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Experimental Investigation on Effect of Fiber Orientation on Modulus of FRP

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ABSTRACT

In a present era importance of FRP are steadily increasing due to its advantageous properties by enhancing mechanical properties of matrix by using fibers. Various researchers have worked for high strength fiber reinforces plastic as an attractive feasible material to replace metal and conventional materials. In last two decades the attempts are also made with natural fibers to replace conventional FRP, normally Glass and Polyester or Epoxy. Normally the rule of mixture can give reasonable results for predicting the end properties of FRP in longitudinal direction. However, for different fiber arrangement and length of fiber the loss in modulus is expected. Further, interfacial de-bonding, poor adhesion and voids also create loss in modulus of FRP. Hence, this research work is aimed to found the losses in modulus of FRP by considering natural fiber jute as a reinforcement and polyester as a matrix. The systematic experiments are carried out by using suitable molds and appropriate equipment. The attempts are made to study the effect of orientation of fibre is studied for modulus under longitudinal loading. Modulus property is simulated using standard FEA packages. The results obtained by 3D FEA analysis, theoretical models and experimental results for losses in modulus are following the same trend. The comparative assessment give the divergence of experimental results from available predictive model in term of modulus losses is the range of (0.16-75.06)% depending on various parameters.

Keywords : Oriention of fibers, Modulus, FRP, FEA, ANSYS, I-DEAS, RVE.

I. INTRODUCTION

The term FRP means fiber reinforced plastic which is a combination of Plastic materials with some reinforcing material. They are also called as composites at a macroscopic structure level. The importance of Polymers, Composites and Ceramic based composites is steadily increased in a present era [1] as shown in **Fig 1.**

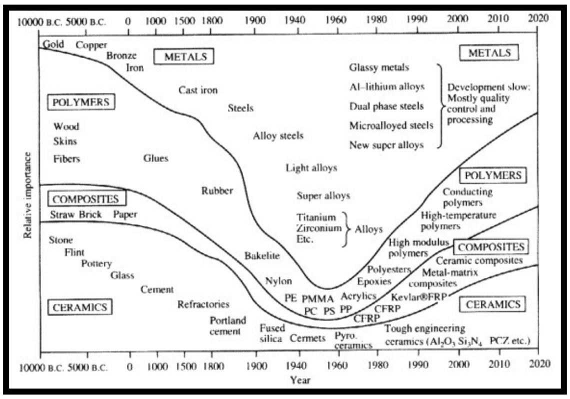


Figure 1. History of Materials

The composites are extremely attractive for air craft, automobile and many other applications. The reason for their increased use in present era is focus around weight saving and economy of construction by tailoring material to structural application. The mechanical property of composite reveals high strength, high modulus and high stiffness as a construction material in the field of engineering. Since, the forms of fiber possess highest strength they are utilized as reinforcements for many applications, ranging from improvement of the strength to lowering the cost of material. They also exhibit outstanding corrosion and fatigue damage resistance. The main role ofmatrix is to transmit and distribute the stresses among the individual fibers and to maintain the fibers separated in the desired orientation. The matrix also provides protection against both fiber abrasion and fiber exposure to moisture or other environmental conditions and causes the fibers to act as a team in resisting failure or deformation under load.[2].

II. METHODS AND MATERIAL

1. Reinforcement of Natural Fibers

The term advance composite leads towards the use of high strength fibers such as carbon, graphite, Kevlar, boron, SiCetc, for their optimum property utilization at various applications. However, there is enough potential for agro based product as an additives / reinforcement in the formation of composite material. Jute, kenaf, coir, cotton, sisal, bamboo and their plants etc, are also found to be feasible reinforcement materials. Numerous attempts are already made to study properties of jute and other natural fiber in combination with thermosetting and thermoplastics in a last two decades. [3]

LOSSES IN PROPERTY OF FRP MATERIALS

Generally the rule of mixture gives reasonable results for predicting the end properties of FRP in longitudinal direction. However, experimental condition may affects the loss of modulus will be inevitable [4, 5, 6, 7]. Further, the concept of poor adhesion, interfacial debonding and voids also creates loss in modulus of composite [8].

MICROMECHANICS MODELS

The simplest form of reinforcement widely used in practice is the use of unidirectional long fibers to fabricate composite material in matrix media. To determine modulus, strength etc using the propertiesand arrangements of constituent fibers and matrix material micro mechanic analysis is used while; macro mechanic analysis provides analytical solution for thick Composite made by number of plies, where individual ply may have individual characteristics, arrangements which are governed by micro mechanic model. Considering isotropic reinforcement in isotropic matrix media, modulus, strength, Poisson's ratio etc of composite material are predicted along longitudinal directions using simple rule of mixture. The basic assumptions in deriving it are as below:

1. Fibers remain parallel and that the dimensions do not change along the length of the element.
2. Perfect bonding at interface (no slip occurs between fiber and composite).
3. Fiber and matrix materials are linearly elastic and homogeneous.
4. Matrix is isotropic.
5. Fiber as an anisotropic.

Variety of predictive models in the literature which are either derived theoretically based on parametric constraints or semi empirically based on experimental studies. Few of such predictive models are available in the literature along with the models incorporating effect of various constituent parameters.

Effect of fiber orientation on modulus of FRP.

