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Studies on Mechanical Properties of Jute Sliver Reinforced Unsaturated Polyester Resin (UPE) Composite

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Abstract

Natural fiber reinforced composites are potentially useful materials with respect to environmental concerns. The geometry or the forms of the reinforcement in a composite greatly influences the mechanical properties of the composite. The common forms of jute reinforcement are chopped fiber, sliver, yarn, woven fabric, knitted fabric and nonwoven mat. In the present study, Composites were fabricated by incorporating jute sliver in unsaturated polyester (UPE) resin. Jute sliver (JS) reinforced unsaturated polyester (UPE) resin composites [JS/UPE] were prepared by compression molding technique. Jute fiber content in the composites were varied from 10-60% by weight and mechanical properties were measured in both longitudinal (along fiber/sliver axis) and transverse direction. Composite comprised of 50% jute sliver showed the best mechanical properties. At optimized fiber content (50% fiber by weight) the value TS, TM, BS, BM and IS of jute sliver reinforced UPE composite, JS/UPE, were found to 140.25 MPa, 6.75GPa, 160.5. MPa, 13.7 GPa and 27.2 KJ/m2 in longitudinal direction and 18.32 MPa, 0.8 GPa, 44.1 MPa, 1.3 GPa and 5.2 KJ/m2 in transverse direction respectively.

Keywords: Composite; Jute; Sliver; Resin; Mechanical Properties

Introduction

Composites made of jute fiber have high tensile and flexural properties compared to other natural fibers (Hassan et al., 2003). Besides, jute has high cellulose content and low microfibril angle which are desirable properties of a fiber to be used as reinforcement in polymer matrix (Bogoeva-Gaceva et al., 2007). Bast fibres are advantageous over the other cellulose-based fibers (seed fibre, leaf fibre or fruit fibre) due to high modulus, tensile strength and low specific gravity (Nabi Saheb, 1999). Among all the natural fibers, jute is abundantly available in tropical countries like Bangladesh and India. It is, therefore, of particular interest to use jute fiber as reinforcement in polymer matrices. Though jute fiber reinforced composites exhibit higher mechanical properties than other natural fibers but the properties are strongly depended on the type of resin used, and the form in which the fibres are incorporated.

Composites made of high strength conventional synthetic fibers such as glass, carbon and aramid are commonly used in broad range of applications from aerospace structure to automotive parts and from building materials to sporting goods (Arib et al., 2006). The greatest problem of using such materials is how to conveniently dispose of them once they have come to the end of their useful life span (Bodros et al., 2007). For these reasons, alternative reinforcement with natural fibers in composites has gained much attention having low cost, low density, CO_2 neutrality, biodegradability, and recyclable nature (Mohonty et al., 2000; Mohonty et al., 2002.; Mohonty et al., 2005) and natural fiber composites have been emerging as realistic alternatives to glass-reinforced composites in many applications since 1990 (Joshi et al., 2004).

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Jute fiber forms an intimate bond with polyester resin (Roe and Ansell, 1985). Moreover, it is cheap. That's why polyester resin has been chosen as matrix or binder. In the present study, jute sliver has been considered as reinforcements and unsaturated polyester resin as binder or matrix. There are very few reports on jute sliver reinforced composites reported so far. Roe and Ansell (Roe and Ansell, 1985) published the first paper on jute sliver reinforced polyester composite. They fabricated jute sliver reinforced polyester matrix composite by compression moulding up to 60 vol. % of fiber. The ultimate tensile strength and modulus of the resulting composite along the fiber length or axis at 0.6 volume fraction were 250 MPa and 35.5 GPa respectively. The Charpy impact strength was 22 KJ/m^2. Dash et al. (1999) studied the mechanical properties of both unbleached and bleached jute sliver reinforced polyester composites with various percentage of fiber loading. Composites made of both unbleached and bleached sliver and having 60 wt. % of fiber exhibited the best mechanical properties but unbleached one showed better mechanical properties compared to bleached sliver reinforced composite. Bleached sliver reinforced composite showed the better flexural properties (flexural strength 171.8 MPa, modulus 18.84 GPa) over unbleached one (flexural strength 140.41, modulus 3.85 GPa), although the tensile properties of the latter were better. The inter laminar shear strength (ILSS) of the unbleached jute sliver reinforced composite was found to be better than the unbleached jute sliver reinforced composite. The high flexural properties and inter laminar shear strength of bleached jute sliver reinforced composite were attributed to the high fiber-matrix bonding strength which was achieved because of bleaching.

