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Research Article

Experimental Investigation on Hybrid Composites for characterization and prediction of properties

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Abstract

The main aim of present research work to study the effect of fibre loading and orientation on the physical, mechanical and water absorption behaviour of jute/glass fibre reinforced epoxy based hybrid composites. A hybrid composite is a combination of two or more different types of fibre in which one type of fibre balance the deficiency of another fibre. Composites of various compositions with three different fibre loading (30wt%, 40wt% and 50wt%) and three different fibre orientation (0°, 30° and 60°) are fabricated using simple hand lay-up technique. It has been observed that there is a significant effect of fibre loading and orientation on the performance of jute/glass fibre reinforced epoxy based hybrid composites. TOPSIS a multi-criteria decision making approach is also used to select the best alternative from a set of alternatives.

Keywords: *Hybrid Composites, TOPSIS.*

1. Introduction

A composite material is a combination of two or more chemically different materials with a distinct interface between them. The constituent materials maintain their separate identities in the composite, yet their combination produces properties and characteristics that are superior to those of the constituents. One of the constituents forms a continuous phase and is called the matrix. The other major constituent is reinforcement in the form of fibers or particulates that is in general added to the matrix to enhance matrix properties. In most of the cases, reinforcement is harder, stronger and stiffer than the matrix. The matrix material in a composite may be a polymer, a metal, or a ceramic, depending on which composite materials are classified as polymer matrix composite (PMCs), metal matrix composite (MMCs), or ceramic matrix composite (CMCs). Polymers are classified as thermosets (epoxies, polyesters, phenolics, polyamide etc) and thermoplastics (polyethylene, polystyrene, polyether-ether-ketone (PEEK) etc). Examples of metal matrices are aluminium, magnesium and titanium and examples of ceramic matrices are alumina, calcium alumino silicate.

Particulate reinforcements have dimensions that are approximately equal in all directions. The shape of the reinforcing particles may be spherical, cubic, platelet or any other regular or irregular geometry. A fibrous reinforcement is characterized by its length being much greater than its cross-sectional dimensions. However, the ratio of length to the cross-sectional dimension, known as aspect ratio, can vary considerably.

1.1 Hybrid composites

Incorporation of two or more fibers within a single matrix is known as hybridization, and the resulting material is generally referred to as hybrid composite or simply hybrid. Hybrid composites are made in order to combine the advantage of one fiber with the other. For example, high modulus fiber like graphite has exceptionally high strength-to-weight ratio, but their impact strength has generally been found to be relatively low compared with conventional steel and aluminum alloys, and also with glass-fiber reinforced composites. An effective method of enhancing the impact properties of graphite fiber reinforced composites is to add to them a small percentage of low modulus high strength glass fibers. Besides improving impact performance, the incorporation of glass fibers, reduces the cost, which is a limitation for the application of graphite fiber composites.

2. Experimental characterization

Experimental characterization refers to the determination of the material properties through tests conducted on suitably designed specimens as

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per standard procedures. The properties evaluated can later be used for design and analysis of practical structures. The mechanical properties of a composite material mainly depend on the properties of its constituents. For fiber reinforced composites the mechanical properties are affected by a number of parameters such as length, orientation, dispersion, geometry, fiber volume fraction and degree of interfacial adhesion between the fiber and matrix.

2.1 Material used

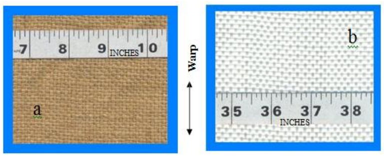

Fig.1 (a) Woven jute fabric (22 × 12) (b) Balanced plain weave glass woven roving

Isothalic (or Isophthalic) polyester NRC 200-220, supplied by Naptha Resins and Chemicals Pvt Ltd, Bangalore, India, MEKP Catalyst and Cobalt Naphtenate accelerator constitutes the resin system. PVA and Polyester film were used as releasing agents.

2.2 Jute yarn and fabric testing

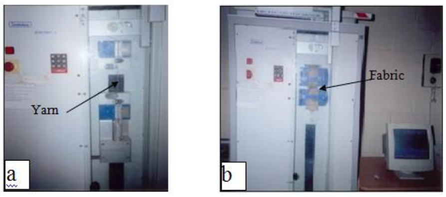

Fig.2 (a) Jute yarn and (b) jute fabric test set-up

The jute yarn and fabric tests were conducted at room temperature as per ASTM standards 5526 and 5035 respectively. For yarn testing 100 N load cell was used and the test speed was selected as 30 mm/min so that the breaking time is 20 ± 3 secs. For testing of the fabric 1000 N load cell was used and the test speed was 300 mm/min. Properties such as tensile strength, percentage elongation, tenacity in both warp and weft directions were recorded. For yarns 20 samples and for fabric 5 samples were tested and average results were obtained.

