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# Elastic property evaluation of jute-glass fibre hybrid composite using experimental and CLT approach

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Elastic properties are the basic quantities that are required during design and optimization of a laminated structure. Though the literature on elastic properties of conventional single fibre composite is well published, the same is scanty in the case of natural and hybrid composites. This work is focused on evaluation of in-plane elastic properties of untreated woven jute and jute-glass fabric hybrid polyester composites, under tension. The specimens have been fabricated by hand-lay-up technique with different relative weight fraction of jute and glass fibre. Theoretically, the laminate elastic properties are predicted by using the classical lamination theory (CLT) and rule of hybrid mixture model, using the resin and fibre properties together with the volume fraction (micromechanics). Experimentally, the elastic properties have been evaluated by tension test in warp and weft direction and in-plane shear test as per ASTM standards. The results indicated that the Young's modulus in both warp and weft direction improve by the inclusion of glass fibre, where as Poisson's ratio is decreased. Prediction by CLT and model showed close agreement with experimental values with a maximum deviation of about 20%. The possible causes for this deviation are discussed.

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There is a growing interest in the use of natural fibres as reinforcement in polymer matrix composites due to their various advantages over conventional fibres. These advantages[1,2] include low density, acceptable specific strength, less wear during processing, low cost, low energy, renewability and biodegradability. Among the various natural fibres, jute appears to be most promising material due to its good thermal and electrical insulation characteristics, appreciable toughness and, as a very important topic, wide commercial availability in various forms at a very low-cost. However, the major challenges[3] of natural fibres that limit their use in most of the applications are, affinity for moisture absorption resulting in strength degradation, variations in properties and quality due to growing conditions, limited maximum processing temperatures, lower impact strength and poor fire resistance. Attempts have been made by various researchers to meet these challenges by adopting techniques such as, fibre surface treatment, proper selection of resin and additives and hybridization of natural fibre with more durable glass fibre. Mohan and Kishore[4] reported that glass skin with jute core reinforced in epoxy matrix, not only improve the flexural properties, but also protect the jute core from weathering. Pavithran *et al.*[5] evaluated the enhancement in the properties of coir-polyester composites by incorporating glass as intimate mix with coir. Mishra *et al.*[6] proved that modification of sisal fibre by 5% alkali treatment will yield optimum tensile and impact properties of sisal-glass polyester composites. Verma *et al.*[7] studied the effect of silane, titanate and tolylene disocyanate treatment to jute fabric on tensile, flexural and interlaminar shear properties of jute-glass reinforced unsaturated polyester composites. Mechanical properties and durability of bamboo-glass fibre reinforced polymer matrix composites are also reported[8,9]. The mechanical properties have also been evaluated for natural-synthetic fiber hybrid composites by various researchers[10-12].

Several models for prediction of elastic properties of composites have also been proposed by the researchers. Ishikawa and Chou[13] proposed three analytical models, viz., mosaic model, fibre undulation model and bridging model for stiffness and strength investigation of plain and satin weave composites. They applied the mosaic model to hybrid satin weaves. Hine *et al.*[14] evaluated three models for prediction of elastic constants of short carbon fibre

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reinforced epoxy composites. The elastic properties predicted by these models were compared with those obtained by finite element technique. Excellent agreement was obtained for longitudinal modulus. Transverse modulus indicated a deviation up to 17.9% between modified Brody/Ward and finite element model. Transverse shear modulus indicated a deviation of 25% between modified Brody/Ward and finite element model and 34.7% between modified Brody/Ward and Wilczynski model. Wilczynski *et al.*[15] presented an algorithm for obtaining numerical values of elastic constants of unidirectional fibrous composites with both isotropic reinforcement, such as glass fibres and monotropic reinforcement such as polyethylene. Gommer *et al.*[16] investigated the elastic properties of knitted fabric reinforced composites. Tensile and shear tests were performed as per ASTM standards to determine the in-plane Young's modulus, Poisson's ratio and shear modulus of different types of glass/epoxy warp-knitted fabric composites. Young's modulus predicted by Krenchel was up to 40% of the test results and Poisson's ratio predicted by Voigt and Reuss was not significantly related to experimental values. Scida *et al.*[17] proposed an analytical model called MESOTEX (Mechanical Simulation of Textile) for predicting 3D elastic and failure properties of woven fibre composite materials. The proposed model is a point-wise lamination approach which uses the classical thin-laminate theory. Experimentally Young's modulii $E_x$, $E_y$ and Poisson's ratio $\upsilon_{xy}$ were determined by tension test and shear modulus $G_{xy}$ was determined by shear test, using biaxial strain gauge instrumented on the samples. The elastic properties predicted by the model were compared with experimentally measured values for materials like E-glass-vinylester plain weave composite, E-glass eight-harness satin weave/epoxy, 2/2 twill E-glass woven fabric/epoxy, 2/2 twill carbon woven fabric/epoxy and 2/2 twill carbon/aramid woven fabric/epoxy hybrid composites. Their results indicated reasonably good agreement between the measured and predicted values.

