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Tensile behavior of environment friendly jute epoxy laminated composite

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Abstract

Jute fiber has gained interest in the composite field due to its superior specific properties compared to manmade synthetic fibers like glass, kevlar, asbestos, etc. In this study, jute composites were made with the vacuum assisted resin infiltration (VARI) techniques having jute fiber preform staking sequences (0/0/0/0), 0/+45°/-45°/0 and 0/90°/90°/0. For all cases, a total of 25% volume fraction of jute fiber was incorporated. The developed composites were characterized by tensile and three point bend tests and the experimental results thus obtained were compared with that of the theoretical values. After both mechanical tests, fracture surfaces were cut and observed under high resolution FEG SEM (field emission gun scanning electron microscopy). In the case of 0/0/0/0 and 0/+45°/-45°/0 laminate, longitudinal tensile strength has been found to be higher than that of the transverse direction. However, for 0/90°/90°/0 laminate, tensile strength in both directions have been found to be very close to each other. For all developed composites, experimental results revealed that the tensile properties of the developed composites are strongly dependent on the tensile strength of jute fiber and that the tensile properties of jute fiber are very much defect sensitive. Finally, initiative has also been taken to discuss the mechanical behaviors of the composites in terms of the fracture morphologies observed under the SEM.

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Keywords: Jute; laminate; lumen; resin penetration

1. Introduction

Jute as a natural fiber is eco-friendly, low cost, versatile in textile fields and has moderate mechanical properties, which replaced several synthetic fibers in development of many composite materials. However, the hydrophilic nature of the jute fiber affects the mechanical properties of the developed composites [1, 2]. Another important issue to note that the tensile strength of jute fiber is extremely defect and span sensitive. As a result, the stiffness values are usually corrected as per various failure strains following the proposed mathematical relationships [3, 4].

Usually, it is difficult to make unidirectional (UD) jute preform manually under dry condition [5]. Hackling under dry or wet condition introduces more defects on the fibrous preform. However, fiber matrix interface is better understood by UD composite [6, 7]. As a result, UD jute preform or roving preparation has become a valuable step and that, nowadays, it is gaining a great importance [8, 9].

Multidirectional isotropic behavior can be achieved by staking the UD ply in different angles, which yields composite with anisotropic physical and mechanical properties [10, 11]. Conventional composite fabrication procedures like

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compression molding, hand–lay–up for jute like natural fiber, with moderately higher volume fraction (50%) of fiber reinforcement could produce composites of moderate to superior mechanical properties [12].

Synthetic fiber reinforced composite processing procedures are prepregging, resin transfer molding (RTM) and vacuum assisted resin infiltration (similar to RTM, but different in infiltration pressure) [13]. However, its versatility still attracted the intention of natural fiber composite researchers to utilize these techniques [14]. In this work, jute–thermoset continuous and angel ply laminated composites were made by vacuum assisted resin infiltration (VARI) technique and their mechanical properties (tensile and three point bend) were characterized.

1.1. Experimental

1.1.1 Materials and methods

In this research work retted, water washed and sun dried Bangla White Grade B (BWB) jute was collected from Bangladesh Jute Research Institute (BJRI) and single jute fiber tensile tests were carried out.

Four layer laminate preforms of size 400mmX400mm were made with jute fiber bunch and staking them in the following sequences (0/0/0/0), 0/+45°/-45°/0 and 0/90°/90°/0. Preforms were dried at 60°C overnight prior to composite fabrication.

As resin epoxy Epikote 828Lvel (Bisphenol A and Epichlorehydrin) and Diaminocyclohexane hardener were used. Then jute epoxy based composite was made employing standard VARI technique [13].

