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# PROCESSING DEPENDENT FLEXURAL STRENGTH VARIATION OF JUTE FIBER REINFORCED EPOXY COMPOSITES

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## ABSTRACT

Environmental awareness of human society towards materials usage has attracted attention of many researchers in the natural fiber reinforced polymer composite because of its specific mechanical properties and biodegradability. However, in many cases, composite properties are dependent on its manufacturing routes. In this research work, various conventional composite processing routes (hand-lay-up, vacuum assisted resin infiltration; VARI and compression molding) were chosen for manufacturing 35% volume fraction of jute fiber epoxy composite. The developed composites were characterized by three point bending test according to ASTM D 790 standard and the fracture surfaces analysis under FEG SEM. The transverse three point bend properties were experimentally analyzed with fiber center to center distance (strain magnification) model. The observed experimental results revealed the maximum flexural strength for the compression molded composite and the minimum for that of hand-lay-up process. The mechanical properties were also explained in terms of fractographs obtained from SEM observation.

**Keywords:** jute epoxy, Bangla white, VARI, resin infiltration, fiber array, lumen.

## 1. INTRODUCTION

Artificial fiber reinforced polymer composites in practical use is almost 5 decades old. However, due to the environmental concern in last decade, natural fiber and its composite have drawn attention of many researchers. These natural fibres can be used to reinforce both thermosetting and thermoplastic polymer matrixes [1].

In contrast to natural fiber, the artificial fiber size and shape distributions are uniform. As a result, similar kind of uniform fiber matrix distribution is expected regardless of processing technique that enables their uniform properties [2, 3]. For natural fiber, the main drawback is its hygroscopic nature that influences the mechanical properties of composite panel [1, 4]. Not only hygroscopic nature, but also these fibers show wide scatter in their physical, chemical and mechanical properties that ultimately influence properties of composites [4]. Additionally for jute fibers, have empty spaces (lumen) and many naturally occurring defects. So, under processing condition, these defects interact differently with polymeric materials [4, 5]. Also yarn and woven fabric making process introduces artificial defect on the natural fiber [6]. Some other parameters as composite fabrication processes and related processing variables (total process time, temperature, polymer viscosity, etc) also influence the composite properties [7, 8].

As allied natural fiber reinforced polymer composites are growing in various modal sectors due to cost and environmental standpoint, so more research on processing and mechanical properties of thermoset polymer based natural fiber composite is necessary. The study will provide in-depth understanding of processing and properties of natural fiber reinforced composite and will help selection of application dependent composite fabrication procedure.

## 2. MATERIALS AND METHODS

Bangla white grade B (BWB) jute fiber was procured from Bangladesh Jute Research Institute. As matrix, Epikot 828 LVEL [Epi-chlore-hydrine and Bis-phenol A type] epoxy resin was used. Prior to composite fabrication, single jute fiber tensile characterization was carried out. Then unidirectional jute fiber preform was made following dry preforming technique. To keep jute fiber straight, the fiber bunch (350mm long) was adhesively bonded at both the end. In this experiment, three different processing techniques such as hand layup, vacuum assisted resin infiltration (VARI) and compression molding (pressure) were selected for composite manufacturing. For all cases, 35% volume fraction jute was utilized to develop the epoxy composites. Longitudinal and transverse fiber matrix impregnation was observed under SEM (model PHILIPS XL30 FEG) for all the composites.

In order to avoid contamination and cutting related degradation (introduction of more micro flaw by high speed cutting) of the composites, three point bend specimens were cut by slow speed diamond coated disk saw under dry condition. Longitudinal and transverse three point bending test were carried out with UTM machine (Instron, model 4467, 30 KN load cell) at a strain rate of 0.85mm/min, according to the ASTM D 790 standard and failure characteristics were analyzed by fracture surfaces studies under the SEM.

## 3. RESULTS AND DISCUSSIONS

### 3.1. Mechanical properties of BWB jute

Before composite manufacturing, details characterization of the tensile properties of jute fiber and epoxy were carried out [9]. The average tensile properties of jute fiber and epoxy matrix represented in Table-1.