Most of the models proposed in the past have been mathematically very rigorous. Further, the literature reveals that, neither the CLT nor the models were applied to predict the elastic properties of jute and jute-glass hybrid composites. Table 1 presents the density and elastic properties of jute and glass fibre[18] and experimentally evaluated elastic properties of isothalic polyester resin. An orthotropic lamina subjected to in-plane loads can be defined by four independent elastic constants, viz., Young's modulus in warp direction, Young's modulus in weft direction, major or minor Poisson's ratio and shear modulus. In this paper, an attempt is made to predict these in-plane elastic properties for woven jute-glass fabric reinforced polyester hybrid laminate using classical lamination theory together with mechanics of materials approach, for different relative weight fractions of jute and glass fibre. A theoretical model based on rule of hybrid mixture is also proposed to predict the laminate elastic properties. The predicted values from classical lamination theory and the model are compared with the experimental values and the results are discussed.

## Theoretical Predictions

### Elastic properties of unidirectional fibre lamina

Assuming uniform distribution of resin in the composite, the average fibre volume fraction in each ply is same as total fibre volume fraction. The elastic properties of unidirectional jute fibre lamina and glass fibre lamina were predicted using simple rule of mixture relationships from the mechanics of materials approach.

For unidirectional jute ply,

$$E_{lj} = E_j V_j + E_m V_m \quad \dots (1)$$

$$\frac{1}{E_{tj}} = \frac{V_j}{E_j} + \frac{V_m}{E_m} \quad \dots (2)$$

$$\frac{1}{G_{ltj}} = \frac{V_j}{G_j} + \frac{V_m}{G_m} \quad \dots (3)$$

$$\upsilon_{ltj} = \upsilon_j V_j + \upsilon_m V_m \quad \dots (4)$$

For unidirectional glass ply,

$$E_{lg} = E_g V_g + E_m V_m \quad \dots (5)$$

Table 1—Properties of jute fibre, glass fibre and isothalic polyester resin

| | | | |
|---|---|---|---|
| Density, g/cm$^3$ | 1.45 | 2.5 | 1.1 |
| Young's modulus , GPa | 20 | 73 | 4.375 |
| Poisson's ratio | 0.38* | 0.2 | 0.46 |
| Shear modulus, GPa | 7.24 | 30.42 | 1.49 |

*Established from experimental value of jute composite using rule of mixture

$$\frac{1}{E_{tg}}=\frac{V_g}{E_g}+\frac{V_m}{E_m} \quad \ldots (6)$$

$$\frac{1}{G_{ltg}}=\frac{V_g}{G_g}+\frac{V_m}{G_m} \quad \ldots (7)$$

$$\upsilon_{ltg}=\upsilon_g V_g+\upsilon_m V_m \quad \ldots (8)$$

**Elastic properties of woven fabric lamina**

From the values of elastic properties $E_l$, $E_t$, $\upsilon_{lt}$, and $G_{lt}$ determined for unidirectional plies, the elastic properties of 0/90° woven jute fabric ply and glass fabric ply, were predicted by using the relations[19]. The constants $K_j$ and $K_g$ required for determination of elastic properties of woven plies are defined as:

For woven jute ply,

$$K_j=\frac{N_{1j}}{N_{1j}+N_{2j}}=0.647 \quad \ldots (9)$$

For woven glass ply,

$$K_g=\frac{N_{1g}}{N_{1g}+N_{2g}}=0.5 \quad \ldots (10)$$

**Elastic properties of hybrid laminate using CLT**

***Approach 1 (CLT AP-1)***

In this approach, each woven ply was represented as two unidirectional plies of 0° and 90° as shown in Fig. 1, so that 10 woven ply laminate can be treated as 20 unidirectional ply laminate.

