Experimental and FE Analysis of Tensile and Bending Properties of Glass/Jute Epoxy Hybrid Composite

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Abstract- This paper explores on comparison of tensile and bending stresses of hybrid composite specimens by experiments and with finite element analysis ANSYS. The hybrid composites are prepared with woven E-glass fibre, woven Jute fibre reinforced in the Diglycidyl ether of Bisphenol-A (EP-306) epoxy along with hardener Diethylene tetra amine (EH-758). Composite is prepared by the hand layup technique at room temperature (28^{0}C). Tensile specimens with ASTM 3039 standard and bending specimens with ASTM 7264 standard dimensions were cut from the laminate. The specimens FEA models were created using ANSYS 19.2 and failure loads of specimens from experiments are applied on the specimen models. The tensile stresses and bending stresses developed in the specimens were observed at failure loads. The results ensured that the experimental results have well agreed with the ANSYS results.
KEY WORDS- Woven jute fibre, Woven glass fiber, hybrid composite, tensile strength, bending strength, ANSYS 19.2

I. INTRODUCTION

A composite is a material made of two or more materials. They have reinforcement and matrix material. If it consists of more than one reinforcement then it is called a hybrid composite. In hybrid composites the advantage of one fibre would complement what is lacking in another. A continuous fibre composite made of layers of fibres in unidirectional, bi directional etc. Each layer is called lamina and the composite is called laminate. Nowadays the use of natural fibres [1] (sisal, hemp, kenaf, jute and coir) draws more attention for low load applications, and now the research has moved towards sustainability of dynamically loaded components by partial replacement with natural fibres. Ashik et al. [2] found that hybrid glass/jute(60%-40%)-epoxy composite has 66% more tensile strength than non-hybrid jute-epoxy composite and hybrid glass/jute(40%-60%)-epoxy composite has 49% more tensile strength than non-hybrid jute-epoxy composite. Hybrid glass/jute-epoxy composite (60%-40%) has 61% more flexural strength than non-hybrid jute-epoxy composite and hybrid glass/jute-epoxy (40%-60%) composite has 44% more tensile strength than non-hybrid jute-epoxy composite.It is also observed that increasing glass fibre volume increases both tensile strength and bending strength in hybrid composite. However, for tensile specimen tabs modeling is not done and stress variation is not properly shown. Saravana Bavan et al. [3] had fabricated the natural composite beam using Maize fibre reinforced in unsaturated polyester resin polymer matrix and carried out a test to determine the deflection and stress characteristics finite element technique using ANSYS software.The research reveals by increasing the fibre content to an optimum content, there is a possibility of reducing the stress concentration in the matrix and at the fibre interface. But more stress deviation on the fibre matrix, and at the interface regions of the composite tends to fibre debonding. Khatri et al. [4] assessed the mechanical characteristics such as tensile strength, flexural strength, impact strength and Young’s modulus of multiple composites. Free vibration features are also analyzed for natural fibre composite beams. In addition to analytical study from experiments on composites from various researches, finite element analysis is also carried out using ANSYS. The test specimens were modelled in accordance with the experimental test specimens and model analysis was carried out with each specimen. The elaborate analysis proves that the natural composites have moderate mechanical properties and better vibration characteristics and the natural fibres can be employed for low and moderate load applications. Shankar et al. [5] had chosen epoxy resin for matrix and continuous banana fibres as reinforcement for composite preparation and tested its mechanical properties for tensile strength, flexural resistance and impact strength. ANSYS software has been used to analyze stresses, strains and displacements under different volume fractions of fibre from 5% to 20% by increasing the volume fraction by 5%. Hari prasad et al. [6] had experimented with banana coir reinforced epoxy composite materials to assess the tensile, flexural and impact properties for treated and untreated fibres. The tensile and impact tests showed that treated banana-coir epoxy hybrid composites have higher tensile strength and impact strength than untreated composites. Untreated fibre composites, however, have greater flexural resistance than the composites with treated fibre. ANSYS software for finite element analysis was effectively used to assess and evaluate the mechanical characteristics.Venkata Sushma Chinta et al., [7-9] estimated lamina properties of bidirectional jute fibre /epoxy, bidirectional glass fibre/epoxy and successfully applied in determining fracture parameters using ANSYS. Lakshman et al. [10] used Polyester as matrix and banana fibres as reinforcements to produce the composites. The mechanical properties such as tensile strength, impact strength and flexural strength were determined by appropriate test procedures and are validated using analysis software. ANSYS software is used to evaluate the stresses, strains and deformation under different fibre volume percentages varying from 5% to 20% by incremental volume fraction of 5%. From the exhaustive survey on composites it is obvious that components prepared using natural fiber reinforced can replace the component made of any other materials as it has enhanced mechanical properties besides its eco-friendly property. Glass fibres are mixed with Natural fibres by many researchers to increase their strength properties. So many researchers have found the tensile and bending properties of hybrid composites but analytical validations are quite low. The assumption of composite behavior as isotropic in ANSYS may not yield correct output from the model if it is applied to real world problems. As a hybrid composite contains layers made of different materials, the material definition in ANSYS should be accurate to apply it for real problem simulations. Material properties definition of hybrid composite in ANSYS depends on parameters like thickness of lamina,type of fibres, direction of fibres, volume fraction of each fibre and constituent matrix in the lamina. so, the estimation of lamina properties plays a crucial role in the analysis of composite materials using ANSYS. For tensile specimen modeling in ANSYS tabs definition is arduous.