2.3 Fabrication of laminates and specimen preparation

Simple hand layup technique was used for fabrication of laminates at laboratory temperature. Unlike glass fabric, impregnated jute fabric layers needs pressure to be applied for effective bonding between the layers. Hence, the fabrication of laminates was carried out in a mold with provision to apply the pressure. The mold was designed and fabricated to consist of two mild steel plates of 300 mm × 280 mm × 30 mm, each. The inner surfaces of both the plates were grounded to obtain smooth perfectly horizontal planes.

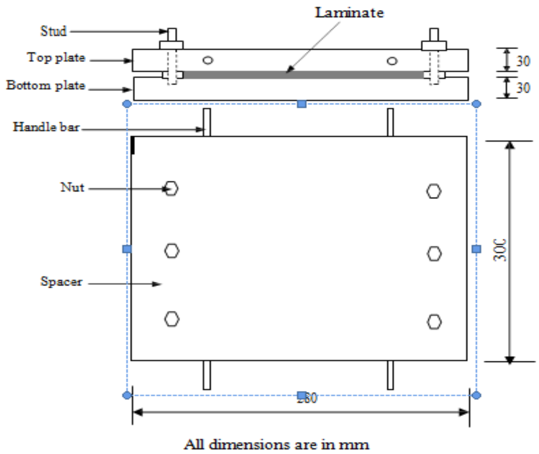

Fig.3 Constructional details of mold plates

The top plate was provided with handles to facilitate its easy removal and insertion over the studs of the bottom plates. Spacers of desired thickness were used to maintain uniform thickness of the laminate. In the closed position, uniform open gap can be maintained between the plates across the two ends for the hot gases to escape. For fabrication of the laminate, PVA release agent was applied to the surfaces of the mold. Jute and glass fabrics were pre-impregnated with the matrix material consisting of isothalic polyester, accelerator and catalyst in the ratio of 1:0.015:0.015 respectively. The impregnated layers were placed one over the other on the bottom plate of the mold. Top plate was placed over the impregnated stack of layers and pressed by uniformly and simultaneously tightening the nuts. Curing was done for one hour under pressure. After one hour, the laminate was removed from the mold and cured at room temperature for 48 hours.

All the composites were processed at total weight fraction of 42(±1)% except for impact test, where the total weight fraction was maintained at 46(±1)%. The total fiber volume fraction was calculated using the equation (1).

$$V_f = \frac{(W_j/\rho_j)+(W_g/\rho_g)}{(W_j/\rho_j)+(W_g/\rho_g)+(W_r/\rho_r)} \quad (1)$$

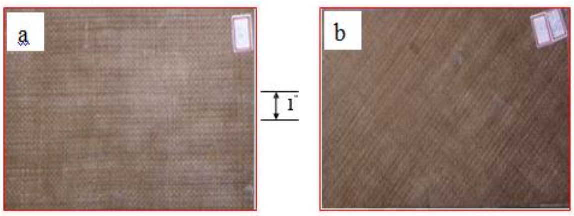

Fig.4 All jute laminates (a) $0^{O}/90^{O}$, (b) ± 45^{O}

3. Mechanical Testing

All the tests on jute and jute-glass hybrid composite specimens (except impact) were carried out at room temperature on closed loop servo hydraulic MTS 810 Material Test System having a maximum capacity of 100 KN.

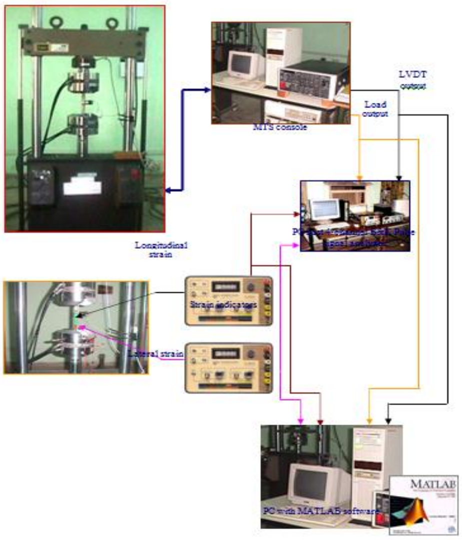

Fig.5 Test set up and details of instrumentation

Load Cell, Linear Variable Differential Transformer (LVDT) and clip-on type MTS extensometer were used to measure force, displacement and strain respectively. Material testing software *Test Works-II* was used for the testing. The output signal from MTS 458.20 Micro console controller was converted into digital signal by employing 3 channel ADC card. For determination of Poisson's ratio and shear modulus, strain gauges of 120 ohms resistance and G.F 2.1 were mounted in the longitudinal and transverse direction on tension test and in-plane shear test specimens. The strain was measured using strain indicator B & K type 1526. In all the cases, five identical specimens were tested for each type of material and average results were obtained.

