Effect of fibre geometry on the tensile properties of thermoset jute fibre composites

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Abstract- Thermoset composites made from jute woven fabric, jute non-woven mat and jute carded-sliver have been manufactured in this project. For manufacturing different composite laminates, four & nine layers of woven fabric, one & two layers of non-woven mat and three layers of carded sliver have been used. Various tensile properties (tensile strength, tensile modulus & elongation at break percentage) have been investigated according to ASTM D3039 as functions of preform architecture (woven, non-woven and sliver) and direction of applied load. Each of the three different composites exhibited reinforcing effect to the epoxy matrix system. It has been found that in terms of stiffness sliver reinforced composite shows the highest stiffness and non-woven composites shows the lowest stiffness. In terms of strength, non-woven reinforced composite shows the lowest values. The strength of woven and sliver reinforced composites have been found to be almost similar.

Index Terms- Jute composites, epoxy, jute fibre, tensile properties, fibre architecture

I. Introduction

Composite materials have been already established as superior and unique in the world of modern engineering materials in comparison with the conventional metallic alloys[1, 2]. Superior specific strength and stiffness, corrosion resistance, high specific modulus made them most attractive and suitable for different high-tech engineering application [3]. Composite materials already came a long way to replace the conventional materials like wood and metal with its wonder properties. Among different types of composites, fibre reinforced composites are most important one. The technology of fibre reinforced composites has come of age with the advancement in aerospace applications [4]. Now after meeting the challenge of aerospace sector, it shows the potentiality to cater from domestic to industrial applications. Because of good performance, versatility and special advantage during processing; fibre reinforced composites demand is increasing rapidly in last few decades[5].

The fibre reinforced composites made from synthetic fibres are not biodegradable and environment friendly. That is why with the increase of environmental consciousness; the uses of synthetic fibre reinforced composites are now critically considered [6]. Apart from this, scientists are looking for some cheap reinforcing materials to cut down the high cost of fibre reinforced composite materials [4]. Natural fibre with biodegradability, environment friendly characteristics and low cost are presenting themselves to serve this purpose. Also natural fibre composite shows their great potentiality as structural materials due to its low density, good specific properties and low abrasiveness [7].

Various natural fibres such as flax, hemp, jute, sisal and few others are now being used as reinforcement in composites. Among all, jute is one of the cheapest and commercially most available fibres, especially in the tropical countries like Bangladesh or India [6, 8]. High cellulose content and low micro-fibril angle of jute fibremake it very suitable to use as reinforcement[9]. The composites from jute fibre reinforcements are not suitable for high tech applications such as aerospace, but it can serve some other needs such as interior parts of automobiles, furniture's, partitions etc.

There is a long history of jute fibre reinforced composites research. Several important researches have been recognized to characterize jute fibre reinforced composites. Long jute fibre, short jute fibre, jute woven fabric, jute knitted cloth, jute sliver, Jute 2D & 3D preforms has been used as reinforcement for composites manufacturing in different research[10, 11]. Along with this, different resin system has also been used by different research groups.These investigations were targeted to find the optimum fibre contents, best reinforcing structures, suitable matrix systems etc for jute fibre reinforced composites[12, 13]. There were few researches which investigated the combination of jute fibres with other natural or synthetic fibres (hybrid composites) to improve the mechanical properties of reinforced composites [14-18]

One of the major limitations of jute fibre reinforced composites is its lower mechanical properties compared to glass or carbon fibre composites. Different fibre treatment such as alkali treatment, permanganate, peroxide, silane oxidization, detergent wash, acetone wash, treatment with N, N-Dimethylaniline, chemical coating has been applied on jute fibre before using as reinforcement to improve the mechanical performance of composites[6, 19, 20]. Post-treatment of composites was also found to be a successful technique to improve the mechanical performance of jute fibre reinforced composites[21]. Several approach of interfacial modification is been observed to improve the composites properties [22-24].

