

Experimental Investigation on Effect of Fiber Content on Longitudinal Modulus of FRP

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ABSTRACT

FRP is the Fiber Reinforced Plastic which means enhances the mechanical properties of matrix by using reinforcing fibers. In a present era importance of FRP are steadily increasing due to its advantageous properties. 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. Hence, this dissertation 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 Tensiometer. The attempts are made to study the effect of volume fraction of fiber on modulus for continuous long fibers.

Keywords: FRP, UTM, ANSYS, IDEAS, CAD, RVE, ROM, Epoxy, Volume Fraction

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 Figure 1.

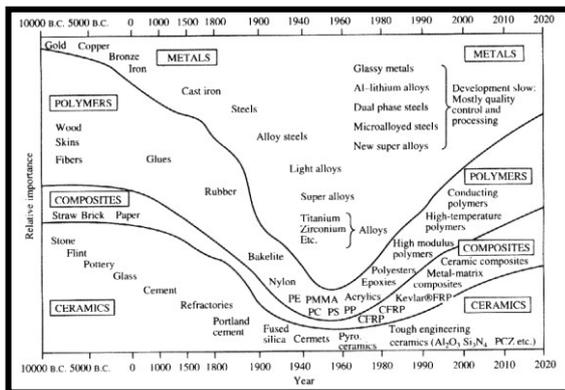


Figure 1. History of Materials

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 of matrix 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]

2. 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].

3. 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 properties and 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.

3.1 Effect of Fiber Content on Longitudinal Modulus of FRP

J. M. Whitney [4] static equilibrium requires that the total resultant force on the element must equal to the sum of forces acting on the fiber and matrix. Combining the static equilibrium condition leads to formation of Rule of mixture equation 1.

$$E_c = E_f v_f + E_m v_m \quad \text{Equation 1}$$

Puck also proposes the model based on the concept of approximation considering the properties of longitudinal equation 2.2.

$$E_c = E_m (3.92 v_f + 0.89) \quad \text{Equation 2}$$

As per the C. Chamis [11] Various researcher (1967 to 2000) believes that rule of mixture can be used as tool primarily for predicting end properties of composites. However, experimentally it is observed that composites always exhibit low strength and lower modulus of elasticity than that predicted by rule of mixture. The voids formation at interface may be one of the factors to reducing strength and modulus of elasticity.

N.L.Hancox, [12] observed the same that as void content increase, the strength and modulus of elasticity of composite decreases while improving the fiber surface by treatment improves the strength and modulus of elasticity .

S. Subramanian [5] reported that failure of composite due to interfacial debonding which is violation of basic assumption in rule of mixture i.e. condition of perfect bonding is not fulfilled he defined the parameter efficiency factor η which determines how well load is transferred from matrix to fiber . If $\eta=1$ the bonding is good and efficient load transfer occurs across the interface then the modulus of unidirectional composite will be equal as predicted by rule of mixture. He used the same fiber and matrix to see the interphase effect by using untreated and treated fiber surface, the efficiency was found in the range of 0.75 to 0.98. Under ineffective condition he mentions that interfacial debonding occurs when average shear stress in matrix exceeds interfacial shear strength.

4. Mold and Specimen Preparation

The mold is developed for experimentation during the course of this work. It primarily consists of bottom plate attached with detachable pieces to form a rectangular

cavity. The arrangement is done in such a way that five specimens can be prepared at a time at a uniform pressure. The top plate of mold is fixed with individual punches to form punch plate assembly. Entire mold is prepared from wooden material glued with 1 mm thin Formica sheet at contact surfaces. The intension of using Formica is to provide smooth surface. The oil is also used at matting surface to avoid sticking of specimen with cavity or with the punch after solidification. The schematic diagram of mold is shown in Fig 2. The unit of mold is placed under the compression press which is essential unit to transfer pressure from punch to matrix material for penetrating in to the area around and within the fibers. Also multiple cavity die is directly used with dead weights to maintain the contact pressure required for specimen formations. The compression unit comprises of two plates guided with pillars using screw & nut type compression mechanism. The schematic diagram of the same is shown in Fig 4.