Thickness of 0° and 90° jute and glass plies can be determined using Eqs (11) and (12) respectively.

$$t_{1j}=K_j\,t_j,\ t_{1g}=K_g\,t_g \quad \ldots (11)$$

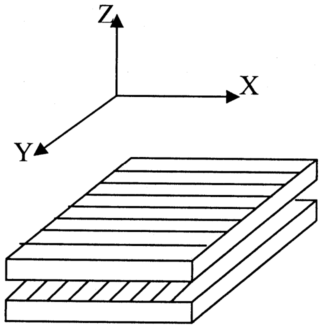

Fig. 1— Schematic representation of (0°/ 90°) as non-symmetric two-ply laminate

$$t_{2j}=(1-K_j)t_j,\ t_{2g}=(1-K_g)t_g \quad \ldots (12)$$

where, the thickness of each woven jute and glass ply, $t_j$ and $t_g$ in the laminate were evaluated using the derived Eq. (13).

$$t_j=\frac{hV_{jc}}{n_jV_j} \text{ and } t_g=\frac{hV_{gc}}{n_gV_g} \quad \ldots (13)$$

where $n_j$ and $n_g$ are the number of jute and glass layers in the laminate.

From classical lamination theory, extensional stiffness matrix for hybrid laminate can be written as

$$[A_{ij}]=[\bar{Q}_{ij}]_{0j}(n_j\,t_{1j})+[\bar{Q}_{ij}]_{90j}(n_j\,t_{2j})+[\bar{Q}_{ij}]_{0g}(n_g\,t_{1g}) + [\bar{Q}_{ij}]_{90g}(n_g\,t_{2g}) \quad \ldots (14)$$

where, $\bar{Q}_{ij}$ are the transformed reduced stiffness coefficients, MPa

The elements of $[\bar{Q}_{ij}]$ for 0° and 90° laminae were evaluated for both jute and glass plies by the known values of their elastic properties $E_l$, $E_t$, $\upsilon_{lt}$ and $G_{lt}$ using the relevant Eq. (15) of $Q$ and the transformation matrix.

$$Q_{11}=\frac{E_l}{1-\nu_{lt}\nu_{tl}},\quad Q_{22}=\frac{E_t}{1-\nu_{lt}\nu_{tl}},\quad Q_{12}=\frac{\nu_{lt}E_t}{1-\nu_{lt}\nu_{tl}},$$

$$Q_{66}=G_{lt} \quad \ldots (15)$$

where, for 0° unidirectional lamina, $[\bar{Q}]_{ij}=[Q]_{ij}$, the reduced stiffness coefficients, MPa

for 90°ply, $\bar{Q}_{11}=Q_{22},\ \bar{Q}_{22}=Q_{11},\ \bar{Q}_{12}=Q_{12},\ \bar{Q}_{66}=Q_{66},$

and

for both 0° and 90° laminae, $\bar{Q}_{16}=\bar{Q}_{26}=0$.

The laminate elastic properties were estimated using the relations[20] (16).

$$E_x=\frac{A_{11}A_{22}-A_{12}^2}{hA_{22}},\quad E_y=\frac{A_{11}A_{22}-A_{12}^2}{hA_{11}},\quad \nu_{xy}=\frac{A_{12}}{A_{22}},$$

$$\nu_{yx}=\frac{A_{12}}{A_{11}},\quad G_{xy}=\frac{A_{66}}{h} \quad \ldots (16)$$