3.1 Tension Testing

Tensile properties such as tensile strength, tensile modulus and Poisson's ratio in both warp and weft direction were determined by conducting static tension test in accordance with ASTM D3039.

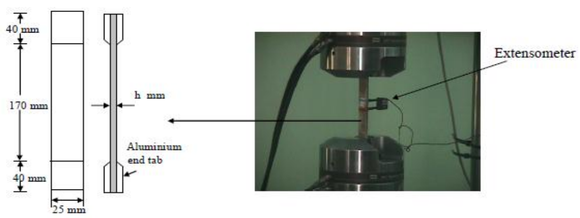

Fig.6 Tension test configuration

Aluminum end tabs of 38 mm length were bonded to the specimens and were held in the hydraulic grips at a pressure of 600 psi (4.2 MPa). Load cell of 50 kN was selected for this test. The specimens were loaded in tension at a constant stroke rate of 2 mm/min. Clip-on type MTS extensometer of gauge length 25 mm was mounted on the specimen for measurement of the strain. One group of unreinforced resin sample was also tested in tension for comparison purpose.

3.2 Compression Testing

Compressive properties such as compressive strength and compressive modulus were determined by static compression test in accordance with ASTM D 3410. The test coupons were prepared in such a way that jute warp yarns are oriented in the loading direction. Aluminum end tabs of approximately 56 mm length were bonded to the specimens at both the ends to leave a small gauge length of 12.7 mm in order to avoid buckling of the specimen. The geometry of the test coupon is shown in Figure 3.7. Load cell of 20 kN was selected for this test. The load was applied at a constantstroke rate of 1.5 mm/min.

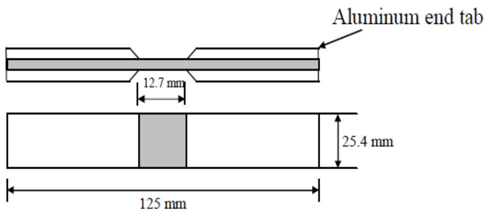

Fig.7 Compression test coupon

3.3 Flexural testing

Flexural test was conducted as per ASTM D 790. Specimens of 125 mm overall length and 10 mm wide (jute warp yarns oriented along the lengthwise direction) are loaded in three-point bending with a recommended span to depth ratio of 16:1. The test was conducted using a load cell of 10 kN at 2.8 mm/min rate of loading. The flexural stress in a three point bending test is given by $\sigma_b = (3\ P_{max}\ L) / (bh^2)$, where P_{max} is the maximum load (N) at failure, L is the span (mm), b and h is the width and thickness of the specimen (mm) respectively. The flexural modulus is calculated from the slope of the initial portion of the load-deflection curve. Flexural modulus is given by $E_b = (m_s L^3) / (4bh^3)$, where m_s is the initial slope of the load deflection curve. One group of unreinforced polyester samples was also tested for comparison purpose.

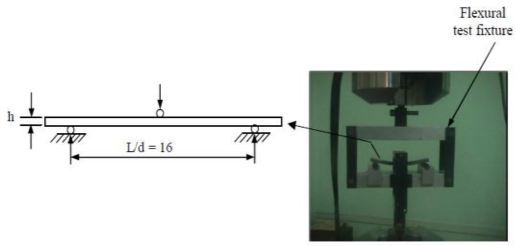

Fig.8 Flexural test configuration

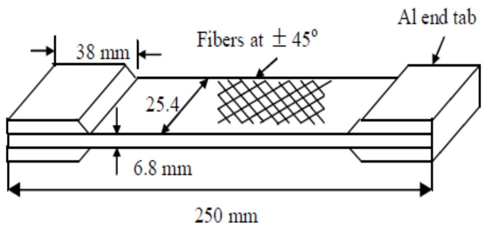

Fig.9 In plane shear test coupon

3.4 Impact Testing

Charpy impact test was conducted on instrumented pendulum type Tinius Olsen Dynatup model 1730 impact tester as per ASTM D256. The test set up is shown in Figure A.1.3 (Appendix 1). The un-notched specimens were supported on the platform of the machine at a span 40 mm. The square cross sectional specimens was impacted by 10 mm hemispherical head. The impact velocity was 0.75 m/s for polyester specimens and all jute laminates and 1.5 m/s for hybrid laminates. The impact events such as load-time, energy-time and load-deflection plots were recorded using the data acquisition software.

