Effect of lay-up angle on mechanical properties of composites based on rib knit jute preforms

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The mechanical properties of knitted jute reinforced composites with different stacking sequences have been studied. Flat rib knit ted preforms have been produced in manual flat bed knitting machine followed by composite laminate preparation using simple hand lay-up technique. It is observed that the mechanical properties are dependent upon the stacking sequence. The improvement in course-wise mechanical properties of the laminates has been observed with [0°/±450] and [0°/90°/90°] lay-up sequences compared to [0°] lay-up sequence which shows improvement in properties in wale-wise direction.

Keywords: Composite, Jute, Knitting, Mechanical properties, Textile preform

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1 Introduction

Glass, carbon, boron and kevlar fibres are being used as reinforcing fibres in fibre reinforced plastics which have been widely accepted as materials for structural and non-structural applications. Fibre reinforced plastics have gained importance due to their high specific modulus, stiffness-to-weight ratio and strength-to-weight ratio compared to conventional materials. These materials are expensive and find their use in high class applications. Natural fibres, like banana, cotton, coir, sisal and jute, have attracted the researchers for their application in consumer goods, low-cost housing and other civil structures. Jute appears to be a potential candidate because of its commercial availability and inexpensiveness.

Researchers have characterized and discussed in detail the mechanical properties of woven jute reinforced composite using thermostet and thermoplastic resins for its tensile strength and modulus, flexural strength and modulus, impact strength, in plane shear strength, interlaminar shear strength and hardness. Knitting, as one of the preforms manufacturing techniques for composite, has caught the eyes of researchers for past few decades for its ability to conform into complex contours because of its superior drapeability. Studies on knitted glass fabrics and other high performance fibres reveal that the knitted fabric reinforced composites possess superior impact properties compared to their woven counterparts. Tensile properties of knitted reinforcements are found to be poor compared to that of woven fabric reinforced composites. Several attempts have been made to improve the properties of knitted composites by the introduction of inlay at first in course direction followed by in biaxial direction, and by the variation in knit architecture, stitch density, pre-stretching percentage on fabrics and tow size of bundles. Limited work has been reported so far on the mechanical behaviour of knitted fabric reinforced with different stacking sequences. It has been found that the mechanical properties of composites are sensitive to stacking sequence, leading to variation of properties in wale-wise and course-wise directions.

In this work, an attempt has been made to study the mechanical behaviour of knitted jute reinforced composites with various stacking sequences [0°]4,
Materials and Methods

2.1 Knitting of Jute

Jute yarn (272 tex and 187 twists/m), spun from a jute fibre of 29.5 cN/tex bundle tenacity, was knitted on a manual V-bed flat knitting machine with a gauge of 5 needles/inch. The tenacity and elongation-at-break of jute yarn were 11.50 cN/tex and 1.67% respectively. Care was taken to adjust the knitting feed tension so that there were few breakages while knitting of jute yarns. The wales/inch and courses/inch were 6 and 12 respectively.

2.2 Composite Fabrication

A simple hand lay-up method was used for the preparation of composites. The working surfaces were coated with wax and polyvinyl alcohol (PVA) for the easy removal of lamina tes from the moulds. The matrix material was prepared from commercially available vinylester resin (cured at room temperature) procured from Vaasivibala Resins Pvt Ltd. The resin, accelerator and catalyst were taken in a weight ratio of 1:0.02:0.02 respectively. The resin, catalyst and accelerator were thoroughly mixed together, followed by a vacuum treatment for 3-5 min to remove entrapped air bubbles. Prior to commencing the composite fabrication, the knitted jute fabrics were dried in an oven at 100°C for 2.5 h to remove moisture in the fabric. Each layer of the fabric is then pre-impregnated with the matrix material and placed one over the other in the mould. A brush was used to push any air cavity to sides, before applying pressure. The resin-impregnated fabrics were cured at room temperature for 24 h. Lamina tes of three different stacking configurations, i.e. 

\[0°/90°/90°/0°\], \n
\[0°/±45°/0°\] and \n
\[0°/90°/90°/0°\]. The weight fraction of the jute fibre in the multi-layer laminates was 27.27%.

2.3 Tensile Tests

Tensile tests were carried out according to ASTM D3039 standards on an Instron tester (Model 4301). The size of the specimens was 250 x 25.4 x 4 mm and the cross-head speed was kept at 2 mm/min.