***Approach 2 (CLT AP-2)***

In this approach, laminate was considered to be composed of 10 woven layers directly without considering each layer as two unidirectional laminae. All the layers were oriented at [0/90], so that $[\overline{Q}]_{ij} = [Q]_{ij}$. The extensional stiffness matrix for woven fabric hybrid laminate can be written as

$$[A_{ij}] = [\overline{Q}_{ij}]_j (n_j t_j) + [\overline{Q}_{ij}]_g (n_g t_g) \quad \ldots (17)$$

The elements of $[Q_{ij}]$ were evaluated by the known values of the elastic properties of woven layer $E_{11}$, $E_{22}$, $\upsilon_{12}$ and $G_{12}$ using the relevant Eq. (18).

$$Q_{11} = \frac{E_{11}}{1-\nu_{12}\nu_{21}}, \; Q_{22} = \frac{E_{22}}{1-\nu_{12}\nu_{21}}, \; Q_{12} = \frac{\nu_{12}E_{22}}{1-\nu_{12}\nu_{21}},$$
$$Q_{66} = G_{12} \quad \ldots (18)$$

The laminate elastic properties were then evaluated using Eq. (16).

**Prediction by rule of hybrid mixture model**

The elastic properties of single woven jute and glass fabric plies were already determined[19]. Elastic properties of hybrid composites were determined using rule of hybrid mixtures. The proposed rule for elastic properties of hybrid laminates is given by Eqs (19)-(22).

$$E_x = E_{11j}V_{jp} + E_{11g}V_{gp} \quad \ldots (19)$$

$$E_y = E_{22j}V_{jp} + E_{22g}V_{gp} \quad \ldots (20)$$

$$\nu_{xy} = \nu_{12j}V_{jp} + \nu_{12g}V_{gp} \quad \ldots (21)$$

$$G_{xy} = G_{12j}V_{jp} + G_{12g}V_{gp} \quad \ldots (22)$$

where $V_{jp}$ and $V_{gp}$ are the volume fractions of jute and glass plies in hybrid laminates (Table 2).

The minor Poisson's ratio can be determined from the following well known expression

$$\nu_{yx} = \nu_{xy}\frac{E_y}{E_x} \quad \ldots (23)$$

## Experimental procedure

**Materials**

Plain woven jute fabric 22 × 12 (22 yarns of Tex 310 in warp direction and 12 yarns of Tex 280 in weft direction, per inch) having an average weight of 367 g/m$^2$ and average thickness of 0.8 mm is directly procured from Kolkota, West Bengal, India. The balanced plain woven glass fabric of weight of 360 g/m$^2$ is supplied by Binani Industries Limited, Mumbai, India. The resin system consists of Isothalic polyester NRC-200-220 supplied by Naphtha Resins and Chemicals Pvt Ltd, Bangalore, India, cobalt naphthenate accelerator and MEKP catalyst in the ratio of 1: 0.015: 0.015 respectively.

**Composite fabrication**

Hybrid laminates of woven jute and glass fabric were prepared by simple hand lay up technique in a mold at laboratory temperature. 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 above said ratio. The impregnated layers were placed one over the other in the mold and pressed for one hour before removal. Provision was made in the mold to allow the hot gases to escape. Uniform thickness was achieved by using spacers of desired thickness between the mold plates. After one hour, the laminate was removed from the mold and cured at room temperature for 48 h. All the laminates were made with total ten plies by varying the number of extreme glass plies to obtain various hybrid combinations (Table 3). The thickness of jute and glass plies in the hybrid laminates was also measured using optical microscope and lumagry illuminated magnifying glass Model No. 7547. The measured values were compared with those evaluated by using Eq. (13) and were found to be in good agreement. The fibre volume fraction is calculated using Eq. (24). The density of Isothalic polyester is 1.1 g/cm$^3$ which is obtained from the manufacturer's test report.

$$V_f = \frac{(W_j/\rho_j)+(W_g/\rho_g)}{(W_j/\rho_j)+(W_g/\rho_g)+(W_r/\rho_r)} \quad \ldots (24)$$