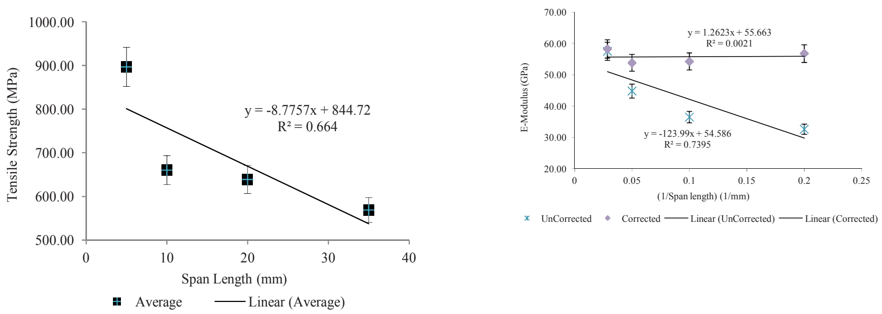
Tensile properties in longitudinal and transverse directions of the jute epoxy laminated composites were characterized as per ASTM D3039 standard. Three point bending as per ASTM D790 was also carried out to see the trend in strength and stiffness variation of the composites. Here 0˚ laminate direction is always taken as the principle loading direction.

After all mechanical tests, composite fracture surfaces were cut off and they were observed under a very high resolution FEG SEM of model PHILIPS XL30 FEG.

2. Results and discussion

2.1. BWB jute fiber properties

The tensile properties of used BWB jute and epoxy matrix are strength 844.72 ± 142.47 and 81.72 ± 13.16 MPa, stiffness 55.66 ± 2.11and 3.89 ± 0.53 GPa, and strain to failure 1.67% ± 0.31% and 2.23% ± 0.50% respectively [4]. But, as an anisotropic material, jute fiber has a large scatter in tensile properties depending on test specimen span length, test machine slippage and presence of inherent and surface of defects, which is graphically shown in Fig 1 a and b.



(a) (b)

Fig. 1. Tensile strength and stiffness of BWB jute fiber in relation to span length; a) tensile strength curve and b) tensile stiffness curve.

Fig 1 represents the strength of BWB jute fiber as a function of test specimen lengths. The tensile strength of the jute fiber decreases with increase in the span length and scatter for each span is relatively higher for lower span length compared to that of the higher span length. The probability of finding a defect along the loading direction of fiber is very much unpredictable for low span. But for higher span the probability of finding a single or a number of defects are greater and so the tensile strength value is lower along with lower scatter band. On the other hand, stiffness/E-modulus/Young's modulus is independent of span length, defect of fiber and machine slippage [4]. Typical BWB jute fiber defects are shown in Fig 2.

This is since the load bearing part of the fiber is the cellulose micro fibril and the lower the micro fibril angle (jute micro fibril angle is less than 8°) the higher the mechanical properties [4]. Also cellulose micro fibril is the purest form of natural cellulose, which could be in crystalline and amorphous forms that contribute as the fiber stiffness enhancer similar to that of the fiber reinforcement in composite.

(a) (b)

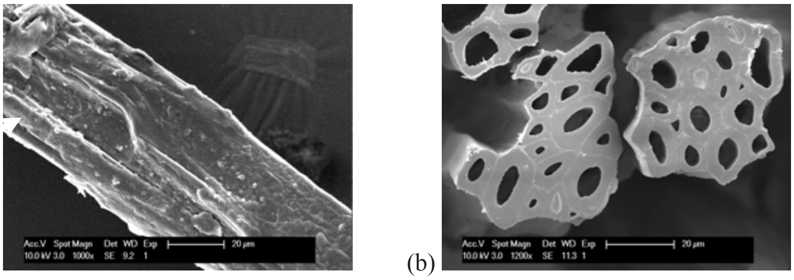


Fig. 2. Typical defects of BWB jute fiber; a) lateral surface defect and b) cross-sectional defect.