Research has been carried out jute sliver reinforced epoxy composites (Mishra et al., 2000). The composites were fabricated by compression moulding technique using untreated (named controlled = C) and bleached (B) jute sliver as reinforcement. Different fiber loading percentages were used in different composites. The maximum tensile modulus was found for 50% fiber loading. Beyond 50%, tensile modulus decreased with the increase of fiber loading %. According to the researchers, this is due to poor wetting of jute fiber by resin above 50% fiber content. Laranjeira et al. (2006) investigated the influences of fiber orientation on the mechanical properties of unsaturated polyester/jute composites. They prepared composites from uniformly distributed long jute fiber (200 mm) and randomly oriented short jute fiber (10 mm) using compression moulding technique. The tensile properties for uniformly distributed long jute fiber composites were found to be higher (tested along fiber length) compared with randomly oriented short jute fiber composites. From the literature review of jute sliver reinforced composites, it is seen that effect of fiber loading on mechanical properties along fiber axis have been investigated. No one investigated the effect of fiber loading on mechanical properties perpendicular to the fiber axis. Although Laranjeira et al. (2006) investigated the influences of fiber orientation on the mechanical properties of unsaturated polyester/jute composites, but this investigation was on 200 mm long parallel jute fiber instead of jute sliver.
The aim of this study is to achieve a greater understanding of the mechanical parameters that contributes to sliver properties, and their reinforced composites in case of jute sliver (JS) reinforced unsaturated polyester (UPE) composites.

Materials and methods

In the present study woven jute fabrics (JF) has been used as reinforcement and unsaturated polyester (UPE) resin as matrix. Methyl ethyl ketone peroxide (MEKP) has been used as catalyst.

Jute Sliver

Jute slivers were collected from the Experimental Spinning Mill of BJRI, Manik Mia Avenue, Dhaka. The specifications of Jute sliver are shown in table 1.

Table 1. Specifications of jute sliver

Length	Thickness	Width in inch	Linear density	Areal density in
Continuous	6mm	4.5 (11.43)[b]	63.5Ktex	625 g/m^2

[b] Number in parenthesis is sliver's width in cm

Unsaturated Polyester (UPE) Resin

General purpose unsaturated polyester resin of orthophthalic grade was used as matrix material. The resin was supplied by Singapore Highpolymer Chemicals Products Pte Ltd. The trade name of the resin is SHCP 268 BTQN and its specifications are shown in table 2.

Table 2. Specifications of the matrix material (Liquid SHCP268BTQN Polyester Resin)

Appearance	Pink
Specific gravity at 30°C	1.10-1.15
Viscosity	400-600mPas
Gel time at 30°C	8-15minute
Cure time at 30°C	14-30minute
Peak exothermic temperature	135-155°C
Stability in the dark below25°C	6months
Acid value	20-24mgK°H/g (styrenated resin)

Catalyst

Methyl ethyl ketone peroxide (MEKP) was used as a catalyst. The specification of Catalyst is shown in table 3.

Table 3. Specification of Catalyst

Materials name	Tradename	Supplier/producer and country of origin	Density
Catalyst(MEKP)	ButanoxM-50	HSBCPte Ltd.,Singapore	0.909

Methods–Fabrication of Cured Resin Specimens and Composites

Preparation of Cured UPE Resin Specimens

A glass tray was used as a mould for making resin specimens. The mould was cleaned and dried with tissue paper. Then 1% (v/v) MEKP was added with UPE resin and the resin/catalyst mixture was mixed manually with a glass rod for 3 minutes and laid up in the mould for 24 hours. A mould release agent (wax) was laid up on the mould before pouring the mixture. Test samples were properly shaped according to ASTM specifications (ASTM D638) to perform mechanical tests.