Table 1 Properties of Epoxy Resin

Resin	Araldite LY563
Hardener	Aradur 3486
Curing cycle	80° C for 8 hrs.
Tensile Strength	70 - 74 MPa (in cured state)
Tensile Modulus	2.8 – 3.0 GPa (in cured state)

In fibre reinforced composites, fibres have been reinforced in polymer matrix in different forms and structures. One of the most economical techniques of using the fibre inside a polymer matrix is using of “Textile Preforms”. Textile preforms are structures made from fibre strands using different traditional textile technique and machinery. This is the most effective way of handling fibres without any distortions before impregnation in resin[2, 25, 26].

In this study, composites made using woven fabric, non-woven matt, and carded sliver as reinforcements have been used to characterize their tensile properties. In each different composites, the fibre architectures are different and the focus of study is to determine the effect of this change of architectureinto the composite mechanical properties.

II. Experimental Procedure

A. Jute Preforms

1×1 plain jute woven fabrics (15 yarns in warp and 15 yarns in weft), having area density of 245 ± 5 GSM and average thickness of 1 ± 0.1 mm;Needle-punched non-woven jute mats, having area density of 567.4± 5 GSM and thickness of 5.38 ± 0.3 mm and Jute carded slivers of count 46 KTex weresourced from Janata Jute Mills Bangladesh.

Figure 1: Jute Preforms Structure

There is a woven 3×3 mesh (3 ends & 3 picks per inch) inside the non-woven mat and the ends and picks has same strength.The carded slivers used here were withdrawn from the jute yarn manufacturing line, just after carding process.

B. Resin System:

Epoxy resin ARALDITE LY564 and Hardener ARADUR 3486, sourced from Huntsman Ltdwas used as the matrix system.

C.Fabrication of laminates:

Composite laminates from jute preforms and epoxy resin system were prepared in vacuum bagging technique (VBT). The preforms are cut in necessary dimension and dried at 80 deg C for 1H to remove the moisture from the pre-forms.

Figure 2: Infusion of vacuum bagged reinforcement

After drying, different layer of preforms werevacuum bagged for resin infusion. Preform layers were stacked in 0° direction with each other for different laminates manufacturing. The preforms were laid on a steel plate or mould and the total assemblywas then covered with a flexible bagging material. Then vacuum was drawn and finally the assembly was infused with the properly degassed resin & hardener mixture.This infused assembly was then cured in vacuum oven at 80º C for 8H. After the completion of curing, the bagging materials were removed and the laminate was taken out of the mould.

D.Preparation of specimens for Tensile Test:

Tensile test specimens were prepared from laminates as per ASTM standard, shown in table 2.

Table 2: Composite laminates specification

Reinforcement Types	Number of Layers	Specimen ID	Laminates Test Direction
Woven Fabric	4 layer	W1	Along warp
	4 layer	W2	Along weft
Non-woven Mat	1 layer	N1	Along MD
	1 layer	N2	Along CD
	2 layer	N3	Along MD
Carded Sliver	3 layer	S	Longitudinal direction

E.Tensile test

Tensile tests have been carried out following ASTM D3039 standard on Instron Machine (Model: INSTRON-5569). 2 mm/min cross-head speed using 50kN load cell. Specimen gauge length was 25 cm and strain gauge distance was 50 mm.

III. Result & Discussion

Table 3 shows thetensile modulus &fibre volume fraction of jute woven, non-woven and carded sliver reinforced composite laminates. All the three different kinds of composites showed reinforcing effect in the epoxy resin system. Tensile modulus of woven composites is 247% higher, non-woven composites is 164% higher and Sliver composites is 308% higher compare to bare epoxy (2.8 GPa).