Table 2— Thickness and volume fraction of jute and glass plies in hybrid laminates

| Laminate | $t_j$ mm | $V_{jp}$ | $t_g$ mm | $V_{gp}$ |
|---|---|---|---|---|
| AJ | 0.68 | 1.0 | — | — |
| H1 | 0.722 | 0.876 | 0.41 | 0.124 |
| H2 | 0.773 | 0.725 | 0.44 | 0.275 |
| H3 | 0.82 | 0.538 | 0.469 | 0.462 |

Table 3— Thickness and Composition of hybrid laminates

| Laminate | Thickness mm | Jute fibre | | Glass fibre | | Total fibre (Jute + Glass) | |
|---|---|---|---|---|---|---|---|
| | | Wt. Fraction % | Vol. Fraction % | Wt. Fraction % | Vol. Fraction % | Wt. Fraction % | Vol. Fraction % |
| Resin | 4.3 | — | — | — | — | — | — |
| AJ | 6.8 | 42.60 | 36.00 | — | — | 42.60 | 36.00 |
| H1 | 6.6 | 34.80 | 30.40 | 8.20 | 4.32 | 43.00 | 34.72 |
| H2 | 6.4 | 25.00 | 22.83 | 16.50 | 8.67 | 41.50 | 31.50 |
| H3 | 6.1 | 17.10 | 15.89 | 25.20 | 13.56 | 42.30 | 29.45 |

**Composite testing**

The tension and in-plane shear tests were carried out at room temperature on computer controlled closed loop servo hydraulic MTS 810 Material Test System with a maximum capacity of 100 kN. Load Cell, Linear Variable Differential Transformer (LVDT) and extensometer were used to measure force, displacement and strain respectively. Data acquisition software - Test works II was used for recording the data. The output signal from MTS 458.20 Micro console controller was converted into digital signal by employing 3 channel ADC card. Data was analyzed using MATLAB. For both the tests, five identical samples were tested and average result was obtained.

**Tension test**

Elastic properties such as, tensile modulus, and Poisson's ratio were determined by static tension test in accordance with ASTM D3039. Test specimen of length 250 mm and width 25 mm were carefully cut from the laminate and finished by using medium grade emery paper. Aluminium end tabs of 38 mm length were bonded to the specimens and were held in the hydraulic grips at a pressure of 4.2 N/mm$^2$. 50 kN Load cell, 20 mm LVDT and ±10% maximum strain was selected for the test. The specimen was loaded at a constant 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. For determining the Poisson's ratio, specimens were mounted with strain gauges in longitudinal and lateral directions and the strain was measured using strain indicator B & K type 1526.

**In-plane shear test**

Shear modulus was determined by ±45° shear test as per ASTM D3518. In this method uniaxial tensile loading was applied to the specimen, having the fibres (warp) oriented at ±45°. Specimen geometry, Load cell, LVDT, maximum percentage strain and rate of loading was same as that for tension test. A plot of the shear stress $\tau_{12}$ versus shear strain $\gamma_{12}$ was obtained using $\tau_{12} = P_x/2\,A$, and $\gamma_{12} = \epsilon_{xi} - \epsilon_{yi}$ where $P_x$, A, $\epsilon_{xi}$ and $\epsilon_{yi}$ are the load (N), area of cross section (mm$^2$), longitudinal and transverse strain respectively. The chord modulus $G_{12}$ was determined from the slope of the linear portion of the shear stress-shear strain plot.

## Results and Discussion

The tensile stress-tensile strain behaviour in warp and weft directions and shear stress-shear strain behavior of isothalic polyester based woven jute and jute-glass fabric hybrid composites are shown in Figs 2, 3 and 4 respectively. The initial portion of the curves for all jute and hybrid composites is linear at low strain followed by a change in the slope showing a non-linear behaviour till the failure of the composite. Tensile modulii were determined from the slope of the linear portion of the curves. The predicted and experimentally evaluated longitudinal Young's modulus is plotted as a function of glass fibre loading in Fig. 5. As expected, an increasing trend in Young's modulii ($E_x$ and $E_y$) of warp and weft direction was observed with the increase in the glass fibre content by all the three methods of evaluation. This is because of higher modulus and load carrying ability of the glass fibre than jute fibre. By increasing the glass fibre weight fraction from 0% to 8.2%, 16.5% and 25.2% in a total fibre weight fraction of 42%, the experimental tensile modulus was found to increase by 8.7%, 17.85% and 30% respectively, in warp direction and 21.67%, 32.2% and 63.67% respectively, in weft direction. The predicted value of Young's modulus in warp direction, for all the laminates, is found to be less than experimental. Shear stress-shear strain plots for all jute and hybrid laminates is found to be linear in low strain range of