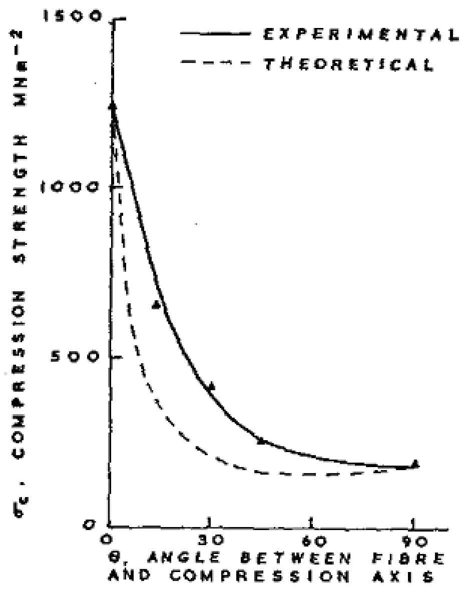
The orientation of fiber is very important factor in reduction of strength of composite material as the fibers contains high anisotropy in their nature. Hence fiber orientation highly affects the interphase which is reported by various researchers Whitney [4], L.E. Nielson & P.E. Chen [9], M. Manera [10] Uses the classical theory of elasticity shown as equation 1 to predict modulus incase of fiber orientation. The effect of orientation angle of fiber on composite strength is as shown in Fig 2.

$$\frac{E_{\parallel}}{E_{\theta}} = \cos^4\theta + \frac{E_{\parallel}}{E_{\perp}}\sin^4\theta + \left(\frac{E_{\parallel}}{G} - 2\mu_{12}\right)\cos^2\theta\sin^2\theta$$ **…Equation 1**

On the same bases the model proposed by Horio [13] is shown as equation 2, composite material.

$$E_{\theta} = \frac{E_{\parallel}E_{\perp}}{E_{\parallel}\sin^2\theta + E_{\perp}\cos^2\theta}$$ **Equation 2**

Abu-Farsakh, [14] describes the modes of failure of fibrous composite material as affected by the orientation angle of fiber using transformation equations of principal material direction.



Compression strength as a function of angle between fibre and axis for 60 vol % type 2 carbon fibre

Figure 2. Effect of orientation angle on composite strength

The interphase becomes critically design variable in case of transverse reinforcement. Transverse loading focuses failure region mainly at interphase and it is reducing gradient between fiber and matrix even less than the matrix. The simplest tool for predicting transverse modulus is inverse rule of mixture as shown in equation 3 , but it is derived based on the assumption of equal stress in fiber and matrix which may not be the true case in practice hence it can only be utilised as approximate primary tool. Whitney [4] uses the transverse properties in rule of mixture and observed better convergence in the result as shown in Fig which is given as equation 4. Nielson proposes model of transverse by equation 5.

$$\frac{1}{E_T} = \frac{v_f}{E_f} + \frac{v_m}{E_m}$$ **…Equation 3**

$$E_T = E_{f2}v_f + E_m v_m$$ **….…..Equation 4**

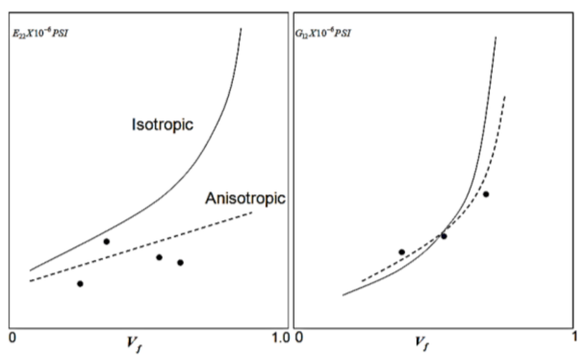


Figure 3. Transverse modulus as a function of fiber volume for anisotropic & isotropic filament Composite and Shear modulus as a function of fiber volume for anisotropic & isotropic filament Composite

$$E_\perp = 2\left[1-\mu_f+(\mu_f-\mu_m)v_m\right]\left[\frac{M_f(2M_m+G_m)-G_m(M_f-M_m)v_m}{(2M_m+G_m)+2(M_f-M_m)v_m}\right]$$ **……Equation 5**

$$G = G_m\frac{2G_f-(G_f-G_m)v_m}{2G_m-(G_f-G_m)v_m}$$

$$M_m = \frac{E_m}{2(1-\mu_m)}$$

$$M_f = \frac{E_f}{2(1-\mu_f)}$$

Manera [10] referred the approximate equation 6 proposed by puck

$$E_c = \left(\frac{E_m}{1-\mu_m^2}\right)\frac{1+0.85v_f^2}{(1-v_f)^{1.25}+\frac{E_m}{E_f}\left(\frac{v_f}{1-v_m^2}\right)}$$ **……..Equation 6**

The random reinforcement is very useful for forming complex shape of component very easily, but it directional control and ineffective length mechanism becomes influencing factors in reduction of composite strength and hence prediction of end properties is done based on approximation. On the basis of experimentationCox [15] proposes a model as equation 7 based on the longitudinal and transverse property.

$$\bar{E} = \frac{3}{8}E_1 + \frac{5}{8}E_2$$ **………Equation 7**

On the same bases the model proposed by Horio&Onogi [13] is shown as equation 8, while he proposed the other model as equation 9 considering the availability of experimental values of longitudinal and transverse values of composite material.

$$E_\theta = \frac{E_\parallel E_\perp}{E_\parallel \sin^2\theta + E_\perp \cos^2\theta}$$ **…….…Equation 8**

$$\frac{<E_\theta>}{E_\parallel} = \left(\frac{E_\perp}{E_\parallel}\right)^{\frac{1}{2}}$$ **…………Equation 9**