3. Mechanical properties of composite laminates

Composite material is composed of two or more materials, where individual constituent material is not capable to provide required service properties. However, combination of the constituent materials provides the targeted service properties and reliability of the product. In this research work, jute reinforced epoxy based composites were developed to improve the service properties of epoxy. Concerning the experimental results, a common remark from Table 1 is that the longitudinal strength, stiffness and strain to failure in the principal (0°) loading direction have a decreasing trend with increasing laminate angle. Whereas, 0/+45/-45/0 laminate under three point load shows higher strength than unidirectional laminate due to fiber-fiber and fiber-matrix shearing in the +45/-45 angle. According to the rule of mixture, the 25 vol% reinforced BWB jute polymer composite should show yield strength 272.47MPa. But, practically, the developed composite showed the yield and three point bend strengths to be, respectively, 112.69 and 138.94 MPa (Table 2). These experimental results clearly revealed a significant loss in reinforcement efficiency, which has also been noticed by other [15]. The reason behind this efficiency loss is due to presence of defects in fibers of various concentrations and geometries.

Table 1. Longitudinal behaviour of laminate

Properties	Laminate Type	Strength MPa	SD	Strain To Failure	SD	Stiffness GPa	SD
Tensile	0-0	112.69	18.31	0.82%	0.17%	14.59	2.28
	0-45	64.31	13.18	0.64%	0.15%	10.46	0.56
	0-90	42.54	6.42	0.43%	0.05%	11.13	1.47
3PBT	0-0	138.94	18.62	1.94%	0.70%	10.31	3.95
	0-45	149.71	20.19	1.99%	0.43%	9.88	2.13
	0-90	106.27	20.44	1.98%	0.45%	7.61	1.95

Table 2. Transverse behavior of laminates

Properties	Laminate Type	Strength MPa	SD	Strain To Failure	SD	Stiffness GPa	SD
Tensile	0-0	11.06	3.30	0.35%	0.04%	3.25	0.62
	0-45	21.33	2.08	0.80%	0.38%	4.46	0.64
	0-90	39.10	10.85	0.53%	0.19%	8.97	0.74
3PBT	0-0	18.24	7.79	1.12%	0.30%	1.68	0.38
	0-45	49.44	8.01	3.67%	0.69%	3.34	0.67
	0-90	50.71	8.13	2.84%	0.15%	2.95	0.43

Transverse mechanical properties of the fabricated composites are shown in Table 2. The strength value in both tensile and 3 point bending showed increasing trend with increasing laminate angle. From Table 1 and 2, we notice that the 0-90 laminate posses similar types of strength and stiffness properties. The strain value of 0-45 laminate under 3 point bend load is distinctly higher and close to 4%. The reason behind this will be explained latter.

3.1. Fracture analysis of UD and 0 – 90 composite

The jute fibers surface conditions are not always similar and the probability of larger size defects in long span test specimen is also high. As a result, compatibility and adhesion between jute fiber and the matrix vary, which also contributes to lower tensile strength of the developed composites.

Tensile strength in the transverse direction is also lower than that of the theoretical values and significantly lower than that of the longitudinal direction. The probable reason could be mixed mode fiber-matrix interfaces. Along with this inhomogeneous fiber content, irregular bonding between matrix/fiber interfaces, voids, inherent defects of the jute fiber, etc. seriously degrade the tensile strength of the composite [15]. As a consequence of the combined degrading effects, the experimental strength of the composites in the transverse direction becomes significantly lower than that of the longitudinal direction. Ultimately, in any direction, the maximum fiber strength efficiency has not been achieved.

The higher values of tensile strengths in the longitudinal direction can be explained by fracture morphology as shown in Fig 3. In this case, at first, matrix was broken because of its relatively lower tensile strength followed by fiber matrix debonding and pullout. At last stage, jute fiber having relatively higher tensile strength was broken. The sequence of events could be; a) loading, b) matrix cracking and crazing, c) fiber/matrix interface or inter-phase debonding, d) start of fiber failure, e) further debonding and pullout of fiber from matrix, and f) final fiber failure followed by composite failure. As the jute fiber has a high tensile strength, so the composite showed higher tensile strength in the longitudinal direction.