2.4 Flexural Tests

Flexural tests were carried out according to ASTM D790 standards on a three-point bending load using an Instron tester (Model 4301). The size of specimens was 130 x 25.4 x 4 mm.

2.5 Impact Tests

Impact tests were carried out according to ASTM D256 standards using the un-notched specimens. The size of specimens was 65 x 12.7 x 4 mm.

3 Results and Discussion

3.1 Tensile Tests

The major factors which affect the tensile strength of a knitted composite specimen are the design architecture, volume fraction of fibres or number of fibres bridging the fracture plane, apart from knitting parameters like loop length, wales per inch and courses per inch. Moreover, the anisotropy of the knitted samples is already known, leading to superior tensile property in wale direction compared to that in course direction.
Figs 2 and 3 give average tensile properties (tensile modulus and tensile strength) of multi-layered knitted jute fabric composites subjected to a uniaxial tensile loading. It can be seen from the figures that the anisotropic nature of the knitted composites to a particular direction of loading is known.

The tensile modulus and tensile strength of the specimens subjected to uniaxial loading are dependent upon the yarn orientation along the applied load. From the figures, it can be seen that the tensile strength of [0°]₄ composites is superior to all other lay-ups in wale-wise direction, whereas in course-wise direction the sequence [0°/90°/90°/0°] is better than the other two lay-ups. Moreover, it should be noted that [0°/90°/90°/0°] specimens show more or less similar properties in both directions.

The fracture mode of [0°/±45°/0°] is different from the other lay-ups. The [0°]₄ and [0°/90°/90°/0°] specimens fracture normal to the vertical axis of the specimen when loaded in wale or course direction. The failure in case of [0°/±45°/0°] is unpredictable, leading to different failure modes.

Recent study on glass-epoxy system offers an explanation for this kind of failure by matrix digestion method. For a particular case of α = 45° (angle of inclined surface to the applied stress), the fracture of monolayer laminate occurs along the inclined surface since the shear strength of the composites is higher than its tensile strength which implies that the failure of single layer composite subjected to the uniaxial tensile load is mainly caused by the normal (tensile) stress component on the inclined surface. On the other hand, the experiment shows that the fracture of [0°/±45°/0°] laminate does not occur along a similar inclined surface. Therefore, the resulting normal (tensile) stress component must be smaller than the shear stress component, leading to different fracture modes.

### 3.2 Flexural Tests

The flexural modulus and flexural strength values of multi-layered knitted jute laminates are given in Figs 4 and 5. The flexural strength of weft knitted
preform is determined by the strength of fibre bundles bridging the fracture planes. The fibre bundles bridging the course fracture planes are less than those bridging the wale fracture planes, leading to superior wale-wise flexural property to that of course-wise property. With the change in lay-up sequence from $[0^\circ]_4$ to $[0^\circ/\pm 45^\circ/0^\circ]$ and $[0^\circ/90^\circ/90^\circ/0^\circ]$, the improvement in course-wise property is observed due to the contribution of more fibre bundles in course-wise direction.

3.3 Impact Tests

The impact tests involve the relatively high contact forces acting on a small area over a period of short duration with both elastic and plastic deformation, leading to fracture. While metals absorb energy in elastic-plastic deformation, the composites generally absorb energy through fracture mechanisms, such as delamination, shear cracking and fibre breakage; however, some portion of energy may be absorbed through the elastic-plastic deformation of the fibre and the matrix. The impact values of multi-layer laminates are given in Fig 6. It is observed that the impact properties improve with the change in lay-up sequencing, leading to improvement of course-wise impact strength compared to wale-wise impact strength. Similar kind of observation has been reported in the study of knitted glass-epoxy matrix system for a four-ply sequencing. This is attributed to the multi-directional nature of knitted loops and intermeshing of loops with different plies on application of load while preparing laminates, leading to superior impact resistance.

4 Conclusions

Mechanical properties, like tensile, flexural and impact strengths, are found to vary with the stacking sequence; $[0^\circ]_4$ laminates exhibit superior properties in wale-wise direction whereas $[0^\circ/\pm 45^\circ/0^\circ]$ and $[0^\circ/90^\circ/90^\circ/0^\circ]$ exhibit superior properties in course-wise direction. The fracture mode of $[0^\circ/\pm 45^\circ/0^\circ]$ multi-layer laminate is found to be different compared to the other laminates when subjected to a uniaxial tensile load.

References