II. EXPERIMENTATION

2.1 Materials:

A Bidirectional Glass fiber of 0.3 mm thickness is as shown in the fig.1. The woven jute sheet of 0.5 mm thickness was collected from a local market as shown in the fig.2. Epoxy resin (EP-306 grade epoxy resin & EH-758 grade hardener) as shown in fig.3 is selected as a matrix. Epoxy resins are more expensive than polyester, but possess better mechanical properties like dynamic strength and fatigue resistance, so as to impart good interlaminar strength to the composite.

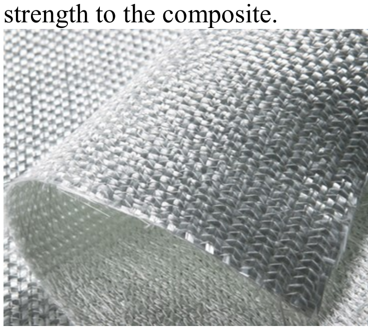


Figure.1. Woven Roving Glass

Figure.2. Woven Jute

Figure.3. Epoxy and Hardener

Properties of the constituents are as shown in the Table 1.

Table 1.
Mechanical Properties of glass fibre, jute fiber and epoxy

Properties	**Glass Fiber**	**Jute Fiber**	**Epoxy Resin**
Young's Modulus (GPa)	**72.4**	**28**	**3.45**
Density (gm/cc)	**2.6**	**1.45**	**1.14**
Rigidity Modulus (GPa)	**29.67**	**10.37**	**1.277**
Poisson's Ratio	**0.22**	**0.35**	**0.35**

2.2 Specimen Fabrication:

For the fabrication of Glass/Jute Epoxy hybrid composite laminate 5 layers of bi directional glass fibre of weight 160 g , 4 layers of bi directional jute fibre of weight 88 g , resin (epoxy + hardener in 1:10 ratio) 456g is taken. To consider the resin ooze out losses 1.5 times of required resin is taken.
The density of the hybrid composite and volume fractions are calculated from the rule of mixtures.

i.e.,

Weight of the composite= $W_c = W_g+W_j+W_m$ (1)

W_c= 160+ 88+ (456/1.5) =552 g

We know, Weight fraction of composite= $wf_c= wf_g+ wf_j+ wf_m$ (2)

The weight fractions of glass= wf_g= 0.29

The weight fractions of jute= wf_j= 0.16

The weight fractions of matrix= wf_m= 0.55

$1/\rho_c= 1/((wf_g/ \rho_g)+ (wf_j/ \rho_j)+ (wf_m/ \rho_m))$ (3)

Then the density of the composite is found by using the equation (3) as ρ_c=1.419.