L.E. Nielson [9] provided the concept of fiber efficiency to consider the fact of ineffective load transfer load transfer by fiber the proposed model is shown as equation 10.

$$<E_\theta> = E_1v_1 + F*E_2v_2$$ **……Equation 10**

M. Manera [10] reported numerical approximation for the glass reinforcement in the range of [0.1 to 0.4] and polyester resin having stiffness in the range of 2GPa<Em< 4GPa. The proposed equation for approximation is considered based on the concept of averaging the strength from longitudinal to transverse with suitable interval which is shown as equation 11.

$$<E_\theta> = \frac{\int_0^{\frac{\pi}{2}} E_\theta d\theta}{\int_0^{\frac{\pi}{2}} d\theta}$$

…………Equation 11

Puck also proposes the model based on the concept of approximation considering the properties of randomly oriented fiber composite as shown equation 12.

$$\bar{E} = V_f\left(\frac{16}{45}E_f + 2E_m\right) + \frac{8}{9}E_m$$

………Equation 12

Study of literature indicates that there exists variety of models based on individual parameters to predict the end properties of fiber reinforced plastics and they all exhibits the concept of losses in end properties.The attempts made for jute and other natural fibers, of course provides data but their behaviour characteristics with respect to various affecting parameters still requires detailed systematic study.Hence the need is felt to carry out systematic experiments for in depth study. As the jute is easily available stiff fiber, which is also exhibits interface uncertainty. Hence jute and general purpose polyester resin is used to carry out experiments. Also, the effect of matrix contribution, interfacial parameters and voids are not studied extensively in the literature. The lack of sufficient experimental data in the literature gives clear indication regarding requirement of an in-depth study to carry out detailed experimental & analytical investigations to find parametric losses in end properties and to correlate them in generalized manner.

OBJECTIVES OF PRESENT WORK

Based on the conclusions derived from the literature the objectives of present work are:

i. To develop a mold and press set up for preparing specimens using jute as reinforcement and polyester resin as a matrix material.
ii. To study the effect of orientation angle of fiber with respect to longitudinal axis on Modulus of jute composite.
iii. To simulate modulus losses of jute reinforced plastics by FEA through standard FEA package like IDEAS and ANSYS and to carry out comparative study of these results with experimental results and to analyse the losses in Modulus.

EXPERIMENTAL METHODOLOGY

The experimental investigations are carried out in different orientation of fibers as described below:

Orientation of fiber

This stage of investigation deals with the effect of orientation with constant volume fraction [28%] of fiber subjected to longitudinal loading. The intentional direction change of fiber is applied to group of fibers which act as oriented lamina. The light stitching is also done to maintain orientation. The orientation angles are varied in the range of 10° to 80°. The volume fraction of fiber and other parameters are kept constant during this stage of investigations. Mold set up as shown in Fig 4 and Specimens of oriented fiber composite are shown in Fig 5.

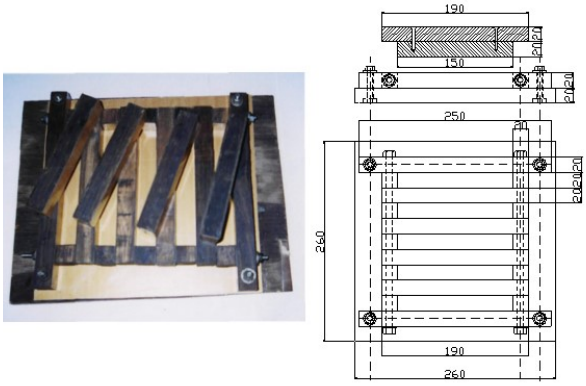


Figure 4. Mold set up

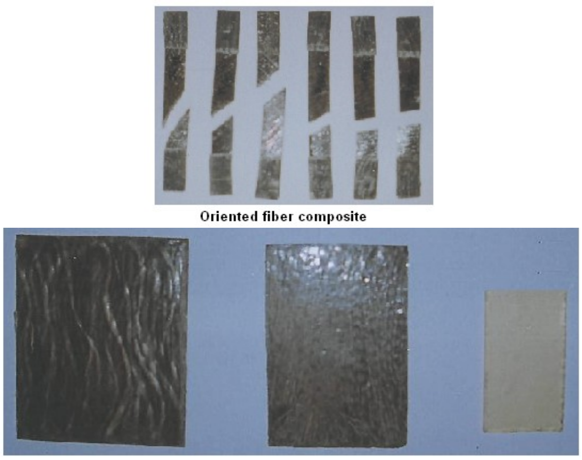


Figure 5. Specimens of Fiber Reinforced Polyester

EXPERIMENTAL DETERMINATION OF MODULUS

The prepared specimens in mold as shown in Fig 6 are initially tested the tensile strength on UTM (make: AMILI Co. Ltd., London) of capacity 20 ton, with minimum accuracy of 5 kg and finally testing was carried out on Tensiometer (make Mikrotech, manufactured by Kudale Enterprise, Pune.) is used for measuring the breaking load capacity is within 2 tons, with minimum accuracy of 1 kg and displacement with least count of 0.1 mm. The length of specimen before test and after test was measured by digital verniercaliper of least count 0.01mm. During the test, wedge type grippers are used for flat specimen with rectangular cross section.