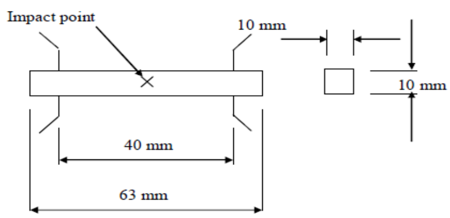

Fig.10 Impact test coupon

4. Results and Discussions

4.1 Jute yarn and fabric testing

Typical load-elongation behavior of jute yarns of warp and weft directions is shown in Figure 3.12(a). Since the yarn samples were taken out from the woven fabric, they were not straight due to slack. The initial portion of the curve, which is more or less horizontal indicate, the straightening effect of the yarns under the load. The curve then progressively increases until the peak load and then drops suddenly representing the failure of the yarns.

Because of non-uniformity in the cross sections of the yarns, there was wide deviation among the curves even though the samples were identical in length. For this reason as many as twenty samples were tested and the average breaking load is found to be 40.79 N for the warp and 29.42 N for the weft yarns. The average percentage elongation at the time of breaking is found to be 2.82 and 3.83 for warp and weft yarns respectively.

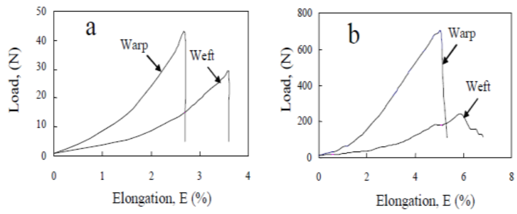

Fig.11 Typical load-elongation behavior (a) Jute yarns and (b) Jute fabrics

Typical load-elongation behavior of the jute fabrics of warp and weft direction shown in Figure also depicts a similar trend with the initial portions of the curves being horizontal representing the initial stretching of the fabric. Different yarns in the fabric will have different breaking strength and fail individually. Thus the progressive failure of different yarns will ultimately lead to the failure of the fabric. The maximum tensile strength of the jute fabric in warp and weft directions is found to be 668.85 N and 240.97 N respectively.

Figures (a) and (b) represents the tensile stress-strain diagrams for jute laminates in warp and weft direction respectively. The initial portion of the curve is linear at low strain rates followed by change in the slope of the curve indicating non-linear behavior of the material. The start of non linearity in the curve is an indication of the initial matrix cracking followed by progressive failure of the fibers.

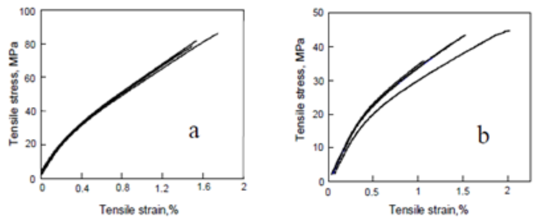

Fig.12 Tensile stress-strain behavior of jute laminates (a) Warp direction (b) Weft direction

The tensile strength of jute laminate in warp direction is 83.96% higher than the tensile strength of unreinforced polyester samples. The strain at maximum tensile stress for jute composite samples ranged from 1.38% to 1.78% in warp and 1.05% to 2.01% in weft direction respectively. Tensile modulii were determined by the slope of the initial portion of stress-strain curves.

A significant improvement in the tensile modulus of polyester samples is obtained by jute fabric reinforcement. The warp direction tensile modulus is 118.97% higher than the modulus of polyester samples. The tensile strength and tensile modulus of jute laminate is found to be higher in warp direction than in weft direction. This is because more number of fibers in warp direction offers greater resistance to crack propagation than in weft direction. As a result, the strength of the material in warp direction is greater than the strength in the weft direction.

The effect of glass fiber addition in different weight fractions, on tensile stress - tensile strain behavior of resulting hybrid composites in war and weft directions are compared with only jute composites and unreinforced resin samples in Figure.

