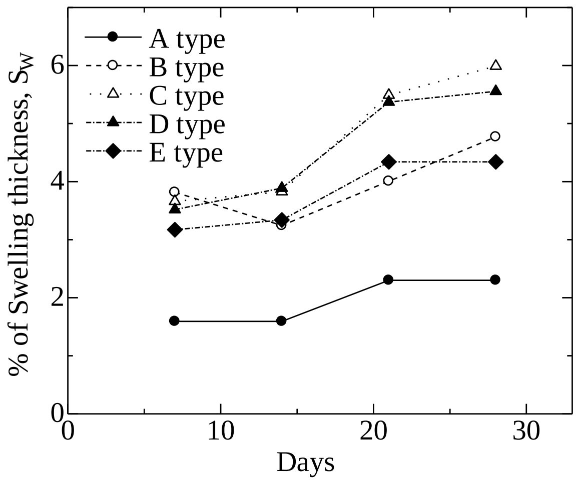


Fig. 14 Swelling thickness of jute composites.

Jute is contained with cellulose and cellulose has hydrophilic properties so that the composites were swelled under submerged condition. The thickness was measured by digital Vernier calipers. The whole procedure was maintained as water absorption test. Percentage of swelling thickness was calculated using Eq. 3.

$$S_w\, T(t) = \frac{T_n - T_0}{T_0} \times 100 \qquad (3)$$

Here, $S_wT(t)$ = Relative thickness of the specimen at each time, t; T_n = Specimen thickness at each time; T_o = Initial thickness of specimen. From figure. 14, it is observed that type *C* has the maximum swelling thickness percentage and type *A* has the minimum. As the bonding between matrix and jute yarn mat is strong, type *A* has the lowest percentage of swelling thickness.

3.9 Rate of change of density

Figure 15 shows the change of density due to absorption of water. From water absorption and swelling test it was found that due to the hydrophilic property, the fabricated composites absorbed water. Therefore, the thickness and the density also changed. However, density-changing rate is in considerable range.

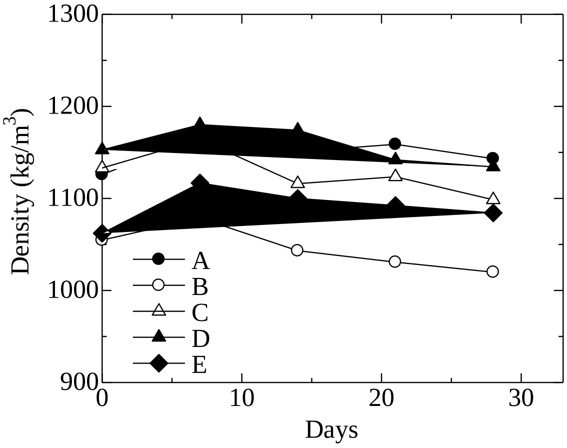


Fig. 15 Change in density.

4. Conclusion

The effect of the fiber orientations on mechanical properties and physical properties were investigated. The following output were found after the experiments and analyzing the results,

1. Unidirectional woven jute mat produced by yarn shows higher mechanical properties than individual jute fibers due to the interfacial bonding between the matrix and the fiber.
2. Higher mechanical and physical properties were obtained when the fiber direction are in the loading direction.
3. There is no impact of fiber orientations on *XRD*.
4. Water has a great effect on the jute fiber epoxy composite as jute has hydrophilic property. But the range is in considerable level. However, by chemical treatment it could be eliminated.
5. The mechanical properties could be improved by eliminating the voids generated during the fabrication. By improving the fabrication process or by *VaRTM* process, it could be done.

5. Acknowledgement

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6. References

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NOMENCLATURE

W_A	: Water absorption
S_W	: Swelling thickness
XRD	: X-Ray Diffraction
GSM	: Gram per Square Meter
SEM	: Scanning Electron Microscope
VaRTM	: Vacuum assisted Resin Transfer Molding