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**Table-1.** Average longitudinal mechanical property of BWB jute fiber and epoxy matrix.

| Material | **Strength** (MPa) | **Strain %** (mm/mm) | **Stiffness** (GPa) |
|---|---|---|---|
| Jute fiber BWB | 844.72 ± 142.47 | 1.67% ± 0.31% | 55.66 ± 2.11 |
| Epoxy resin | 81.72o ± 13.16 | 2.23% ± 0.50% | 3.89 ± 0.53 |

From Table-1, a large scatter band of BWB jute fiber tensile strength is observed, which is attributed to the naturally occurring variability of fiber structures and compositions. Additionally, natural and processing induced defects interact differently under stress. This phenomenon is also true for those fibers that are inside the composites. More precise reason of the fiber property variation could be explained by fiber microstructure as shown Figure-1.

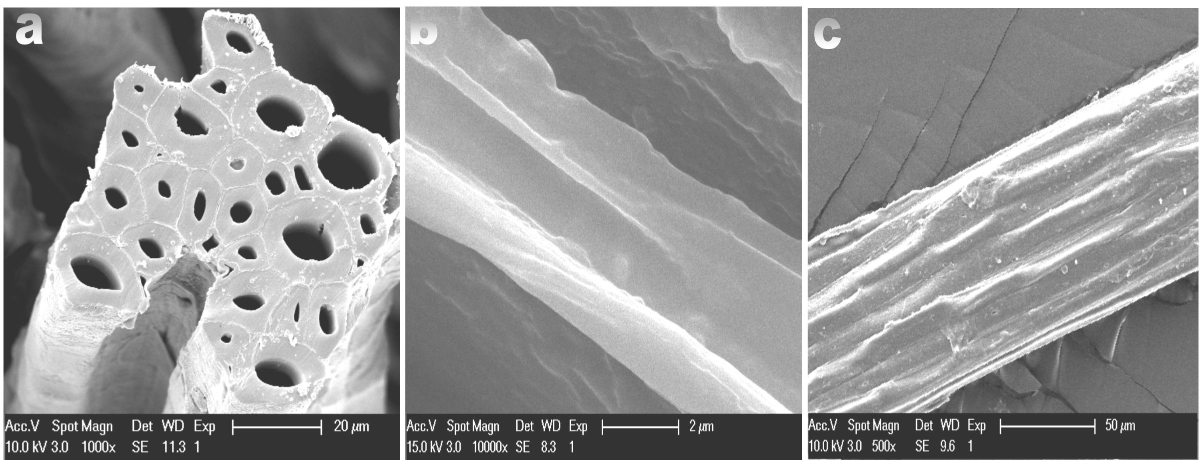


**Figure-1.** SEM micrographs of BWB jute fiber; a) fiber cross section, b) transverse cross section of lumen and c) BWB jute fiber surface.

Figure-1 shows jute fiber lumen, lumen interior and technical jute fiber exterior. In Figure-1(a), it is observed that the lumen size and shape is very random and the cross section of the technical fiber is not circular. Also, it is observed in Figure-1(b) that the lumen interior is also not uniform. Figure-1(c) shows very wavy BWB jute fiber surfaces.

However, from the previous discussion of Figure-1 about the BWB jute fiber, it is clear that naturally occurring fiber size and shape irregularities insist on entanglement of natural fiber. For this reason, BWB jute like natural fiber is very hard to align or in other words unidirectional preform making is very complex process [10]. As unidirectional composite is needed to understand fiber matrix interaction, so a process is needed to make stitched UD fabric other than yarn or woven fabric [4, 6, and 11]. These will create natural fiber and polymer prepreg making possible, which can be used in various modal usages.

### 3.2. Mechanical properties of composites

The summary of longitudinal and transverse three point bending properties is given in Tables 2 and 3.