Fabrication of Jute sliver Reinforced UPE Composite (JS/UPE)

A combination of hand lay-up and compression moulding method was used to prepare the jute sliver reinforced UPE composite samples. Jute sliver was first dried in an electric oven at 100°C for 1 hour to remove moisture. A measured quantity of low viscosity unsaturated polyester resin and catalyst (MEKP) was mixed in a bucket with a with resin catalyst ratio 1:0.01(v/v). The catalyzed resin was poured on a pre-weighed amount of jute sliver, which was placed in a mould. The mould was coated with mould releasing wax to facilitate easy removal of samples from the mould. After pouring the resin, each layer was left for a few minutes to allow the resin to soak into the sliver. Trapped air was gently squeezed out using a roller. Jute sliver and polyester resin were then left for about 3 min to allow air bubbles to escape from the surface of the resin. The mould was closed and the composite panel was left to cure in a hydraulic press at a temperature of 90°C and at a compaction pressure of 2MPa for 30 minutes. A semi-automatic hydraulic press (Carver Bench Top Heat Press, Model 4128, USA) was used to consolidate composite panels. Composite panel was then taken out from the hydraulic press and it was allowed to cool naturally to room temperature for about 30 minutes. Jute sliver reinforced UPE composites were prepared with different fiber contents (10, 20, 30, 40, 50, 60 wt %) and the specimens of required dimensions were cut from them according to ASTM standards (ASTM D 638) for mechanical testing. Jute fiber content in sliver reinforced UPE composite was optimized on the basis of the mechanical properties such as tensile, bending and impact. The specimens of required dimensions were cut from the hybrid composites according to ASTM standards and tested in longitudinal (0°) and transverse direction (90°).

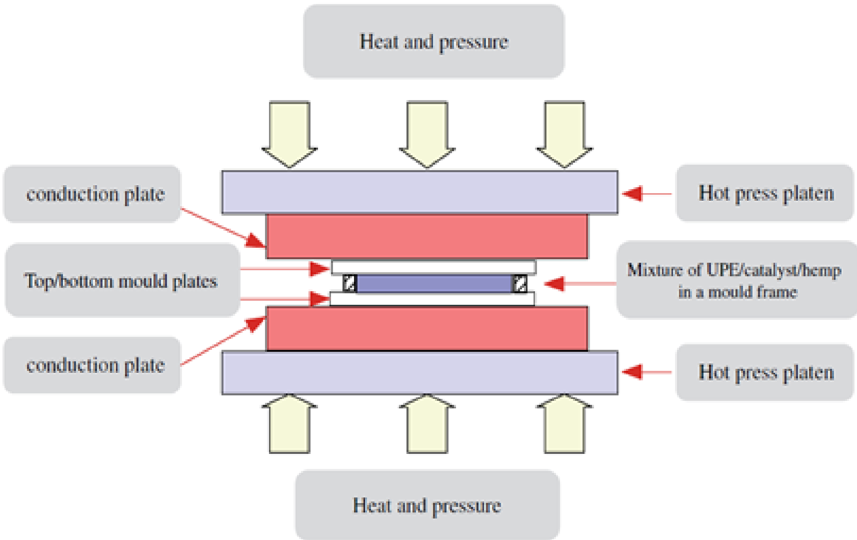

Fig. 1. Schematic diagram of the composite consolidation

Methods –Testing

Detailed descriptions and specifications are given for the applied testing methods. However, for methods described elsewhere in this thesis, only short explanatory descriptions are presented in this section. No information is given on the types of materials actually tested by the methods, but this can be seen from the presented results.