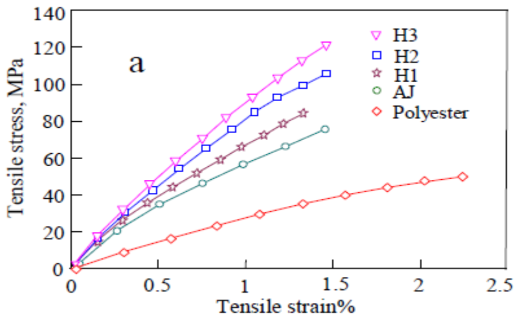

Fig.13 Tensile stress-strain behaviors of hybrid laminates compared with jute laminate in Warp

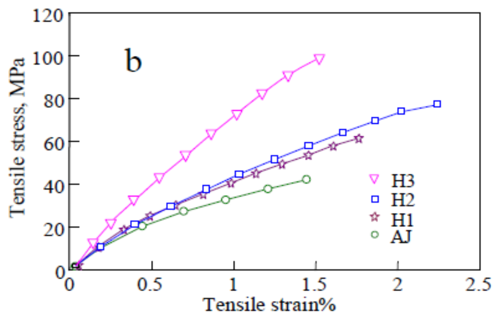

Fig.14 Tensile stress-strain behaviors of hybrid laminates compared with jute laminate in Weft direction

The curves indicate similar kind of behavior with the initial portion being linear upto certain strain, then deviates from linearity. However, the ultimate tensile strength as well as the slope of the curve increases with the increase in the glass fiber content.

Figure shows the variation in the tensile strength with the glass fiber loading. By increasing the glass fiber weight fraction from 0% (AJ) to 8.2%(H1), 16.5%(H2) and 25.2%(H3) in a total fiber weight fraction of 42%, the tensile strength is found to increase by 9.6%, 37% and 54.56% respectively, in warp direction and 54.3%, 91.4% and 148.3% respectively, in weft direction.

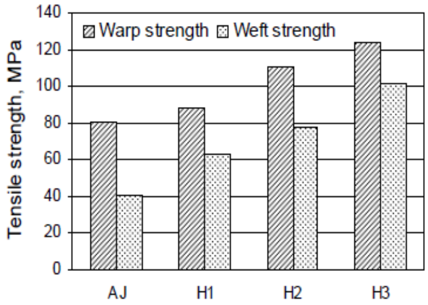

Fig.15 Variation of tensile strength with glass fiber loading

Significant improvement in the tensile modulus in both warp and weft directions is also observed with the addition of glass fiber content, as indicated in Figure 3.16. By increasing the glass fiber weight fraction from 0%(AJ) to 8.2%(H1), 16.5%(H2) and 25.2%(H3) in a total fiber weight fraction of 42%, the tensile modulus is found to increase by 14.3%, 17.85% and 30.17% respectively, in warp direction and 26.96%, 37.91% and 70.96% respectively, in weft direction.

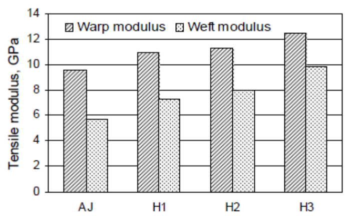

Fig.16 Variation of tensile modulus with glass fiber loading

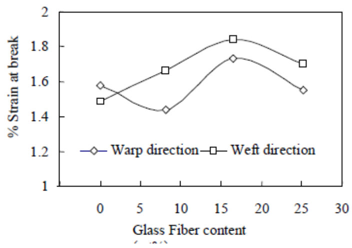

Fig.17 Percentage strain versus glass fiber loading

5.1 Analysis of Compression Test Results

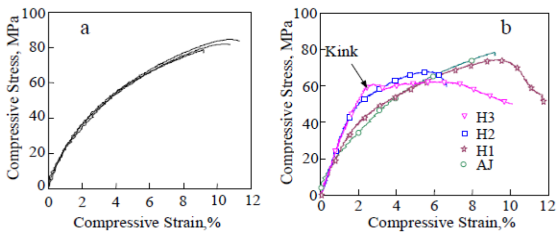

Fig.18 Compressive stress-strain behaviors of (a) All Jute (AJ) (b) Hybrid laminates compared with AJ

All the four identical samples of hybrid laminate H3 with 25.2 wt% glass fiber exhibits kink at the failure point. The experimental results revealed that the average compressive strength of jute laminate (83.38 MPa) is more or less same as tensile strength for the same volume fraction of jute fibers. Unlike tensile strength, the jute laminates exhibit higher compressive strength than jute-glass hybrid laminates, but less than the literature (John and Venkata Naidu 2004) value of 116 MPa for glass fiber reinforced polyester laminate with 8.2% fiber volume fraction. This reduction may be due to non-uniformity of load distribution because of different buckling strength of the two fibers. Addition of glass fiber (wt %) from 0% (AJ) to 8.2% (H1), 16.5% (H2) and 25.2% (H3) in a total fiber weight reduction in compressive strength respectively.fraction of 42% results in 10.2%.