**Table-2.** Longitudinal three point bending properties of composites.

| Process | **Strength** (MPa) | **Strain %** (mm/mm) | **Stiffness** (GPa) |
|---|---|---|---|
| Hand lay up | 123.7 ± 15.42 | 2.54 ± 0.25 | 6.1 ± 0.98 |
| VARI | 152.9 ± 25.04 | 2.68 ± 0.33 | 6.6 ± 1.41 |
| Compression | 233.66 ± 22.54 | 2.01 ± 0.21 | 19.77 ± 2.27 |

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**Table-3.** Transverse three point bending properties of composites.

| **Process** | **Strength** (MPa) | **Strain %** (mm/mm) | **Stiffness** (GPa) |
|---|---|---|---|
| Hand lay up | 22.5 ± 5.04 | 1.92 ± 0.31 | 1.27 ± 0.27 |
| VARI | 26.5 ± 5.72 | 0.99 ± 0.21 | 2.8 ± 0.52 |
| Compression | 23.1 ± 3.37 | 1.3 ± 0.16 | 2.1 ± 0.32 |

Table-2 shows an increasing trend in longitudinal strength property starting from hand layup to compression molding. However, the experimental Young's modulus for the compression molded composite is higher than the theoretical value and the reason is still unknown [12]. But it could be due to the jute preform clamping and pressing the preform with mold plug to assist pre-stretching of the preform during consolidation step, which could have improved the fiber matrix shear and fiber-fiber shear strengths.

The stiffness values of VARI and hand layup composites are relatively poor. Observation showed that these composite specimens when loaded with three point bending, the localized resin reach portion failed earlier than expected; which immediately affects the poorly distributed fiber zone that insisted early failure of the composite. This is attributed to the nonlinear fiber distribution density throughout the matrix [11, 13, 14]. The transverse strength and stiffness showed similar kind of values in comparison to each other as indicated in Table-3, regardless of processing techniques.

Explanation to the discrepancy of jute epoxy composite longitudinal and transverse three point bend property could be primarily explained by the fiber matrix distribution. The effective load transfer from matrix to fiber depends on the fiber matrix interface phenomenon and fiber distribution inside the matrix and both are complimentary to each other. Figure-2 shows the typical fiber matrix impregnation of all the composite samples. The SEM images are taken with same magnification and comparison of the Figure-2(a), (b), and (c) shows that the fiber matrix close packing increases and the local fiber density becomes more with processing condition beginning from hand layup to compression molding. In each figure, the irregular fiber shape of the BWB jute is clearly visible.

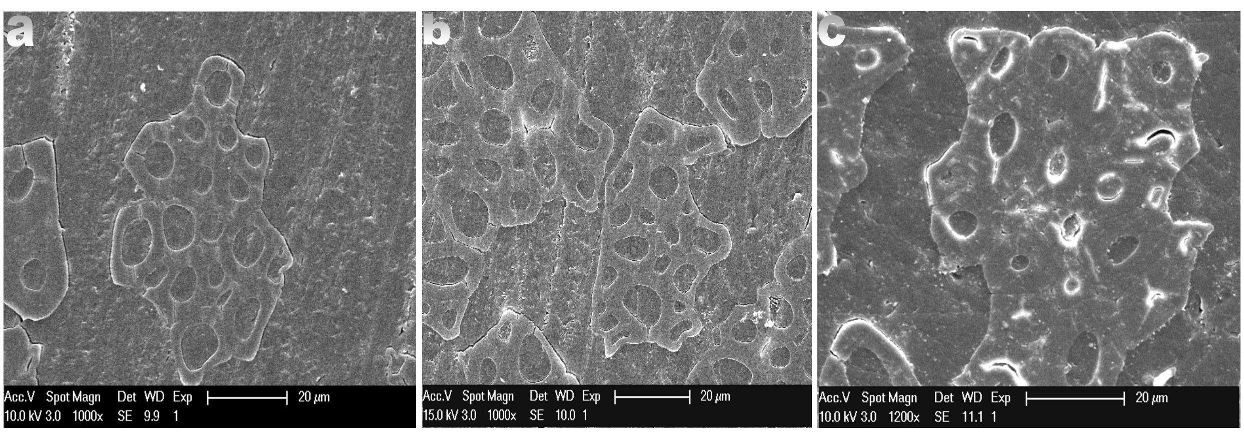


**Figure-2.** Fiber matrix impregnation cross section; a) hand layup, b) vacuum assisted resin infiltration and c) compression molding.