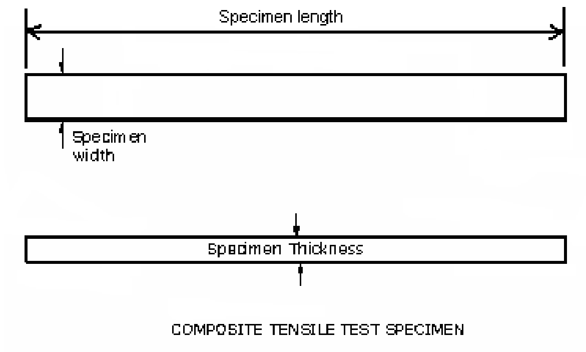


Figure 6. Tensile test specimen

The load is applied to obtain breaking of specimen and the Modulus of composite is obtained by using equation as follows

Modulus Ec(Kg/cm2) = σ/ε

……Equation 13

Where,

σ = stress (Kg/cm2)

σ = P/A

ε = strain

ε =dl/L

P=Breaking load (Kg)

A= Cross sectional area of specimen (cm2)

dl= Change in Length of specimen (Final length – Initial length)(mm)

L= Initial length (mm)

3D FEA MODELING OF JUTE COMPOSITE

The aim to observe the simulated results obtained by standard FEA packages IDEAS and ANSYS. The jute reinforced plastic is represented as a represented volume element in the form two concentric cylinders, where concentric cylinder represents reinforcement and outer cylinder represents matrix material. The condition of perfect joining at interface is maintained in both the FEA packages without considering any other interfacial effects.

SIMULATION OF MODULUS BY FEA PACKAGES

Three dimensional representative volume elements are modeled in FEA packages. In both the FEA packages the necessary boundary conditions are applied. All degree of freedom is restricted at back face and front face of fiber and matrix is allowed to undergo displacement for a experimental strain value in longitudinal direction. The property of fiber and matrix is assigned to respective part of representative volume element. The meshing is carried out by solid tetrahedron element.

The solution is carried out by applying unidirectional nodal displacement at one end till the failure strain of composite and based on the criteria of matrix failure. The solution, thus obtained by both the packages are shows maximum stress in the core of the fiber which is quite in tune with theoretical models [35, 36].

SIMULATION METHODOLOGY IN PACKAGES

- Bonding of core cylinder presenting fiber and outer hollow cylinder is accomplished by extruding circles their dimensions are calculated based on the volume fraction of failure of fiber as shown in equation 14.
- The final CAD model presenting representative volume element is shown in Fig 7 the boundary condition is then applied for restraining back face and forced displacement to front face is shown in Fig. 8.

v_f = volume fraction of fiber

Assume, d = 100 mm

$$D = \sqrt{\frac{d^2}{v_f}}$$

….Equation 14

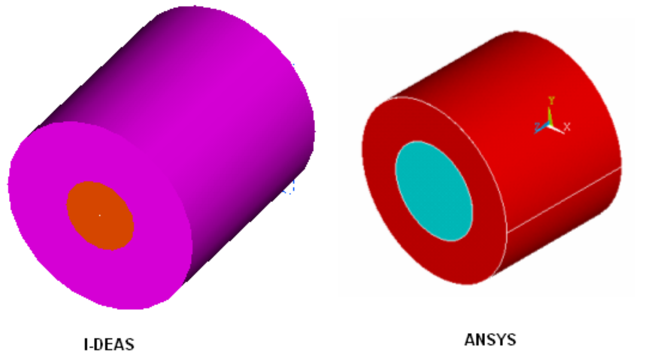


Figure 7 volume of composite

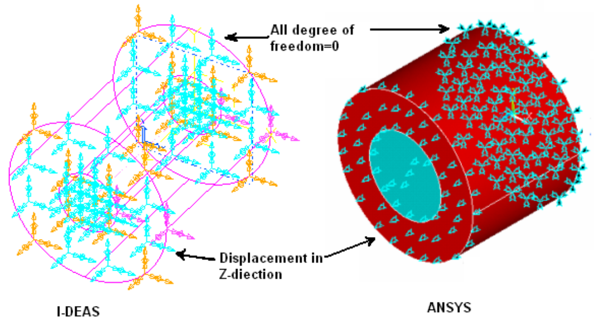


Figure 8. Boundary conditions

- The next task is assigning constituents properties. In present case the properties of jute and polyester resin is assigned for core cylinder and outer cylinder respectively. The properties of fiber and matrix are shown in Table 1.

Table 1. Properties of fiber and matrix

PROPERTIES		
Material	FIBER (Jute)	Matrix (Polyester resin)
Modulus of Elasticity E (N/m^2)	$1.038\text{x}10^{10}$	$2.285\text{x}10^{9}$
Shear modulus G (N/m^2)	$4.513\text{x}10^{9}$	$8.34\text{x}10^{8}$
Poisson ratio µ	0.15	0.37
Density (kg/m^3)	1500	1250

- Further representing volume element is described by meshing. It using solid tetrahedron element as shown in Fig. 9 and Fig. 10.
- The model thus prepared is solved and the results obtained by post processing in I-DEAS and ANSYS are shown in Fig 4.4 (a, b, c, d) and Fig 4.4 (e, f, g) respectively represents displacement of RVE, state of stress in RVE and stress in individual constituents.
- Based on the stresses observed in constituents at a experimental strain modulus of RVE is calculated using equation 4.2