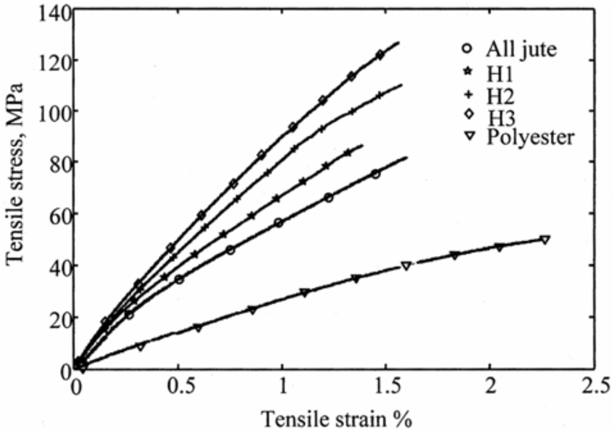

Fig. 2— Tensile stress-tensile strain plot (warp)

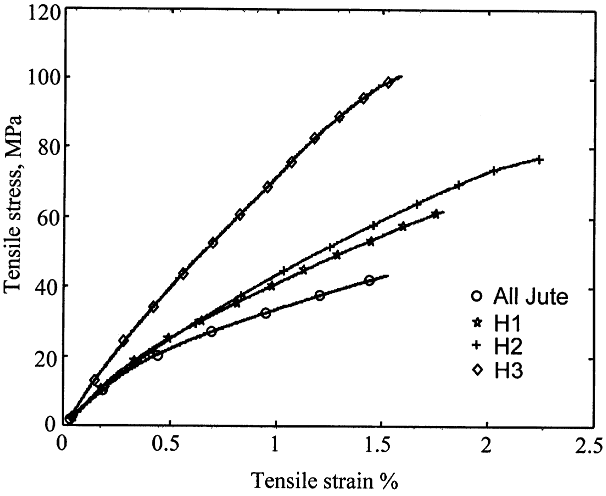

Fig. 3— Tensile stress-tensile strain plot (weft)

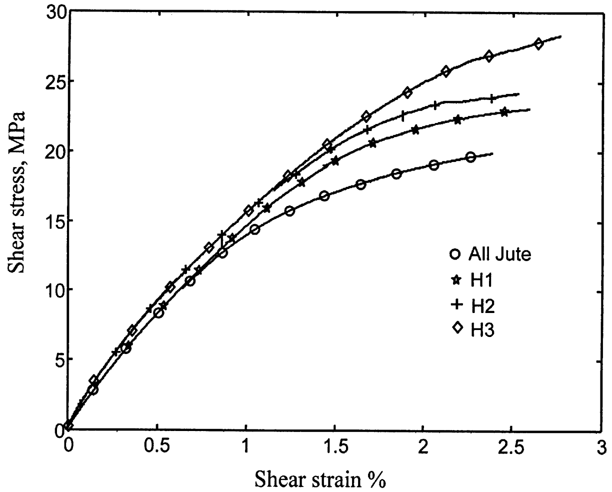

Fig. 4— Shear stress-shear strain plot

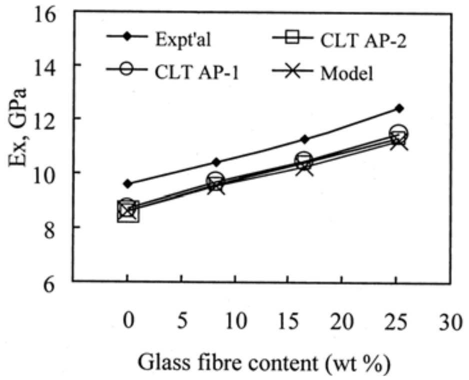

Fig. 5—Correlation between experimental and predicted values ($E_x$)