Figure-3 shows the lateral fiber matrix impregnation of jute epoxy composite. In the case of hand layup composite, compared to other two processes, fibers are more localized in some areas, Figure-3. However, in Figure-3(b) (VARI process based composite) shows much higher fiber matrix impregnation (than the hand layup type) because of relatively higher processing pressure. Along with this in Figure-3(c), the fiber matrix impregnation is much higher compared to the other two processes.

As the unidirectional composites are highly anisotropic, so in transverse direction most composites are weak. As a result, failures are controlled by matrix mechanical property, or by fibre/matrix bonding, or by lateral fiber failure in addition to matrix failure. Although the overall failure scenario is very complex, the precise mechanism mostly depends on the capacity of the matrix for plastic deformation and the strength of the fibre/matrix bond [13]. For better explanation of this type of failure behaviors of composite materials, the following mathematical relationship for strain magnification relation about transverse behavior of the UD composite might be useful.

$$(\varepsilon_2)_{ult} = \left[ (\varepsilon_m)_{ult} \left\{ \frac{d}{s} \left( \frac{E_m}{E_f} - 1 \right) + 1 \right\} \right] \quad (1)$$

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Where the $\varepsilon$ denotes the strain, $d$ denotes diameter of fiber, $s$ denotes space between two adjacent fiber and subscript 2 denotes transverse property, $ult$ denotes the ultimate property and subscript $m$ and $f$ denotes matrix and fiber.

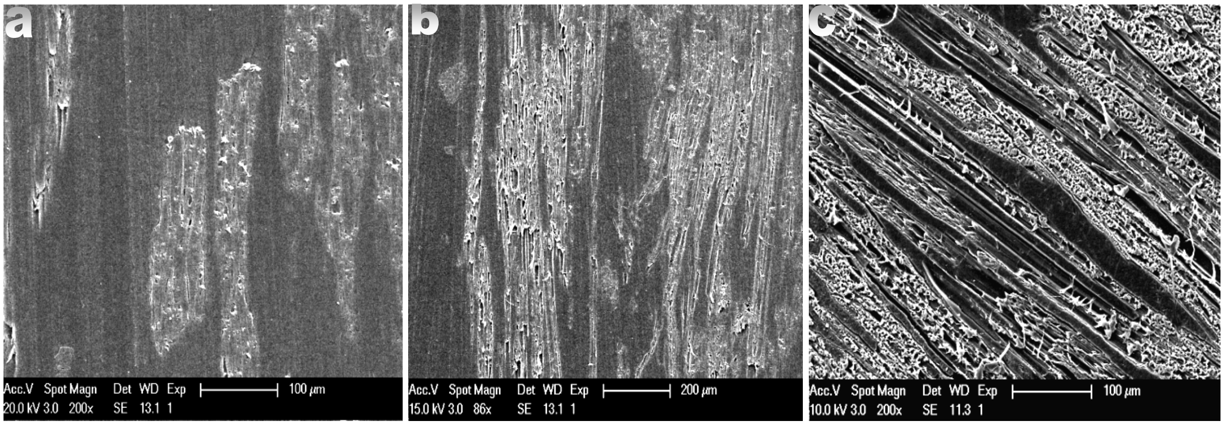


**Figure-3.** Fiber matrix lateral impregnation of BWB jute epoxy composite; a) hand layup, b) vacuum assisted resin infiltration and c) compression molding.

To understand the situation of fiber matrix distribution the individual stain values "$(\varepsilon_2)_{ult}$" of all the transverse test specimens were taken into account and fiber center to center distance was calculated using equation (1), assuming average jute fiber diameter as 60 micron. Then for each calculated value of "$S$" for individual specimen, a curve was plotted (specimen no vs fiber center to center distance) as indicated in Figure-4.