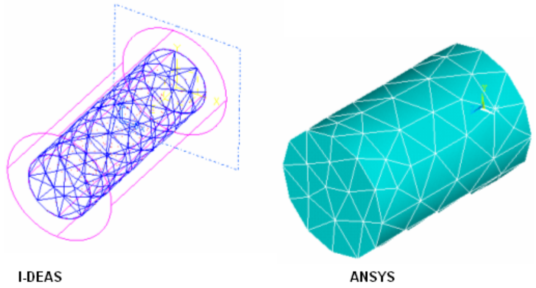


Figure 9. Fiber meshing

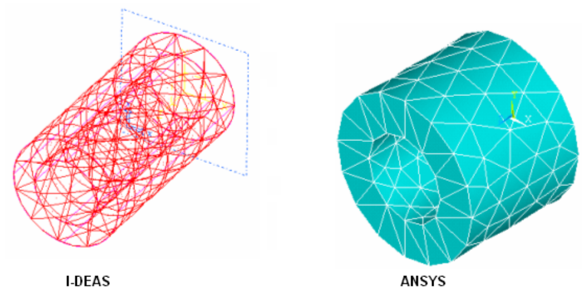


Figure 10. Matrix meshing

Effect of Fiber Orientation on Modulus

- The modeling procedure in this case requires creation of reference plane to create the model at an angle with X-axis. Apply experimental strain normal to the front face in I-DEAS while x and z- direction simultaneously for ANSYS as shown in Fig.11 and Fig 12respectively. Calculation of strain for ANSYS in x- and z- direction by using experimental strain as per equation 15.
- Rest of the procedure remains same as refered earlier. However in this case anisotropic effect in fiber is considered.

$$dl_x = dl\cos\theta$$
$$dl_z = dl\sin\theta$$

where,
dl is the experimental strain
θ is orientation angle of fiber

Equation 15

- The solution obtained is for displacement, state of stress in RVE and stresses in individual constituents as shown in Fig 13 to 16 for I-DEAS and Fig 17 to 22 for ANSYS.