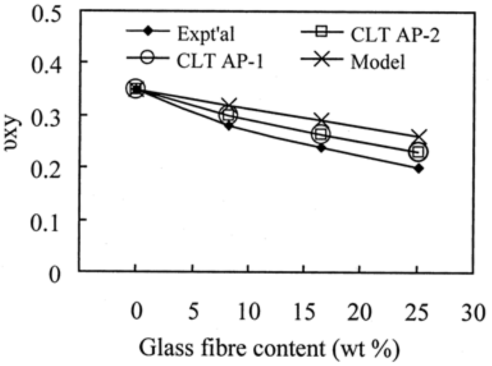

Fig. 6—Correlation between experimental and predicted values ($\upsilon_{xy}$)

about 2000 µ€. Hence this range is selected for determination of shear modulus. No significant improvement in shear modulus is noticed with the addition of glass fibre. The maximum value of experimental shear modulus is 2.03 GPa (for hybrid composite with 25.2% glass wt %), which is just 16.6% greater than that of all jute laminate. The Poisson's ratio was found to decrease with the glass fibre loading. Same trend is obtained by all the three methods of evaluation as shown in Fig 6. Higher Poisson's ratio indicates that, jute composites undergo more transverse strain and less longitudinal strain than jute-glass hybrid composites. This may be because of greater extensibility of glass fibres (2.5-3.0%) than jute fibres (1.5-1.8%)[10,18]. Except for longitudinal Young's modulus, the predicted values of elastic properties are found to be greater than experimental in almost all the cases. The experimental and theoretical results are compared in Table 4. The difference between the predictions by two approaches using classical lamination theory is due to the fact that, the curvature effect due to interlacing of yarns is

Table 4— Deviation in results between theoretical prediction and experimental

| Laminate | Elastic properties | Deviation b/w CLT AP-1 & Exptl % | Deviation b/w CLT AP-2 & Exptl % | Deviation b/w Rule of hybrid mixture model & Exptl % |
|---|---|---|---|---|
| AJ<br>( 0 wt % Glass ) | $E_x$ | +10.11 | +11.39 | +11.17 |
| | $E_y$ | -20.00 | -18.90 | -19.25 |
| | $\upsilon_{xy}$ | 00 | 00 | 00 |
| | $\upsilon_{yx}$ | -16.67 | -16.67 | -16.67 |
| | $G_{xy}$ | -16.54 | -16.54 | -16.54 |
| H1<br>(8.2 wt % Glass ) | $E_x$ | +7.42 | + 8.54 | + 8.99 |
| | $E_y$ | -16.18 | -15.41 | -14.90 |
| | $\upsilon_{xy}$ | -6.67 | - 6.67 | -12.50 |
| | $\upsilon_{yx}$ | -18.50 | -18.50 | -18.20 |
| | $G_{xy}$ | -10.40 | -10.41 | -10.49 |
| H2<br>(16.5 wt % Glass ) | $E_x$ | + 7.73 | + 8.70 | + 9.88 |
| | $E_y$ | -18.16 | -17.39 | - 16.70 |
| | $\upsilon_{xy}$ | - 9.09 | -9.09 | -17.24 |
| | $\upsilon_{yx}$ | -13.93 | -13.93 | -13.20 |
| | $G_{xy}$ | - 4.69 | - 4.45 | - 4.70 |
| H3<br>(25.2 wt % Glass ) | $E_x$ | + 8.53 | +9.93 | +10.95 |
| | $E_y$ | -10.06 | - 8.81 | +8.30 |
| | $\upsilon_{xy}$ | -13.04 | -13.04 | -23.07 |
| | $\upsilon_{yx}$ | -16.67 | -17.05 | -16.67 |
| | $G_{xy}$ | +1.65 | + 2.01 | +1.45 |