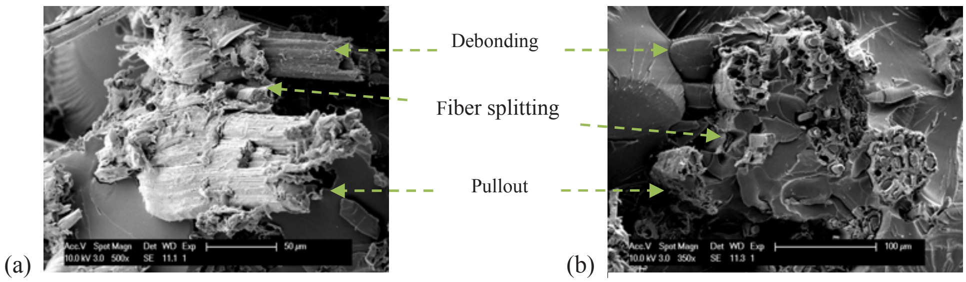


Fig. 3. Composite failure modes under longitudinal loading; a) tensile fracture and b) 3 point bending fracture.

In the case of transverse direction, tensile failure of 0/0 laminate jute fiber composites fiber slicing and debonding at fiber/matrix interfaces have been found to be dominating mode of fracture, Fig 4. Here, most of the cross sectional area is covered by the weak fiber/matrix interface and/or bunch of jute fiber. As a result, for 0/0 laminate of jute fiber composites a drastic decrease in tensile strength was observed.

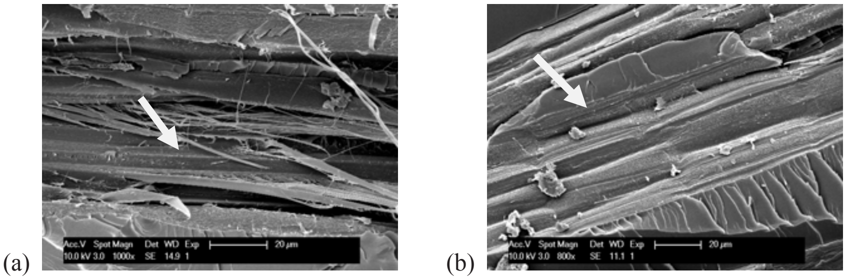


Fig. 4. Fiber and matrix failure under transverse tensile load; a) fiber slicing and b) fiber matrix debonding (3 point bending).

3.2. Fracture analysis of 0/+45/-45/0 composite

The lower strength of 0/+45/-45/0 laminate in the principle loading direction is attributed to matrix dominated shear force, which inherently dependent on the lower fiber volume fraction (25%) of reinforcement. Along with this, the higher transverse strength in this direction is due to the higher shear-force acting between ±45° laminate layers.

Fig 5 indicates the typical fracture surface of 0/+45/-45/0 composite under longitudinal load. Failure is characterized by matrix fiber matrix shearing, matrix and fiber shearing. Some fiber pullout in ±45° direction is also observed. Since, there is fiber matrix shearing, so fiber debris is also observed during 3 point bending. Large matrix crack owing to shearing effect is a characteristic failure criteria of jute epoxy 0/+45/-45/0 composite under the three point bend load as indicated rectangle in Fig 5b.

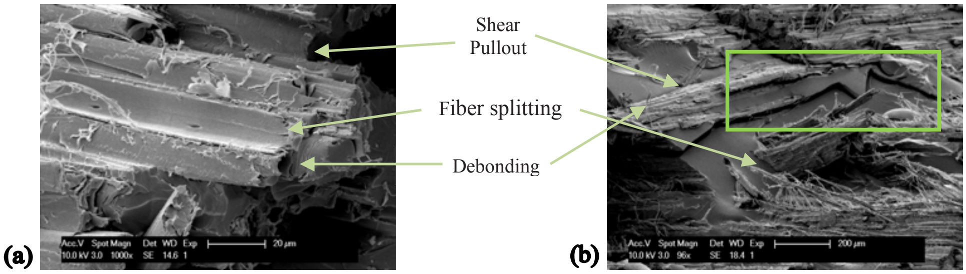


Fig. 5. Fiber and matrix failure under transverse tensile load; a) fiber slicing and b) debonding.