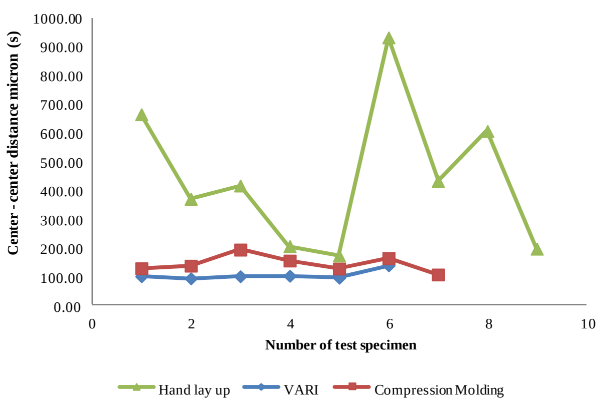


**Figure-4.** Comparison of fiber center to center distance in BWB jute epoxy polymer composite based on different processing.

In Figure-4 it is observed that the hand layup based composite showed maximum deviation from the ideal fiber center to center distance, which is attributed to the inadequate alignment during composite consolidation. So, the localized effective volume fraction in the longitudinal direction is never 35% [2, 8, 13]. Along with this the very low stiffness value of VARI composite is ascribed to the waviness of the dry jute perform which resulted in contained resin rich area and yielded lower stiffness value than the theoretical, regardless of the fiber center to center distance, which is close to ideal value. However, the compression molded composite shows higher fiber center to center distance than VARI but the precise reason of maximum longitudinal three point bend properties of compression molded jute epoxy composite could be due to higher degree of fiber matrix impregnation.

### 3.3. Fracture surface study

For better understanding of the failure behavior of the composites a detailed fracture surface study was done. The fracture surface study of the specimen that failed under longitudinal and transverse loading condition is shown in Figures 5 and 6. Figure-5 reveals the longitudinal fracture surface of jute epoxy composite based on different process. The longitudinal fracture surfaces in Figure-5(a) to (c), shows different degree of fiber pullout from the matrix starting from hand layup to compression molding. The fiber pullout length is similar in the hand layup and VARI processed BWB jute epoxy composite, whereas, in the compression molded composite the pullout length is shortened but the degree of pullout is higher.

Additionally, under longitudinal loading, some matrix crack was also observed in the compression molded composite fracture surfaces. Fiber compaction is much higher in the compression molded specimen compared to the other two processes as shown in the fractographs. Matrix crack under longitudinal load and higher compaction leads to higher longitudinal strength and stiffness of compression molded composite. The degree of resin penetration inside jute fiber lumen is highest in the VARI processed composite compared to the hand layup and compression molding. In case of compression molding, the resin penetration inside jute fiber lumen is intermediate compared to the other two composites. But from the mechanical point of view this resin penetration

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did not contribute to the longitudinal strength or stiffness. In earlier research, it was observed that the jute/epoxy interface conditions are irregular. In this situation, the lack of reinforcement in the loading path enhanced premature composite failure [15].

Figure-6 shows the transverse fracture feature of transversely loaded BWB jute epoxy composite. The common feature of all SEM image shows some clean fiber surface. Some adhered resin debris is also observed on fiber. Along with these transversely failed or sliced fiber is also observed revealing the lumen interior. Fiber matrix delamination with very less or unseen crazing is present along fiber matrix interface, which also indicates localized reinforcement deficient failure [16, 17].