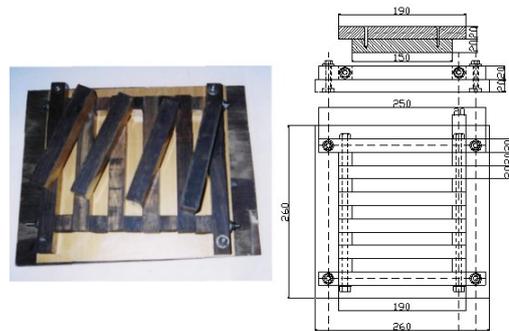


Figure 2. Mold set up

The combination of jute and polyester is attempted during the course of experiments with uniform condition of pre-treatment to fibers. Before placing fibers in to mold the moisture is removed by placing fiber in to Heating chamber at a temp of 110°C for 1 hour and then they are allowed to be cooled in decicator for 1 hour. The weighted fibers are placed in mold cavity and then fixed measured volume of polyester resin is poured in to mold. The parameters are maintained constant for curing of specimen at room temperature and for all cases specimens were allowed to cure in mold for 24 hours. Cured specimens are tactfully removed from mold and cleaned by filing. After cleaning their weight and volume are measured. The weight measurement of fiber and specimen is carried out on digital weight balance (make Adair, Dutt& company (India) Pvt. Ltd.) of accuracy 0.0001 gm, while volume of specimen is measured by standard water displacement technique using 100 ml calibrated measuring cylinder and burette having least count of 0.02 ml as shown in Fig 3.

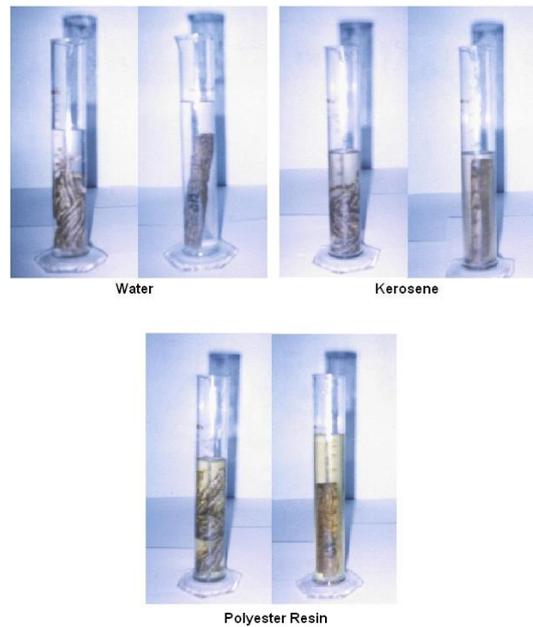


Figure 3. Density and volume measurement of fiber and FRP



Figure 4. Compression Unit

III. RESULTS AND DISCUSSION

1. Experimental Determination of Modulus

The prepared specimens in mold as shown in Fig 5 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. Strength measuring set up is shown in fig.6. The length of specimen before test and after test was measured by digital vernier caliper of least count 0.01mm. During the test, wedge type grippers are used for flat specimen with rectangular cross section.

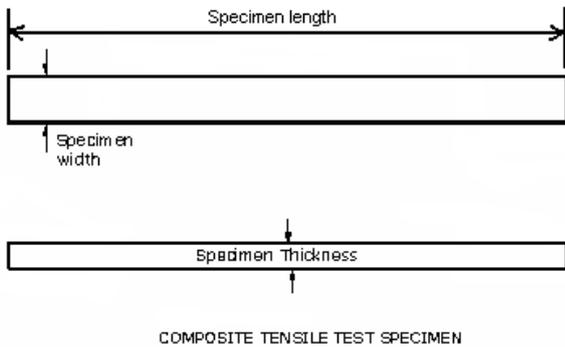


Figure 5. Tensile test specimen

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

$$\text{Modulus } E_c(\text{Kg/cm}^2) = \sigma/\epsilon \quad \text{Equation 3}$$