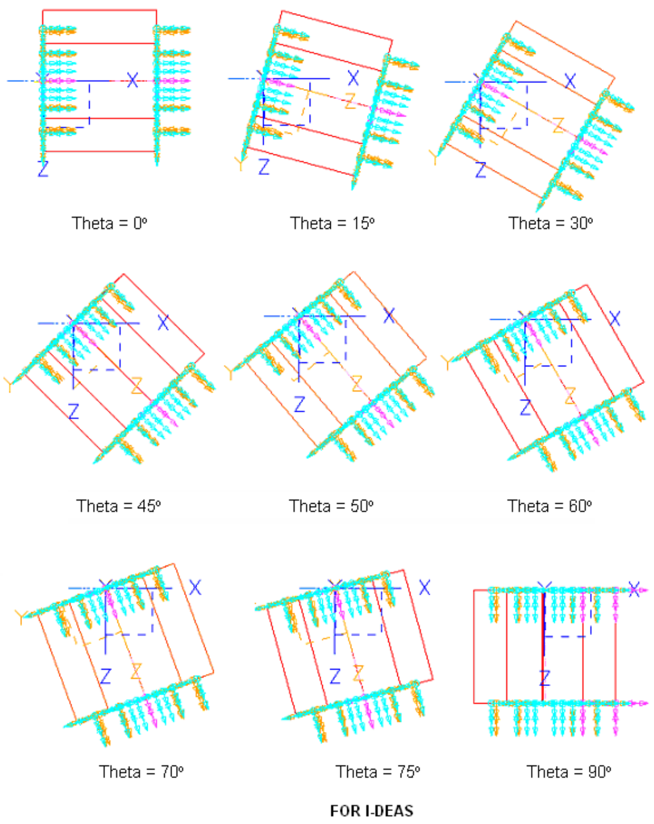


Figure 11. Boundary condition of oriented composite for I-DEAS

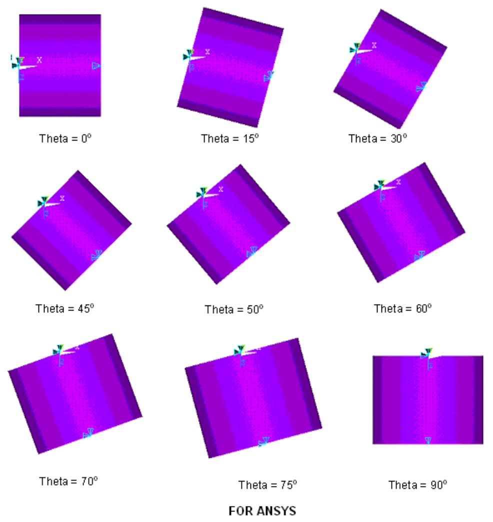


Figure 12. Boundary condition of oriented composite for ANSYS

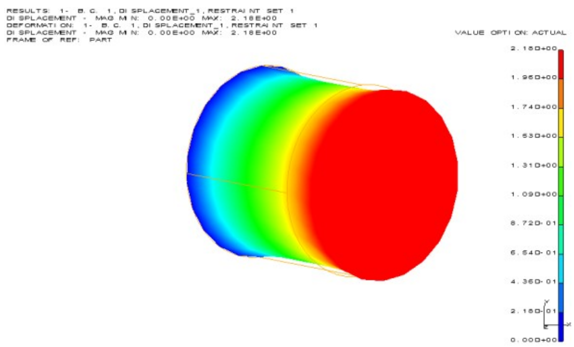


Figure 13. Displacement in Z-Direction

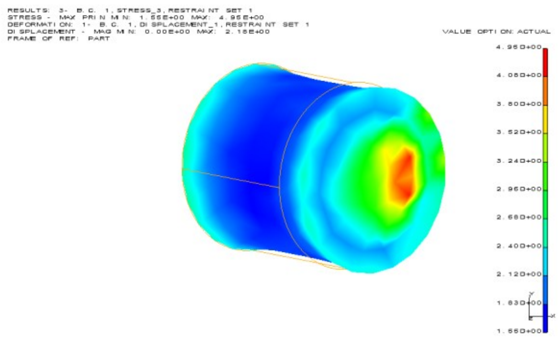


Figure 14. combine stress of both fiber and matrix

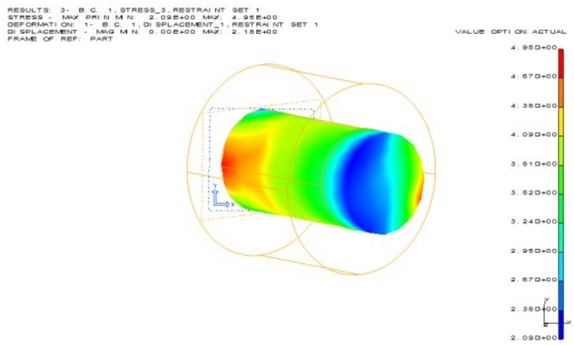


Figure 15. Fiber strength

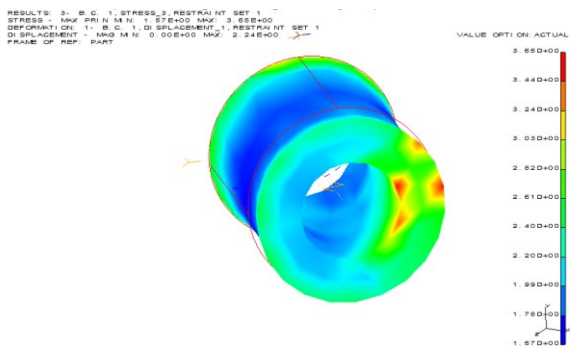


Figure 16. Matrix strength

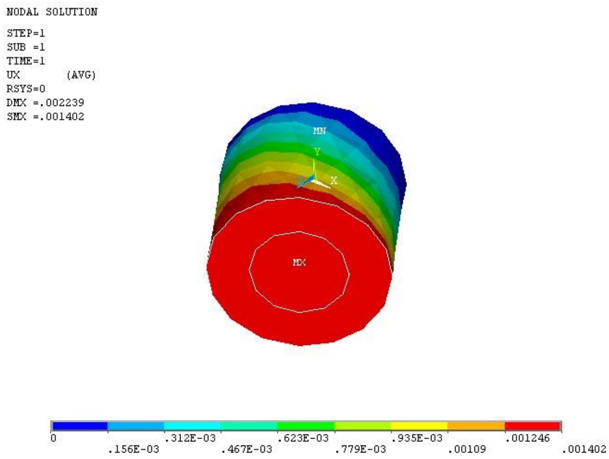


Figure 17. Displacement in X-Direction

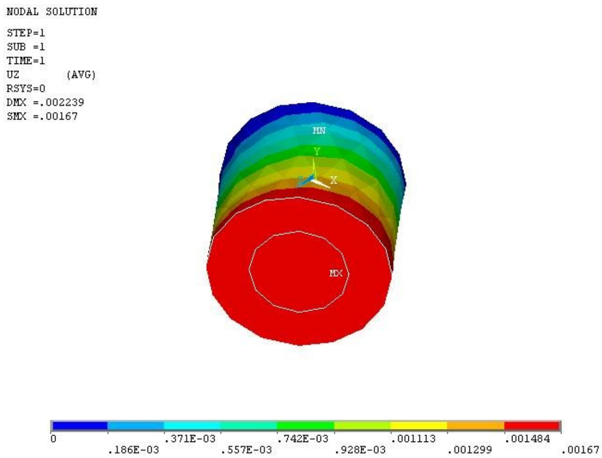


Figure 18. Displacement in Z-Direction

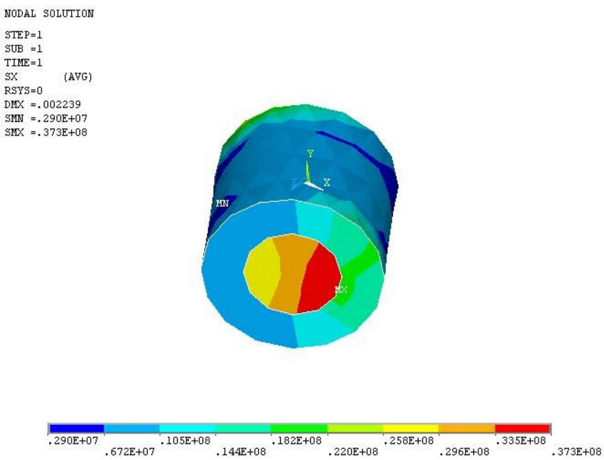


Figure 19. Fiber strength in X-direction

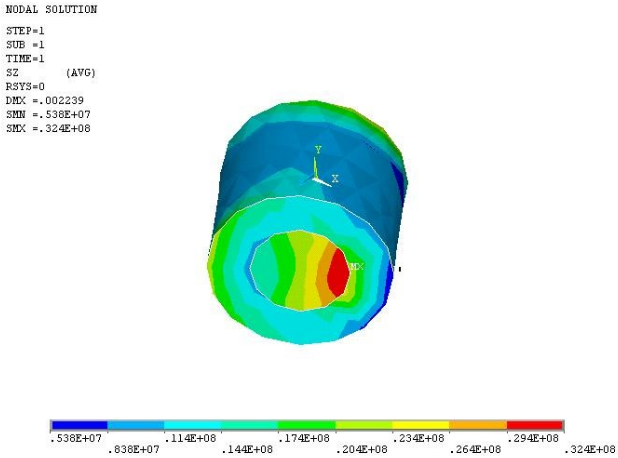


Figure 20. Fiber strength in Z-direction

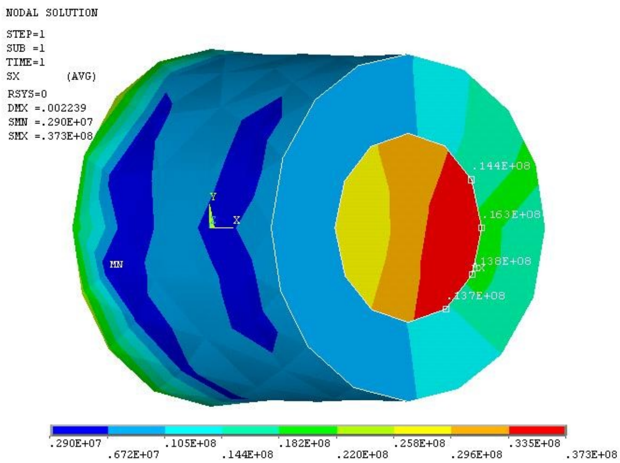


Figure 21. Matrix strength in X-direction

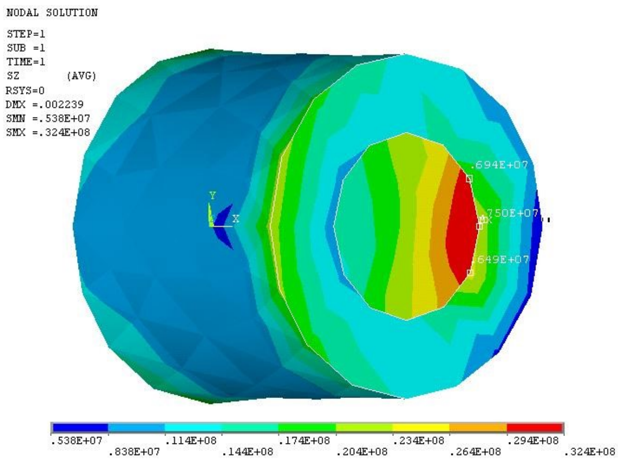


Figure 22. Matrix strength in Z-direction

Calculation procedure of Modulus of FRP is by using equation 16.

$$E_c = E_f v_f + E_m v_m \text{.......................Equation 16}$$

$$E_f = \frac{\sigma_f}{\varepsilon}$$

$$E_m = \frac{\sigma_m}{\varepsilon}$$

$$\sigma_f = \sqrt{\sigma_{fx}^2 + \sigma_{fz}^2}$$

$$\sigma_m = \sqrt{\sigma_{mx}^2 + \sigma_{mz}^2}$$

σ_f is the maximum fiber strength

σ_m is the maximum matrix strength

σ_{fx}, σ_{fz} is the maximum fiber strength in x and z - direction respectively

σ_{mx}, σ_{mz} is the maximum matrix strength in x and z - direction respectively

ε is the experimental strain of composite

III. RESULTS AND DISCUSSION

The characteristics of FRP material using Jute and Polyester is as a constituent. The experimental results obtained for orientation of fibers is attempted during the research of work is described below

Effect of Fiber Orientation on Modulus