Table 3: Tensile modulus & fibre volume fraction of jute fibre reinforced epoxy composite laminates

Specimen ID	Fibre volume fraction (%)	Tensile Modulus, GPa
W1	24.0 ± 0.2	5.27 ± 0.2
W3	26.0 ± 0.1	6.25 ± 0.1

W_{wp} = (W1+W3)/2	25 ± 0.2	5.76 ± 0.2
W2	24.0 ± 0.1	7.9 ± 0.1
W4	26.0 ± 0.1	8.24 ± 0.2
W_{wf} =(W2+W4)/2	25 ± 0.2	8.07 ± 0.2
W = (W_{wp} + W_{wf})/2	25 ± 0.2	6.91 ± 0.2
N1	23.8 ± 0.1	4.38 ± 0.2
N3	25.4 ± 0.1	4.9 ± 0.1
N_{md} = (N1+N3)/2	24.6 ± 0.1	4.64 ± 0.2
N2	23.8 ± 0.1	4.27 ± 0.2
N4	25.4 ± 0.1	4.8 ± 0.1
N_{cd} = (N2+N4)/2	24.6 ± 0.1	4.54 ± 0.2
N = (N_{md} + N_{cd})/2	24.6 ± 0.1	4.59 ± 0.2
S	17 ± 0.2	8.61 ± .3

As the fibre volume fraction of different composites were not equal, fibre bundle stiffness was calculated forcomparison which shows less error% than normalisation. This calculation was carried out on the basis of simple rule of mixture. From the composites strain data, fibrebundle strength has also been calculated. Fig 3 presents the fibre bundle stiffness and figure 4 presents the fibre strain versus strength.Table 4 shows the fibre bundle strength calculated from fibre modulus of composites.

Table 4: Fibre Bundle Strength & Fibre Strength of Jute fibre reinforced epoxy composite laminates

Specimen ID	Tensile Modulus, GPa	Fibre Bundle Stiffness in GPa	Strain%	Strength, in MPa
W	6.91 ± 0.2	8.7 ± 0.2	1.60%	138.4 ± 0.2
N	4.59 ± 0.2	5.6 ± 0.2	1.20%	67.0 ± 0.2
S	8.61 ± 0.3	9.8 ± 0.3	1.30%	127.4 ± 0.3

The uniform and unidirectional fibre assemblyin carded sliver made the sliver reinforced composites stronger than non-woven composites& woven composites. In carded sliver, fibres are arranged in almost parallel to each other without any twist & with a little entanglement. There is no crimp or waviness in the fibre assembly. Carded sliver when reinforced in polymer matrix, a uniform stress transfer from matrix to fibre occurred due to longerfibre length and continuity of fibre. This resulted in the fibre bundle strength of carded sliver reinforced composites highest among the three.Breaking extension of sliver composites is less than woven composites which gives comparatively lower stain and eventually lower fibre strength in the sliver composites.

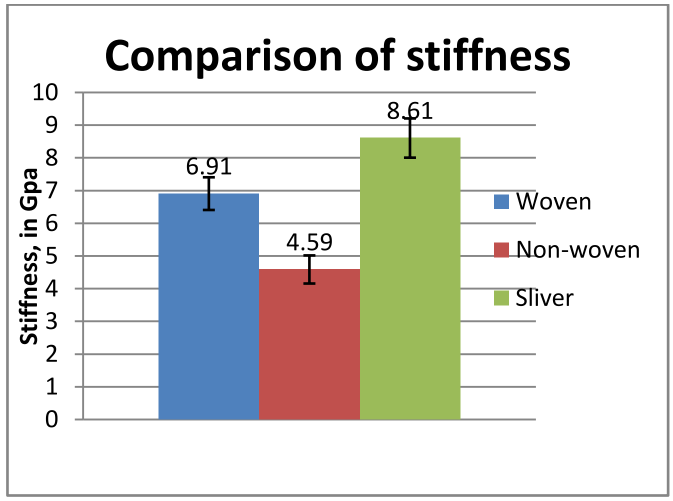

Figure 3: Fibre Bundle Strength in different jute preform reinforced laminates.