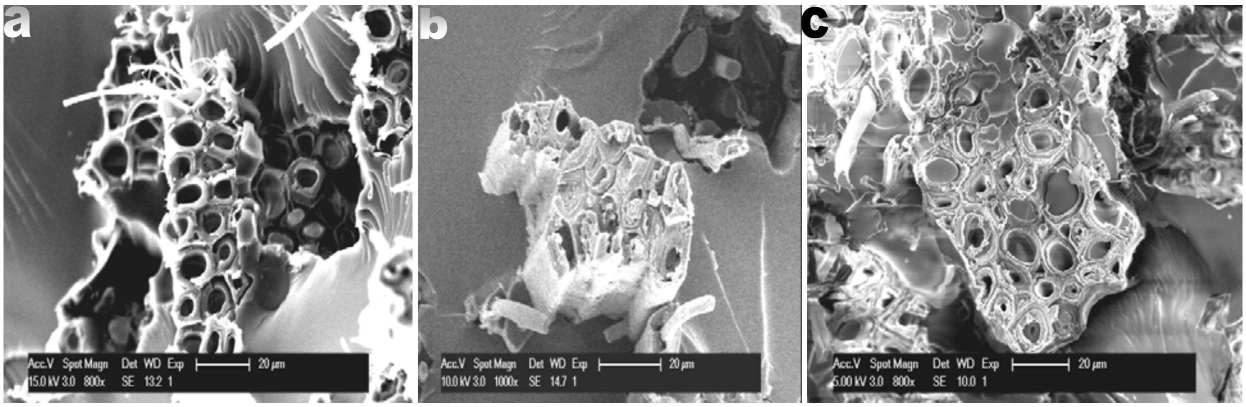


**Figure-5.** Fractographs of BWB jute epoxy composites under longitudinal three point bend load; a) hand layup, b) VARI and c) compression molding.

However, the main mode of transverse failure occurs at the interface and de-cohesion at the fiber matrix interface is predominant rather than debonding. Nevertheless, as there is some shrinkage during resin curing so that may create mechanical locking with the rough jute fiber surface and leads to resin debris on fiber at random places. This may be the reason of transverse fiber failure. Void on the other hand can contribute early failure of the composite during transverse loading [17]. The effect of infiltrated resin inside the jute fiber lumen on the transverse three point bend property is yet unknown, but it might have degrading effects [14].

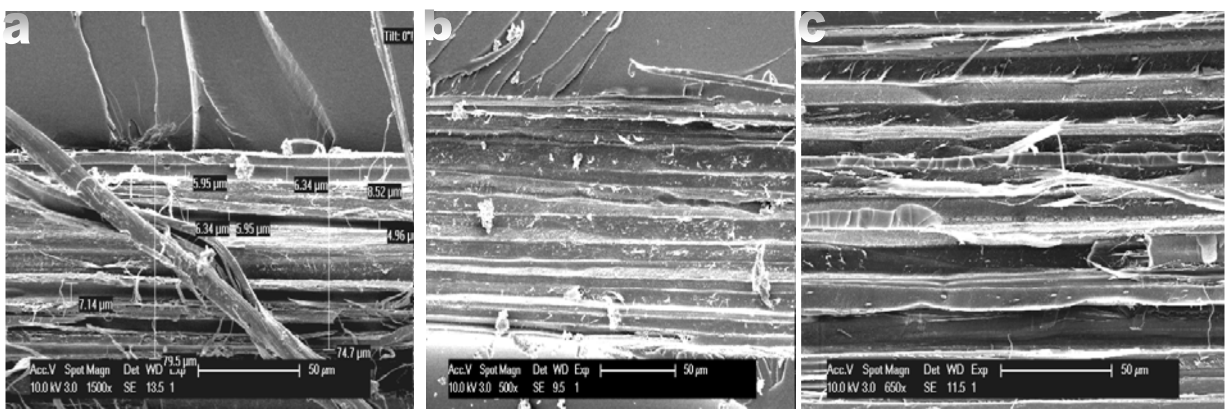


**Figure-6.** Fractographs of BWB jute epoxy composites under transverse three point bend load; a) hand layup, b) VARI and c) compression molding.

## 4. CONCLUSIONS

The conclusive remarks that could be drawn from the research work are given below.

- Jute fiber epoxy impregnation and uniformity of fiber distribution inside the matrix gradually increase with the assistance of pressure and clamping or holding the fibrous preform that helps more uniform fiber alignment.
- Types of processing significantly influence the three point bending strengths of the developed composites. In this respect, compression molding process was the best and hand layup type molding resulted the worst bending strength. However, no significant effect of type of processing was found on the bending strengths of the developed composites in the transverse direction.
- Fracture morphology indicates that fiber matrix shearing is more predominant in compression molded specimen than hand layup or VARI composite for fracture surface of developed composites tested in the

longitudinal direction. It has also been found that the fiber pullout length is shortened with increasing composite processing pressure.

- The main mode of transverse failure in the composites developed by different types molding techniques has been found to be controlled by fiber-matrix de-cohesion as well as debonding and fiber slicing.

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