1. Fig. 23 shows the variation of Modulus Ec as a function of orientation of fiber for composite subjected to longitudinal loading for constant vf content of 28%. It is observed that as orientation of fiber increases Modulus decreases because effective contribution of reinforcement is maximum in longitudinal direction while, the contribution in transverse direction is minimum due to anisotropy of fibers. This observation is quite in line with theoretical models proposed by various researchers [9, 10, 12].
2. Fig.24 and 25 shows the comparative results of theoretically Models and FEA packages simulated values of Modulus respectively as a function of orientation of fiber for aligned fiber composite subjected to longitudinal loading with experimental results. It is observed that theoretical and packages simulated results are on higher side as compared to experimental results. This may be attributed to the presence of voids, loss in contribution due to matrix and other interfacial effects [5]
3. Fig 26 shows the loss in Modulus as a function of orientation of fiber. The loss in Modulus of composite increases as orientation of fibers increases with respect to longitudinal loading direction because of anisotropic of fibers. The loss by FEA packages is high compare to theoretical models because models considers the trigonometric function which affects low value of orientation angle. The losses observed as (24.35-58.24)% in Nielsen model and (25.80-58.82)% in Horio model while in FEA packages, (28.22-60.02)% in I-DEAS and (23.03-58.76)% in ANSYS as orientation angle of fiber varies from 10 to 80 degree to the applied loading.
4. Fig. 27 shows the loss constants m and c for different models and FEA packages. Loss constant m is positive for theoretical models and software packages means loss increases as orientation angle of fiber increase. Loss constant c is high means over prediction of modulus.