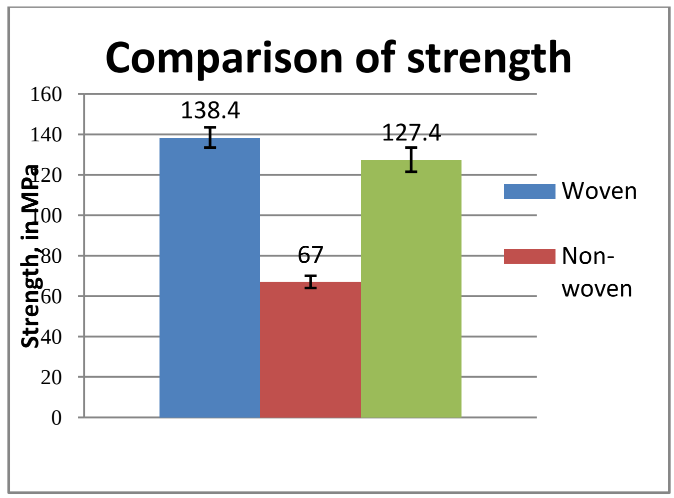

Figure 4: Fibrestrain vs. Fibre Strength for different jute preform reinforced laminates.

Woven fabric is the assembly of numbers of parallel and interlaced spun yarn. In spun yarn, fibre remains well oriented & twisted around the yarn axis (warp yarn twist/inch 4.5 and weft yarn twist/inch 5.5 here) (Fig 5). The insertion of twist increases the strength of the fibre assembly. On the other hand, the interlacement of the yarn during weaving brings a certain amount of crimp in the woven fabric structure (warp way 22.8 ± 0.71 deg and wet way 22.0 ± 0.06 deg here) (Fig-5). Due to crimp, the packing of the fibre assembly in the composite is not as efficient as of single fibre assembly in carded sliver. Moreover, due to the mechanical action during weaving operation kink band forms in the fibre; which further reduces the strength of the fibre[27, 28]. These can be reported as the significant reason of lower fibre bundle strength of woven composites compared to sliver composites. Because of the twisted & interlaced fibre strands in woven fabric, breaking extension is higher for woven composites. This causes highest strain in woven composites and gives the highest fibre strength as well compared to other composites.

The lowest strength of non-woven mat reinforced composites can be explained by its random fibre orientation. In non-woven mat, short fibres remain randomly oriented, locally interlaced, untwisted and discontinuous (Figure-5). Due to these reason when non-woven mat is reinforced in polymer matrix; stress transfer from matrix to fibre is not uniform. This could be the probable reason of lowest fibre bundle strength of non-woven composites compared to others. Due to short & randomly oriented fibre, breaking extension of non-woven composites is lowest among all, that give lowest strain and finally lowest fibrestrength among all the three types of composites.

IV. Conclusion

Fibre architecture has a significant influence on the tensile properties of jute fibre reinforced epoxy composites. The most important observations from the investigation are:

1. Jute woven fabric, non-woven matt&carded sliver bring the reinforcing effect in epoxy system. Woven composites achieved 247% (6.91 GPa), Non-woven composites 164% (4.59 GPa) and sliver composites 308% (8.61 GPa) higher tensile modulus compared to bare epoxy modulus (2.8 GPa).
2. Sliver compositesshowed the highest fibre bundle strength (9.8 GPa) and non-woven composites achieved lowest fibre bundle strength (5.6 GPa); woven composites remained in between (8.7 GPa).
3. Woven composites strain is higher (0.016mm/mm) compared to non-woven (0.012 mm/mm) and sliver (0.013 mm/mm)
4. Fibre strength is found highest for woven composites (138.4 MPa) and lowest for non-woven composites (64.0 MPa). Fibre strength for sliver composites is 127.4 MPa.
5. The theoretical tensile modulus and experimental tensile modulus are coherent, which depicts the accuracy of experiment carried out. However the experimental data deviates because of non-uniform fibre dispersion in the matrix system and poor fibre-matrix interfacial bonding.

V. References

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