The volume fraction of the matrix $vf_m=(\rho_{c/}\rho_m) * wf_m$ (4)

The volume fraction of the fibre $vf_f= (\rho_{c/}\rho_f) * wf_f$ (5)

By using the equation (4), (5) the volume fractions are found as 0.68, 0.16 and 0.16 for matrix, glass and jute respectively.

Hand layup procedure is followed for fabrication of hybrid composite. To start with, a non-sticking release wax is applied on the mould plate to avoid the sticking of the fiber to it. Glass and jute fibers are cut as per the required size. Glass sheet is then placed on the mould plate, over which resin is applied with the help of the brush so as to spread it uniformly over the surface. Then the jute layer is placed and by using a roller, mild pressure is applied to remove the excess epoxy present and the air trapped. The alternate stacking glass and jute layer is repeated till the required number of layers is achieved. After this wax is applied on the inner surface of the top mould plate and are clamped together tightly using bolts. After curing at room temperature for about two days, the composite plate is taken out and is further processed. Normal curing time at room temperature is 24 - 48 hours for epoxy based composite laminates. The composite laminate is further allowed to cure for a week before cutting is done. The thickness of laminate is found as 4 mm.

Tensile test Specimens are prepared as per ASTM D3039 standard with dimensions 163mm * 28 mm* 4 mm are as shown in fig.4. Then aluminum tabs are prepared to prevent the failure of the specimen at fixtures. The tabs are stuck to the specimen with Araldite AV138 IN, and hardener HV 998 IN.

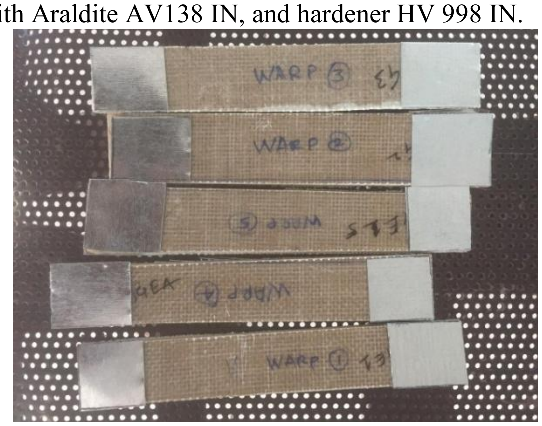


Figure.4. Glass/Jute -Epoxy tension test specimens

III. EXPERIMENTAL RESULT

Glass/Jute-Epoxy tension test specimen is placed between the fixtures. The load is applied on the specimen a rate of 2 mm/min and load is applied until the specimen fails. The Fig.5 shows load Vs deflection for specimen1. It is found that the maximum load at failure is 15.535kN.

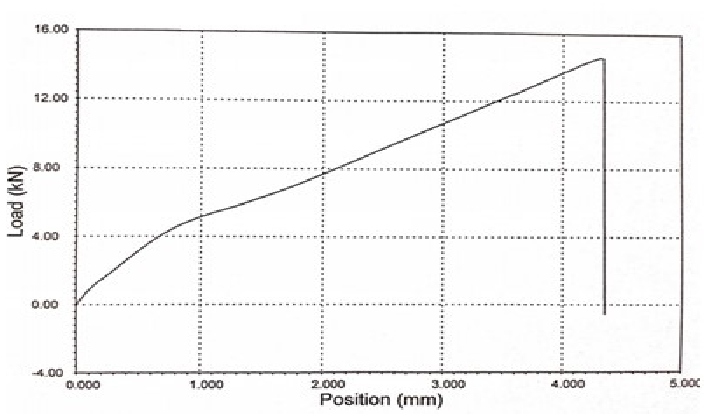


Figure.5.Load vs deflection of tensile specimen1

Table.2

Maximum load and Ultimate Tensile Strength of Glass/Jute-Epoxy specimens

SPECIMEN NUMBER	MAXIMUM LOAD (kN)	Ultimate Tensile strength (MPa)
1	15.535	138.71
2	15.945	142.36
3	16.200	144.64
4	16.325	145.75
5	16.871	150.63
Average	16.175	144.41

The Table 2 shows maximum load for Glass/Jute-Epoxy tension test specimens as 16.871 kN. The average maximum load is calculated as 16.175 kN. The average ultimate strength is calculated as 144.41 MPa.