Sliver Characteristics

Mechanical Characterization of Cast Resin and Composites

Tensile Test

Tensile testing measures the strength of a material. A material's response to tensile, compressive, and shear force is measured by a universal testing machine, commonly referred to as a tensile tester. Hounsfield H50KS(UK) universal testing machine was used to measure the tensile properties of cast resin and the composites. The shape and dimensions of test specimens are different for different materials. Moreover, the shape and dimensions of test specimens also vary with the Standards followed for the measurement of materials properties. The tensile properties of cast resin and composites were measured according to ASTM D 638. Test specimens of required shapes and dimensions were cut from the sheet of cast resin and composites. The cut edges were then smoothed using 240 Grade SiC paper. Tensile properties as determined by the test method help to know the ultimate strength of the test specimens, their fracture characteristics under tensile load, load - strain behavior bearing properties of fiber and matrix material. At least five samples were tested for each specimen.

Bending or Flexural Test (3 Point Bending Test)

The three-point bending test was carried out by universal testing machine. The test specimens were prepared according to ASTMD790. It says that—the span length shall be 16 times of the depth of the beam. Specimen width shall exceed one fourth of the support span for specimens greater than 3.2 mm in depth. Five specimens of each composite were tested and the average value was reported.

Impact Test

Impact strength is used to measure a material's ability to with stand shock loading. Impact tests are used in studying the toughness of material. A material's toughness is a factor of its ability to absorb energy during plastic deformation. The impact strength of a material is expressed in energy lost per unit of thickness (such as ft-lb/in or J/cm). Alternatively, the results may be reported as energy lost per unit cross-sectional area (J/m² or ft-lb/in²). Brittle materials have low toughness as a result of the small amount of plastic deformation that they can endure. Impact is a very important phenomenon in governing the life of a structure. The impact value of a material canal so changes with temperature. Generally, at lower temperatures, the impact strength of a material is decreased.

Izod impact strength testing is an ASTM standard method of determining impact strength. A notched sample is generally used to determine impact strength. Unnotched sample is also used. The North American standard for Izod Impact testing of plastics is ASTMD256.

In the present study Izod impact strength of unnotched specimen was measured according to ASTM D 256 using HT-8041B Izod Impact Testing Machine. Unnotched specimens of required dimensions were cut from the composites. Five specimens of each composite were tested and the average value was reported.

The impact strength was calculated by using the following equation

$$\text{Impact Strength} = \frac{\text{Energy absorbed}}{\text{Crosssectional area of the test specimen}} \quad (\text{Eqa. no. 1})$$

Results and discussion

The mechanical properties of a composite are influenced by the mechanical properties of its constituent parts. So, the properties of cured resin and woven fabrics were measured first before fabricating composites. Then composites were fabricated jute sliver.

Properties of Cured UPE Resin

Physical Properties of Cured UPE Resin

The physical properties of cured UPE resin are shown in table 3.

Table 3. Physical properties of cured UPE resin

Densitying/cc	Volume shrinkage on cure	Colour
1.25	9%	Waterlikecolour

Mechanical Properties of Cured UPE Resin

The mechanical properties such as tensile strength (TS), tensile modulus (TM), bending strength (BS), bending modulus (BM) and impact strength (IS) of cured unsaturated polyester (UPE) resin was measured and the values are shown in table 4.

Table 4. Mechanical properties of cured UPE resin

TSin MPa	TM±SD[a] in GPa	E_b %	BS±SDin MPa	BM±SDin GPa	IS±SDin KJ/m²
32.4±1.34	1.2±0.25	6.3±0.21	60.5±1.20	2.3±0.20	5.6±0.58

Properties of carded jute sliver

They were cut to pieces of length of 20 cm. Five such pieces were weighed in an electronic balance and the linear density as well as areal density of carded jute sliver was measured and the results are shown in table 5 below.

Table 5. Specifications of carded jute sliver

Length	Thickness in mm	Width in cm	Linear density in K tex	Areal density in g/m²
Continuous	6	11.43	63.5 ± 6.29	625 ± 7.56

Mechanical properties of jute sliver reinforced UPE composites

Jute sliver reinforced UPE composites [JS/UPE] were prepared by hot press compression moulding technique. Jute fiber contents in the composites wee varied from 10-60%. The tensile, bending and impacts tests of these composites were performed as per ASTM test standards.