Another characteristic failure feature of 0-45 laminate under transverse loading is fiber matrix interface failure indicated by shear-lip type wavy fracture surface; Fig 6.

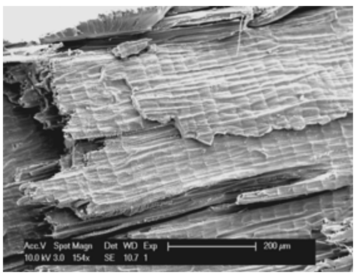


Fig. 6. Fracture surface of 0/+45/-45/0 composite laminate under transverse load showing fracture of share-lip type wavy nature.

Matrix failure in spherulitic fashion indicates the presence of compressive force around fiber (marked by arrow) as shown in Fig 7a. This compressive zone is more brittle than the surrounding matrix and shows the tendency of matrix cracking under longitudinal load in principal loading direction. This presence of compressive force is confirmed by crazing zone (marked by arrow) around fiber under transverse loading condition, which is shown in Fig 7b. In this loading condition brittle fiber failure (marked by arrow) is also observed as indicated by arrow in Fig 7c.

(a) (b) (c)

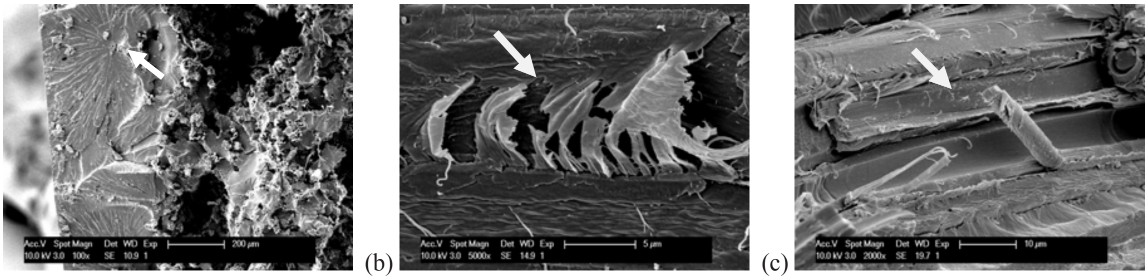


Fig. 7. Crazing of jute epoxy composite under transverse tensile loading; a) spherulitic failure, b) crazing and c) fiber failure.

4. Conclusion

In this research work, vacuum assisted resin infiltration (VARI) techniques with preform staking sequences (0/0/0/0), 0/+45°/-45°/0 and 0/90°/90°/0 were used to fabricate the composites. From this research work, the following conclusions are made.

- In longitudinal direction, the tensile strength and stiffness of 0-0 laminate composites have been found to be higher compared to that of 0-45 or 0-90 laminate composites. In the same direction, however, the trends for bending strength test results were opposite. The higher values of tensile strengths in the longitudinal direction was due to higher degree of fiber pull out in this direction, which caused a relatively higher level of fracture surface.

- In transverse direction, both the tensile and bending strengths 0-0 laminate composites have been found to be lower compared to that of 0-45 or 0-90 laminate composites. In the case of transverse direction of 0/0/0/0 (UD) composites the reinforced jute fiber experienced drastic slicing and fibrillation. This behavior of jute fiber is believed to be the main reason for the poor transverse mechanical properties of the developed composite. Compared to transverse three point bending of 0/0/0/0 (UD) composite 0/+45/-45/0 composite showed higher strength. This relatively higher strength of 0/+45/-45/0 composite is due to the shear lip type fracture surface.

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