The bending specimens are prepared as per ASTM 7264 standard with dimensions 160 mm *16 mm * 4mm. Glass/Jute-Epoxy bending test specimens are supported on the supports with span length (L) is taken as 140mm. The load is applied on the specimen at the middle at a rate of 2 mm/min and load is applied until the specimen fails. The Table 3 shows maximum load for Glass/Jute-Epoxy bending test specimens as 15.945 kN. The average maximum load is calculated as 15.695 kN. The average ultimate strength is calculated as 140.13 MPa.

Table.3

Peak loads and bending strengths of Glass -Epoxy bending specimens

SPECIMEN NUMBER	PEAK LOAD (kN)	Bending strength ($\frac{3PL}{2BD^2}$)(MPa)
1	0.415	340.42
2	0.442	362.58
3	0.433	355.2
4	0.425	348.6
5	0.486	398.67
Average	0.4402	361.1

IV. FINITE ELEMENT ANALYSIS OF FRP

To model tensile and bending specimens ANSYS19.2 software tool is used. ANSYS is commercially available software which works on finite element method. In this method there are three steps to be followed. First step is pre- processing which includes input of material properties.The Elastic constants of unidirectional lamina [6] are estimated by a simple rule of mixtures using the equations (6) to (11). For unidirectional fiber lamina E_1, E_2= E_3, G_{12}= G_{13}, G_{23}, υ_{12}= υ_{13}, υ_{23}. After calculating elastic constants of the unidirectional lamina, the elastic constants of woven lamina are estimated using the equations (12) to (17). For Woven fiber laminaE_1=E_2, E_3, G_{12}, G_{13}=G_{23}, υ_{12}, υ_{13} = υ_{23}.

Equations to estimate the elastic constants of unidirectional lamina are

$$E_1 = E_f v_f + E_m \ (1-v_f) \qquad (6)$$

$$E_2 = E_m\left[\frac{E_f + E_m \;\; + (E_f - E_f)v_f}{E_f + E_m \;\; - (E_f - E_f)v_f}\right] \tag{7}$$

$$\upsilon_{12} = \upsilon_f v_f + \upsilon_m\,(1 - v_f) \tag{8}$$

$$\upsilon_{23} = \upsilon_f v_f + \upsilon_m\,(1 - v_f)\left[\frac{1 + \upsilon_m - \upsilon_{12}\frac{E_m}{E_1}}{1 - \upsilon_m{}^2 + \upsilon_m \upsilon_{12}\frac{E_m}{E_1}}\right] \tag{9}$$

$$G_{12} = G_m\left[\frac{G_f + G_m \;\; + (G_f - G_m)v_f}{G_f + G_m \;\; - (G_f - G_m)v_f}\right] \tag{10}$$

$$G_{23} = \frac{E_2}{2(1 + \upsilon_{23})} \tag{11}$$

For Unidirectional lamina the indices m and f denote matrix and fiber respectively.

The Equations to estimate the elastic constants of woven lamina are

$$\left[\frac{2}{E_1}\,\frac{E_1(E_1 + (1 - \upsilon_{12}{}^2)E_2) - \square_{12}{}^2 E_2{}^2}{E_1(E_1 + 2E_2) + (1 + 2\upsilon_{12}{}^2)E_2{}^2}\right]^{UD} = \left[\frac{1}{E_1}\right]^{WF} \tag{12}$$

$$\left[\frac{4}{E_1}\,\frac{\upsilon_{12}\left(E_2(E_1 - \square_{12}{}^2 E_2)\right)}{E_1(E_1 + 2E_2) + (1 + 2\upsilon_{12}{}^2)E_2{}^2}\right]^{UD} = \left[\frac{\upsilon_{12}}{E_1}\right]^{WF} \tag{13}$$