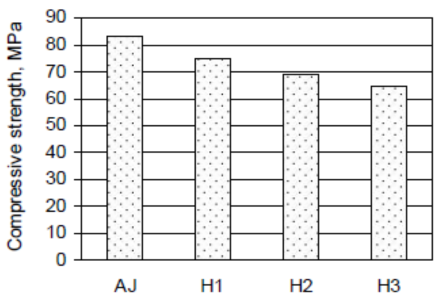

Fig.19 Variation of compressive strength with glass fiber loading

The compressive modulus was obtained from the slope of the initial portion of the stress-strain curve. The compressive modulus of jute composite is reduced by 80.79% of its tensile modulus in warp direction. The drastic reduction in the compressive modulus may be attributed to high percentage strain of the laminates under compressive loading. The strain in the laminates at break under compression test is more than 10%, whereas in tension test it was just about 1.5%.

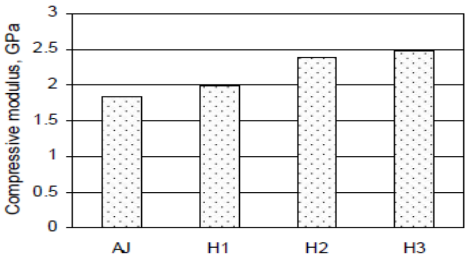

Fig.20 Variation of compressive modulus with glass fiber loading

As evident from the figure, the compressive modulus showed the increasing trend with the incorporation of glass fiber. An increase in the compressive modulus of 7.6%, 28.8%, and 34.24% with 8.2%, 16.5% and 25.2% (by wt) addition of glass fiber respectively, was noticed.

5.2 Statistical Analysis of Compression Test

Table 1 Compressive strength data from experiment

Weight percent glass fiber	Total Observations y_i	Average y_i
0(Aj)	333.51	3.38
8.2(H1)	299.50	74.8
16.5(H2)	276.23	69.0
25.2(H3)	258.74	64.6
	y_n =1167.98	y_n =73.00

Table 2 Compressive modulus data from experiment

Weight percent of glass fiber	Total Observations y_i	Average y_i
0(AJ)	7.34	1.84
8.2(H1)	7.91	1.98
16.5(H2)	9.49	2.37
25.2(H3)	9.88	2.47
	y_n =34.62	y_n =2.165

For compression test, four specimens for each type of laminate were tested. Hence there are four levels (or treatments, a) and four observations at each level. The results of the statistical analysis for compressive properties are presented in Tables 3.8 and 3.9. It can be seen from the tables that between-treatment mean squares are many times larger than within-treatment or error mean square.

5.3 Analysis of Flexural Test Results

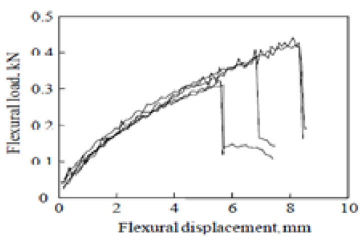

Fig.21 Flexural load-deflection plots for all-jute laminates

The average flexural strength of jute composite is found to be 121.80 MPa which is 31.8% higher than the flexural strength of unreinforced polyester resin. The flexural modulus is a measure of the resistance to deformation of the composite in bending. It is measured from the slope of initial portion of load-deflection curve. The average flexural modulus of jute composite is found to be 7.64 GPa which is 209% higher than the modulus of unreinforced resin.

The effect of glass fiber addition with different relative weight fractions, on load-deflection behavior of resulting hybrid composites are compared with only jute composites and unreinforced resin samples in Figure. Under the flexural loading, the surfaces of the specimen are subjected to greater strains than the sample centre. Hence the flexural strength and stiffness is controlled by the strength of the extreme layers of reinforcement (Munikenche Gowda et al 1999). The failure initiates with the development of crack on the tension side. Obviously,by providing glass layers as the extreme plies, the flexural strength is found to increase significantly. This is because glass fibers offer greater strength and good resistance to propagation of cracks.