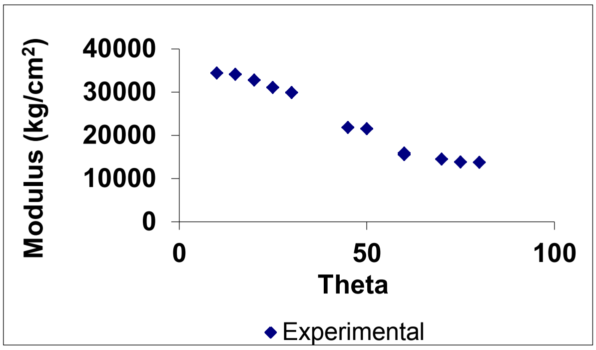


Figure 23 Effect of orientation of fiber on Modulus of composite under longitudinal loading.

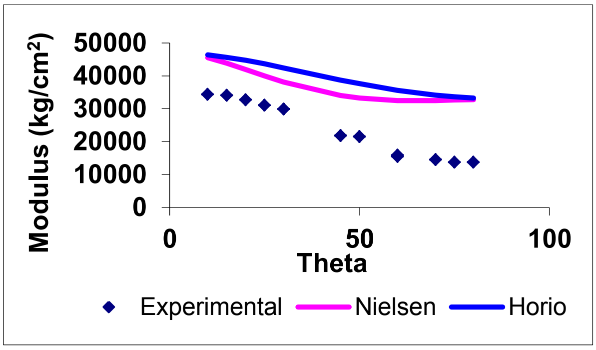


Figure 24. Comparative results of theoretically model predicted Modulus on continuous oriented fiber composite under longitudinal loading with experimental results.

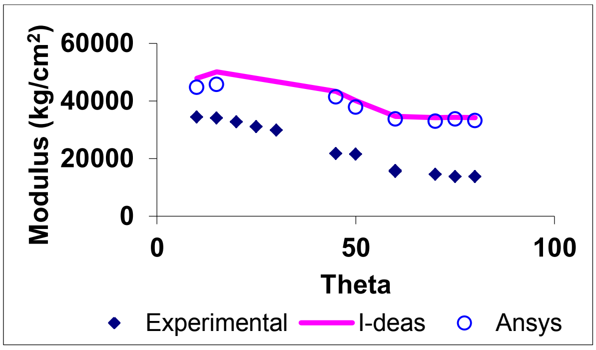


Figure 25. Comparative results of FEA package simulated Modulus on continuous oriented fiber composite under longitudinal loading with experimental results.

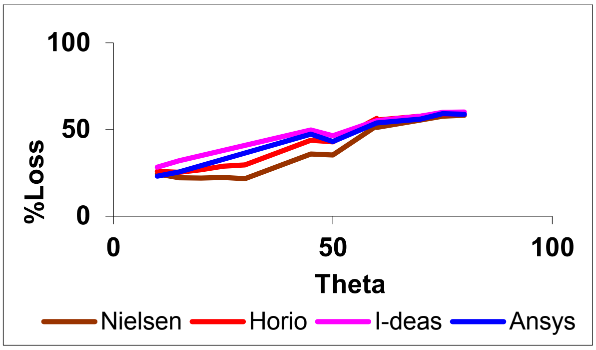


Figure 26. Comparative results of losses inmodulus on continuous oriented fiber composite under longitudinal loading.

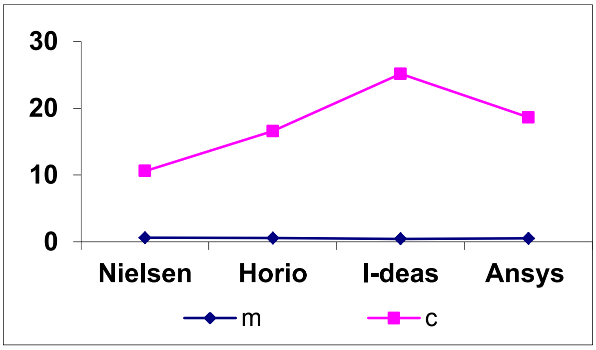


Figure 27. Comparative results of linearity constants for Models & FEA packageson continuous oriented fiber composite under longitudinal loading.

IV. CONCLUSION

Based on the extensive experimental investigations on effect of fiber content for long continuous fibers, short random fibers under longitudinal loading, effect of fiber content for continuous fiber with transverse loading, effect of length of fibers, breakage in fibers and orientation of fibers under longitudinal loading the following conclusions may be drawn:

The loss in Modulus of composite increases as orientation of fibers increases with respect to longitudinal loading direction. The loss in modulus in terms of orientation angle of fiber (θf) is as showing in following forms.

a. Nielsen :%Loss=0.61(θf)+10.60
b. Horio:%Loss=0.57(θf) +16.57
c. I-DEAS: %Loss=0.46(θf)+25.15
d. ANSYS: %Loss=0.53(θf)+18.62

Thus the present work high lights the pattern of loss in modulus of jute reinforced plastic in light of available theoretical models presenting various fiber forms and arrangement. Further the attempts made for simulated results using FEA packages (I-DEAS & ANSYS). The losses also following the same trends are basically divergence from models which is clear indication towards requirement of interphase effects in predictive models. Overall observed the range of losses is (0.16-75.06) % depending on various parameters.

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