$$\left[\frac{1}{E_1}\,\frac{E_1(\upsilon_{12} + \upsilon_{23} + \upsilon_{12}\upsilon_{23}) + \upsilon_{12}{}^2 E_2}{E_1 + (1 + 2\upsilon_{12})E_2}\right]^{UD} = \left[\frac{\upsilon_{13}}{E_1}\right]^{WF} \tag{14}$$

$$\left[\frac{(1 - \upsilon_{23}{}^2)E_1{}^2 + (1 + 2\upsilon_{12} + 2\upsilon_{12}\upsilon_{23})E_1E_2 - \upsilon_{12}{}^2 E_2{}^2}{E_1E_2(E_1 + (1 + 2\upsilon_{12})E_2)}\right]^{UD} = \left[\frac{1}{E_3}\right]^{WF} \tag{15}$$

$$\left[\frac{1}{G_{12}}\right]^{UD} = \left[\frac{1}{G_{12}}\right]^{WF} \tag{16}$$

$$\left[\frac{(1 + \upsilon_{23})}{E_2} + \frac{1}{G_{12}}\right]^{UD} = \left[\frac{1}{G_{12}}\right]^{WF} \tag{17}$$

Because the glass, jute fibres both are bi-directional the lamina constants for them are estimated by using fibre and matrix properties from Table.1, by using the formulas (6) to (17), by taking volume fraction of matrix as 0.68 and volume fraction of fibre as 0.32.The properties of laminas are listed in table.3.

Table.4 - Lamina Elastic Constants

Lamina elastic constants	Glass / Epoxy	Jute/ Epoxy
E_1(GPa)	16399.2	11207.2
E_2(GPa)	16399.2	11207.2
E_3(GPa)	6859.53	5331.81
υ_{12}	0.122	0.148
υ_{23}	0.41	0.43
υ_{13}	0.41	0.43
G_{12} (MPa)	2338.47	1817.86
G_{23}(MPa)	2273.65	1753.57
G_{13}(MPa)	2273.65	1753.57

For tabs which are made of Aluminum the E=72000 MPa and υ=0.28. After entering all material properties in ANSYS then an area is created to represent tension test specimens. SHELL 281 element is selected for meshing, is suitable for analyzing thin to moderately-thick shell structures. The element has eight nodes with six degrees of freedom at each node: translations in the x, y, and z axes, and rotations about the x, y, and z-axes. By using shell layup option all 9 layers of required thickness are defined and respective material property is assigned for each layer. For representing tabs another shell layup is created with 11 layers (aluminum of thickness 1 mm+ Alternate layers of glass and jute + aluminum of thickness 1 mm). Then meshing is done is as shown in the fig.6. Total 520 elements are formed.

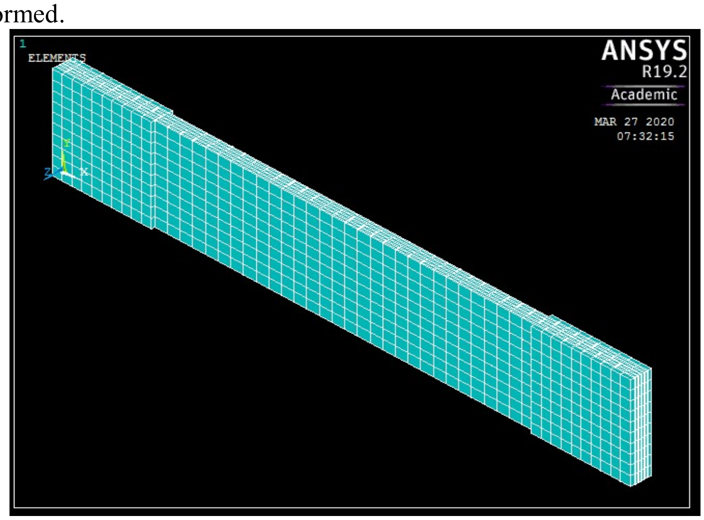
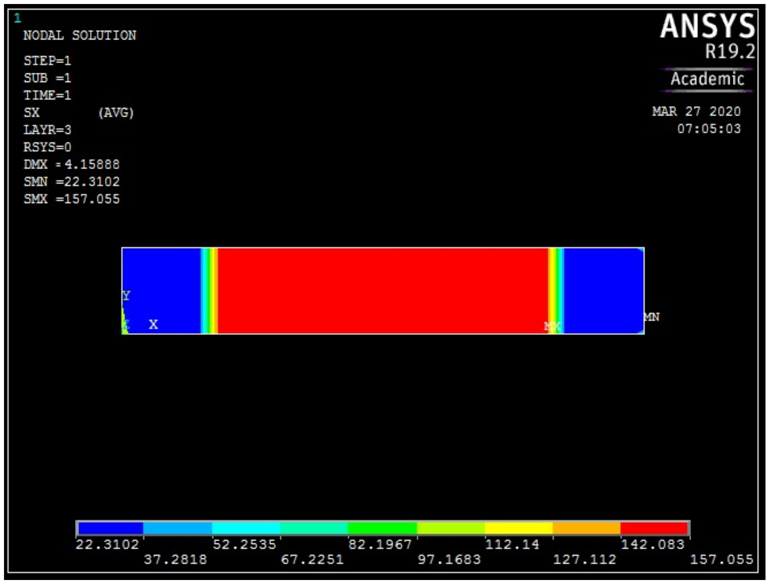