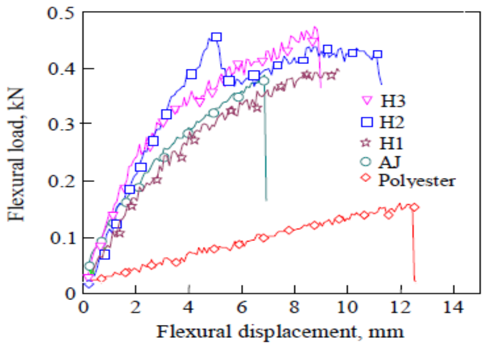

Fig.22 Flexural load-deflection

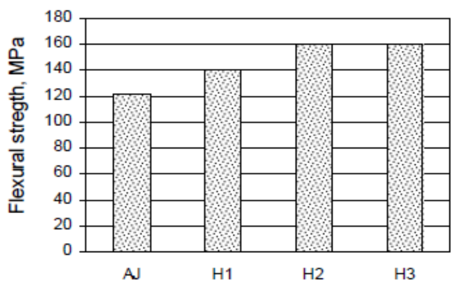

Fig.23 Variation of flexural strength with glass fiber loading

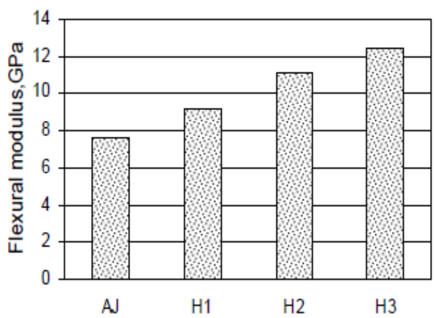

Fig.24 Variation of flexural modulus with glass fiber loading

Table 3 Flexural strength data from experiment

Weight percent glass fiber	Total observations y_i	Average y_i
0(AJ)	608.85	11.77
8.2(H1)	699.90	139.98
16.5(H2)	799.00	159.80
25.2(H3)	799.5	159.85
	y_n =2907	y_n =145.35

Table 4 Flexural modulus data from experiment

Weight percent glass fiber	Total observations y_i	Average y_i
0(AJ)	38.19	7.64
8.2(H1)	45.54	9.11
16.5(H2)	55.30	11.06
25.2(H3)	61.88	12.38
	y_n =200.91	y_n =40.19

For flexural test, five specimens for each type of laminate were tested. Hence there are four levels (or treatments, a) and five observations at each level.

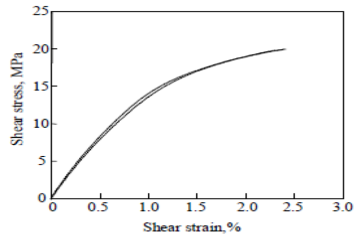

Fig.25 Typical shear stress-shear strain diagram for all jute laminates

All the specimens were failed due to jute fiber breakage, and matrix cracking. The average value of maximum shear stress for jute composite is found to be 20.78 MPa. The shear modulus of jute composite is found to be 1.74 GPa which is just 16.78% higher than the shear modulus of unreinforced isothalic polyester (1.49 GPa).

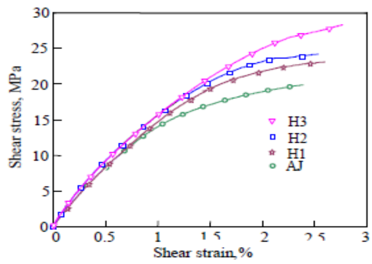

Fig.26 Shear stress-shear strain diagrams for all jute and hybrid laminates

The hybrid laminate with 25.2% glass fiber weight fraction depicted the highest value of maximum shear stress which is 34.74% higher than that of all jute laminate.

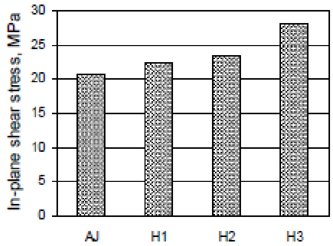

Fig.27 Variation of shear stress with glass fiber loading

The maximum shear modulus is 2.03 GPa (for hybrid composite with 25.2 wt% glass), which is just 16.6% greater than that of all jute laminate. A partial debonding at the jute-glass fabric interface was also observed in hybrid laminates.

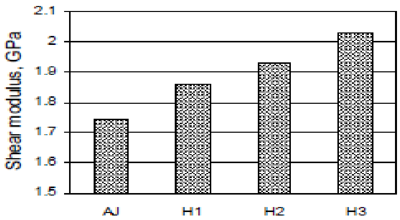

Fig.28 Variation of shear modulus with glass fiber loading

5.4 Analysis of Inter laminar Shear Test Results

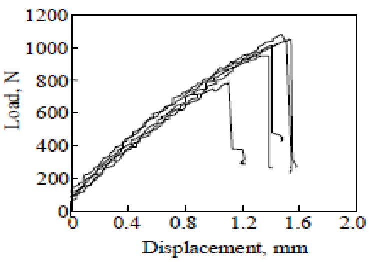

Fig.29 Load-deflection diagram for ILSS test (All jute)

The plots shows similar trend as for flexural tests. In short beam shear tests, the maximum shear stress occur in an area where other stresses may exist unlike homogeneous beam theory; in which maximum shear stress occurs at the neutral plane where normal stresses are zero. This result in combination of failure modes (Mallick 1993) such as fiber rupture, micro buckling and interlaminar shear cracking. Interlaminar shear failure may not also take place at the laminate mid plane and it is difficult to ensure pure shear failure along the interface. For these reasons, it is difficult to interpret the short-beam test data. However, jute laminates exhibit an average interlaminar shear stress value of 13.9 MPa.