Tensile Strength

The tensile strength of JS/UPE composites in longitudinal and transverse direction as a function jute content (wt %) is shown in figure 2. The tensile strength in longitudinal direction (LD) increased with the increase of jute content up to 50 wt. % and then decreased. According to Zini and Scandola (Zini and Scandola, 2011), the tensile strength of jute fiber is 393-773 MPa which is much higher than that of cured UPE resin (32.4 MPa). So, the tensile strength of JS/UPE composite increased in longitudinal direction with the increase of jute content up to 50 wt. %. At 50% fiber loading, the tensile strength of JS/UPE composite along fiber/sliver axis (i.e. in the longitudinal direction) is 140.25 MPa. When the jute content in JS/UPE composite exceeded 50% the tensile strength decreased. This may be attributed to the poor wetting of jute fiber by resin.

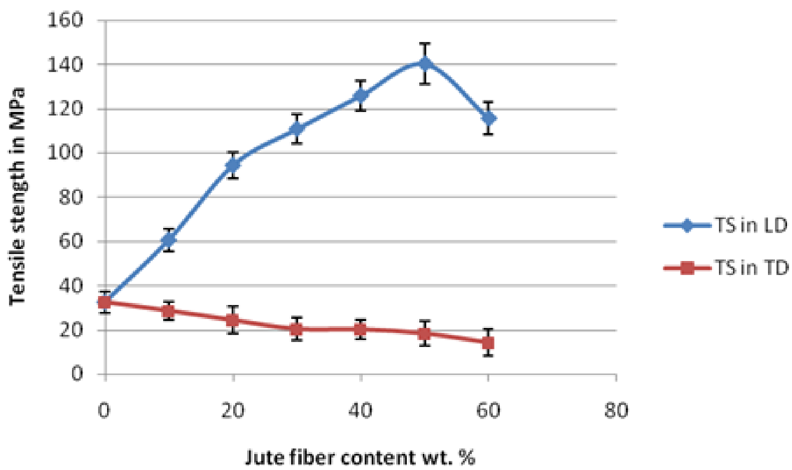

Fig. 2. Effect of jute content on TS of JS/UPE composite in longitudinal and transverse direction

The tensile strength in transverse direction (TD) is much lower than that of the strength in longitudinal direction and even lower than cured UPE resin. It is seen from figure 2 that the tensile strength in transverse direction gradually decreased with the increase of jute content. That is, when tensile load is applied in transverse direction the fiber does not bear any load and stress is not transferred from matrix to reinforcing fiber. So, in transverse direction only resin bears the load. As the fiber content increased the amount of resin, the only load bearing component, decreased which consequently reduced the tensile strength of JS/UPE composites in transverse direction.

At 50 wt. % of jute fiber content, the tensile strength of JS/UPE composite in longitudinal and transverse direction were 140.25MPa and 18.32MPa respectively and their ratio was 7.65: 1. That is tensile strength of JS/UPE composite in longitudinal direction is 7.65 times higher than that of that of its tensile strength in transverse direction. The tensile strength of JS/UPE composite in transverse direction at 50 wt % of jute fiber content is even lower than that of neat UPE resin.

Tensile Modulus

The tensile modulus of JS/UPE composites at different fiber loading are shown in figure 3 where TM was plotted as a function of jute fiber content. It is seen from figure 3 that TM in longitudinal direction increased with the increase of jute fiber content up to 50 wt. % and then decreased. This may be attributed to the higher modulus of jute fiber (13-26.5 GPa) compared to UPE resin (1.2 GPa). The decrease of TM above 50% jute content may be attributed to the poor wetting of jute fiber by resin. At 50 wt. % of jute content, the tensile modulus is 6.75 MPa. It is seen from figure 3 that TM in transverse direction decreased with the increase of fiber content.