Figure.6. Meshed model of tension test specimen

The second step in ANSYS is solution, where boundary conditions and loads are applied on the model. For the tension specimen left side edges are constrained all degrees of freedom. The right edge is subjected to a load of 16.175 kN which is the average maximum load obtained from the tension test. Then the problem is solved. In the third step i.e., post processing the stress developed in the material is checked and is as shown in the fig.7.as 157.055MPa.



Figured.7.Tensile stress distribution in Glass/Jute-Epoxy hybrid composite

Next bending specimen is modeled in ANSYS. Then the model is meshed and 640 elements are formed. Then a load of 0.4402 kN is applied at the middle of the specimen. After solving the problem element table is defined with SMISC,37 to plot the bending stress developed in model. it is found the maximum stress is developed as 357.137MPa is as shown in Fig.8.

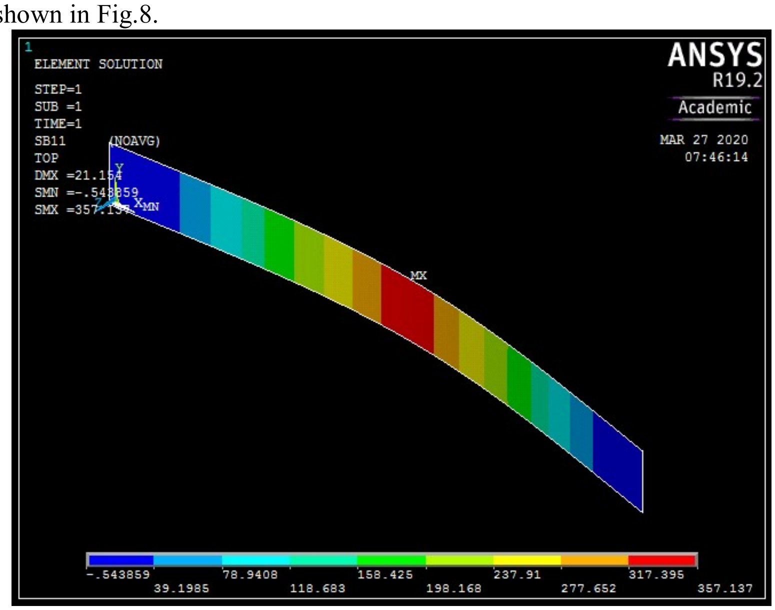


Figure.8. Bending stress distribution in Glass/Jute-Epoxy hybrid composite

V. CONCLUSIONS

The tensile stresses and bending stresses developed in the specimens were observed at failure loads. The glass/jute epoxy composite has tensile strength of 144.41 MPa and bending strength of 361.1 MPa. From Ansys the tensile stress in the specimen for failure load is observed 157.055 MPa and bending stress in the specimen at failure load as 357.137 MPa. The % of deviation in tensile is 8.75% and in bending is 1.1%. The results ensured that the experimental results have well agreed with the ANSYS results.

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