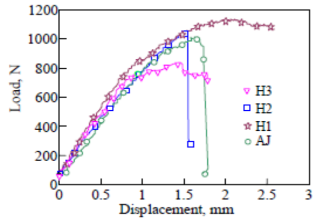

Fig.30 Load-deflection diagrams under ILSS for All jute and hybrid laminates

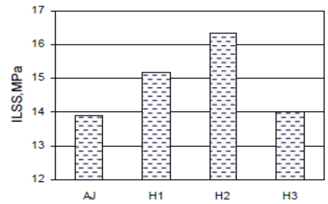

Fig.31 Variation of ILSS with glass fiber loading

5.5 Analysis of Impact Test Results

The impact load causes the damage to the matrix material due to internal delamination or fiber-matrix interface failure (Ghasemi Nejhad and Parvizi-Majidi 1991). However this damage being negligible has no effect on the strength and stiffness of the composite. The non-linear portion of the curve beyond the incipient load and energy point indicates the progressive failure of the fibers until the peak load, which is the maximum load that the material can withstand.

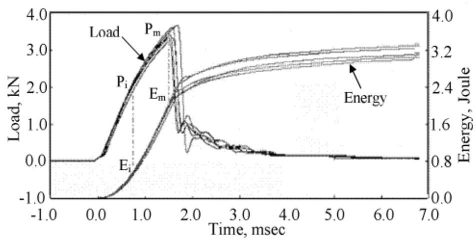

Fig.32 Load-energy-time plot for all jute laminates

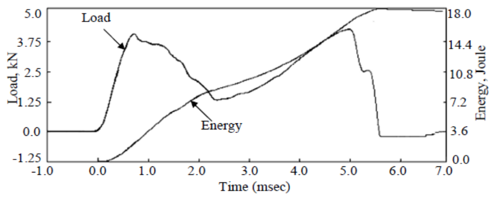

Fig.33 Load-energy-time plot for hybrid laminate (IH3)

The effect of glass fiber addition on impact strength of resulting jute-glass hybrid laminates is shown in Figure 3.44. It can be seen from the figure that, impact strength increases with the addition of glass fiber. The maximum value of impact strength for hybrid laminate IH3 is found to be 214.38 kJ/m^2. The specific impact strength of IH3 laminate that can be obtained by dividing the impact strength with the density of the composite is found to be 140.5 kJ/m^2. This value appears to compare well with the literature value of specific impact strength (160 kJ/m^2 for glass-polyester composite with 60% fiber volume fraction (Pavithran et al 1991).

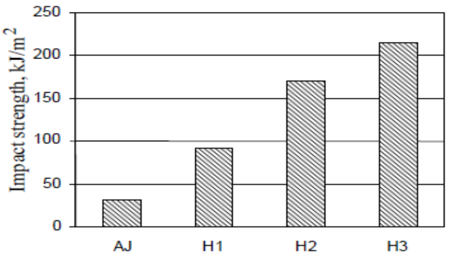

Fig.34 Variation of impact strength with glass fiber loading

Conclusions

Experiments were carried out to investigate the effect of glass fiber addition on mechanical behavior of resulting jute-glass fiber hybrid composites by comparing the results with only jute composites. The analysis of experimental data leads to the following conclusions.

1) Tensile and impact properties of jute-polyester composites are found to improve significantly by incorporation of glass fibers showing positive hybrid effect. Flexural strength and ILSS exhibited improvement upto 16.5 wt% of glass fiber in a total fiber weight fraction of 42 ±1%, beyond which no improvement in these properties are noticed.
2) Jute laminates have higher compression strength than jute-glass hybrid laminates. However their strength is less than all glass laminates.
3) Layering sequence (altering the position of glass plies) significantly affects the flexural and interlaminar shear strength.
4) Analysis of Variance used to analyze the effect of hybridization revealed that glass fiber addition has significant effect on mechanical properties @ 1% level of significance. Cubic regression models showed good agreement with the experimental results for all properties.
5) No improvement in the mechanical properties of jute and jute- glass hybrid composites is noticed by 5% and 10% alkali treatment to jute fabric for 30 and 20 min respectively. Only, under some optimum conditions, chemical treatment may lead to positive results.
6) Thermal conductivity of unidirectional jute composites in fiber direction (longitudinal) is slightly higher than thermal conductivity of woven jute fabric composites in normal to the fabric (transverse) direction.

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