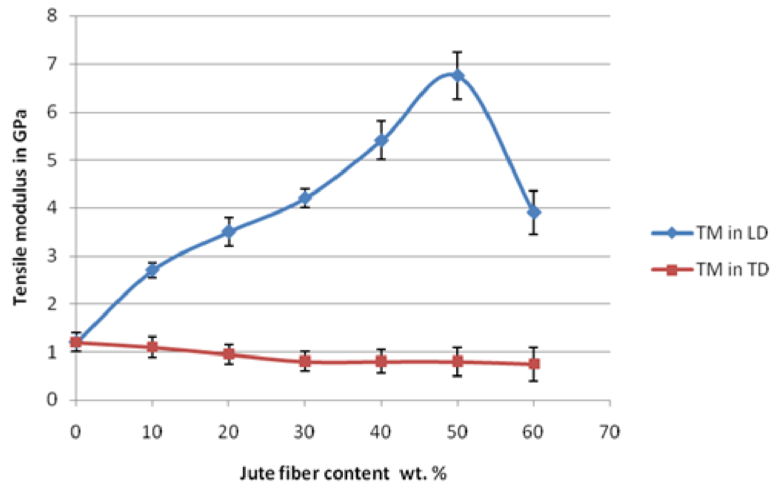

Fig. 3. Effect of jute fiber content on TM of JS/UPE composite in longitudinal and transverse direction

Bending Strength

Figure 4 shows the bending strength (three-point bending) of JS/UPE composites along longitudinal and transverse direction. A significant increase in this property along longitudinal direction is observed with the increase of jute fiber content in comparison to pure UPE resin. It is interesting to observe that the composite with 50 wt. (%) of fiber showed the highest value of bending strength and it was 160 MPa. For composite with fiber content above 50 wt. % the bending strength decreased. This fact can be related with the high content of jute fiber and the poor dispersion and distribution of the fibers in the matrix.

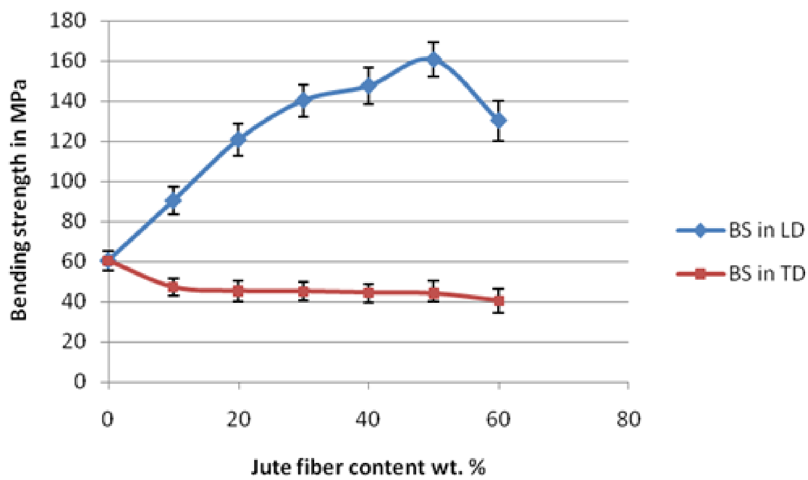

Fig. 4. Effect of jute content on BS of JS/UPE composite in longitudinal and transverse direction

Bending Modulus

The effect of jute content of on the BM of JS/UPE composites along longitudinal and transverse direction is shown in figure 5. The BM values of JS/UPE composites in longitudinal direction increased linearly with the increase of fiber content up to 50 wt. % and then decreased. The values of BM in transverse direction decreased with the increase of fiber content. The BM of JS/UPE composite at 50% jute content in longitudinal direction is 13.7 GPa which is 5.96 times higher than the neat resin and 10.54 times higher than BM in transverse direction.

Impact strength

The effect of jute fiber content on impact strength of JS/UPE composite in longitudinal and transverse direction is shown in figure 6.