neglected, while assuming woven fabric ply as two unidirectional plies crossed at 90°. Excellent agreement between the values predicted by classical lamination theory and rule of hybrid mixture is obtained. However, the theoretical and experimental results are found to be deviated up to 20% (Table 4). The deviation between the experimental and predicted values may be attributed to the following reasons: (i) The strength of materials approach model used in theoretical prediction, assumes that, the bond between the fibre and the matrix is perfect, fibres are continuous with uniform diameter. Non uniformity of jute yarns and poor fibre matrix adhesion (as the fabric is untreated) may also affect the experimental results. (ii) Theoretical prediction by rule of hybrid mixture expects complete intermingling of both the fibres within the matrix, whereas in the present study, glass fibre layers are arranged as extreme layers only. (iii) The theoretical prediction is based on an average literature value of Young's modulus of jute fibre, which is taken as 20 GPa[18]. (iv) Presence of voids, if any may also affect the experimental results.

## Conclusions

In this paper, the effect of hybridization on elastic properties of jute-glass hybrid composites is described. The elastic properties are predicted by using rule of hybrid mixture and are validated by the experimental results. An attempt is also made to evaluate the applicability of classical lamination theory to jute and jute-glass hybrid composites. From this study following important conclusions are drawn:

(i) The Young's modulus of jute composites in warp and weft direction significantly increases with the incorporation of glass fibre.

(ii) Poisson's ratio of jute composites is found to decrease with the addition of glass.

(iii) No significant improvement in shear modulus is noticed with the addition of glass fibre.

(iv) Excellent agreement between the predictions of elastic properties by CLT and rule of hybrid mixture model is obtained.

(v) From the results, it can be concluded that the theoretical approach that is presented in the paper, can be applied to jute and jute-glass hybrid composites, with a deviation up to about 20% with the experimental results.

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## Nomenclature

$W_j$, $W_g$, $W_r$ = weight of jute fabric, glass fabric and resin, respectively, kg

$V_f$ = total fibre volume fraction

$E_j$, $E_g$, $E_m$ = Young's modulus of jute fibre, glass fibre and resin, respectively, GPa

$V_j$, $V_g$ = volume fraction of jute and glass fiber in their respective plies

$V_{jc}$, $V_{gc}$ = volume fraction of jute and glass fiber in hybrid composite

$V_m$ = volume fraction of matrix

$G_j$, $G_g$, $G_m$ = shear modulus of jute, glass and matrix material, respectively, GPa

$E_{lj}$ & $E_{lg}$ = longitudinal modulus of unidirectional jute and glass ply, GPa

$E_{tj}$, $E_{tg}$ = transverse modulus of unidirectional jute and glass ply, GPa

$G_{ltj}$, $G_{ltg}$ = shear modulus of unidirectional jute and glass ply, GPa

$N_{1j}$, $N_{2j}$ = number of yarns in warp and weft direction, respectively in jute fabric

$N_{1g}$, $N_{2g}$ = number of yarns in warp and weft direction, respectively in glass fabric

$E_{11j}$, $E_{11g}$ = longitudinal modulus of woven jute and glass ply, GPa

$G_{12j}$, $G_{12g}$ = shear modulus of woven jute and glass ply, GPa

$h$ = total thickness of the laminate, mm

$E_x$, $E_y$ = longitudinal and transverse modulus of all jute and hybrid laminate, GPa

$G_{xy}$ = shear modulus of all jute and hybrid laminate, GPa

*Greek letters*

$\upsilon_j$, $\upsilon_g$, $\upsilon_m$ = Poisson's ratio of jute fibre, glass fibre and resin, respectively

$\upsilon_{ltj}$, $\upsilon_{tlj}$ = major and minor Poisson's ratio of unidirectional jute ply

$\upsilon_{ltg}$, $\upsilon_{tlg}$ = major and minor Poisson's ratio of unidirectional glass ply

$\upsilon_{12j}$, $\upsilon_{21j}$ = major and minor Poisson's ratio of woven jute ply

$\upsilon_{12g}$, $\upsilon_{21g}$ = major and minor Poisson's ratio of woven glass ply

$\upsilon_{xy}$, $\upsilon_{yx}$ = major and minor Poisson's ratio of all jute and hybrid laminate

$\rho_j$, $\rho_g$, $\rho_r$ = density of jute fibre, glass fibre and resin, respectively, g/cm$^3$

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