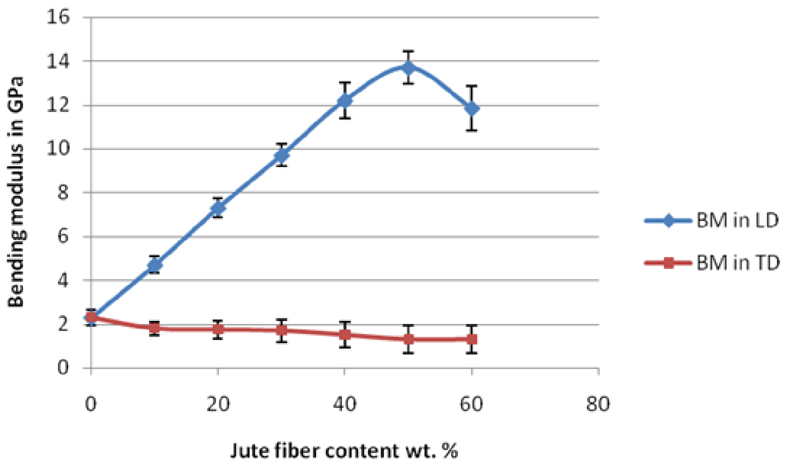

Fig. 5. Effect of jute content on BM of JS/UPE composite in longitudinal and transverse direction

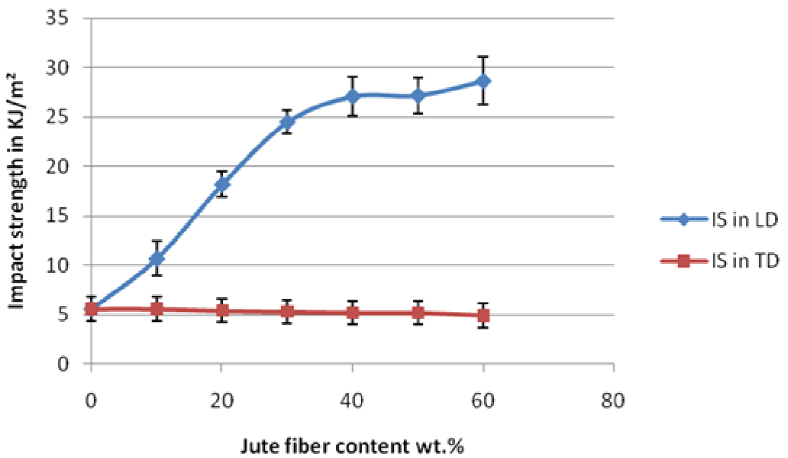

Fig. 6. Effect of jute content on IS of JS/UPE composite in longitudinal and transverse direction

It is seen from figure 6 that the impact strength of JS/UPE composites in longitudinal direction increased with the increase of jute content. On the other hand, the impact strength in transverse direction decreased with the increase of jute content. The TS, TM, BS and BM of JS/UPE composites along longitudinal direction increased with the increase of jute content up to 50% and then decreased. On the other hand, the IS of JS/UPE composites decreased with the increase of jute content up to 60%.

The mechanical properties of JS/UPE composites along transverse direction are much lower than that of their properties in longitudinal direction at all fiber loading. Taking all the mechanical properties into consideration it can be inferred that JS/UPE composite with 50% jute content is the best among all JS/UPE composites and this amount will be maintained for further experiments.

Conclusion

As jute fibers remain almost parallel in sliver, so sliver reinforced composites are unidirectional and they exhibited exceptional mechanical properties in longitudinal direction and very ordinary or poor properties in transverse direction. So, to minimize the difference of mechanical properties between longitudinal and transverse directions woven E-glass roving (WGR) and jute fabric (JF) can be incorporated in different proportions in JS based UPE composite (having 50% jute content). The incorporation of E-glass roving in JS/UPE and jute fabric (JF) is expected to enhance the mechanical properties of JS/UPE composite both in longitudinal and transverse direction .

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Author Contributions

MMR, MOR, MHK, MFAH, HMZH and MK conceived the concept, wrote and approved the manuscript.

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Availability of data and materials

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Competing interest

The authors declare no competing interests.

Ethics approval
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