Where,

σ = stress (Kg/cm²)

$\sigma = P/A$

ϵ = strain

$\epsilon = dl/L$

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)



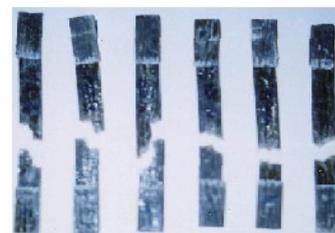
Figure 6. Strength measuring equipment Tensiometer

2. Experimental Methodology

The experimental investigations are carried out as described below:

2.1 Long continuous fibers

The effect of fiber content is investigated by maintaining 0° of fibers with loading direction in case of long continuous fibers. The fibers are taken in bunch with different weight so as to get variation in volume fraction [4 to 38%] and constant quantity of resin is poured. The Modulus of each specimen is measured and the effects of fiber content for long continuous fibers have been investigated. Specimens of longitudinally aligned fiber composite are shown in Fig 6.



Longitudinally aligned fiber composite



Figure 7. Specimens of Fiber Reinforced Polyester

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. In a present chapter the condition of perfect joining at interface is maintained in both the FEA packages without considering any other interfacial effects.

3. 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].

4. Simulation Methodology in Packages

4.1 Effect of Fiber Content on the Modulus for Longitudinal Loading

- 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 4.
- The final CAD model presenting representative volume element is shown in Fig 8. the boundary condition is then applied for restraining back face and forced displacement to front face is shown in Fig 8.

$$V_f = \text{volume fraction of fiber}$$

$$\text{Assume, } d = 100 \text{ mm}$$

$$D = \sqrt{\frac{d^2}{V_f}} \quad \text{Equation 4}$$

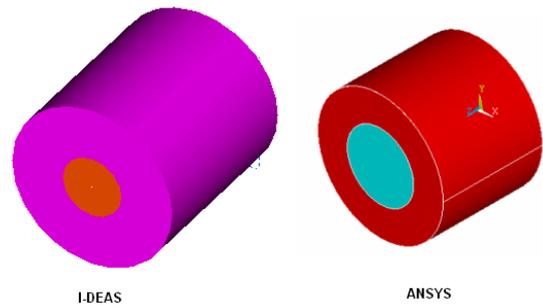


Figure 8. Volume of Composite

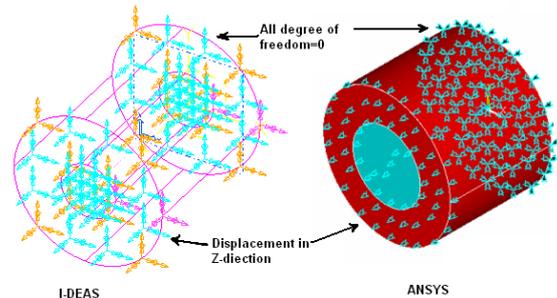


Figure 2 Boundary Conditions

- 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)	1.038x10 ¹⁰	2.285x10 ⁹
Shear modulus G (N/m ²)	4.513x10 ⁹	8.34x10 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 11,12 13 and 14 and Fig 15, 16 and

18 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 5.

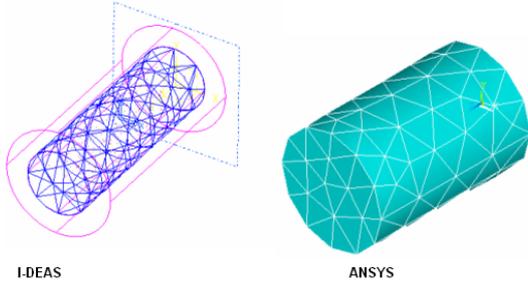


Figure 10. Fiber Meshing

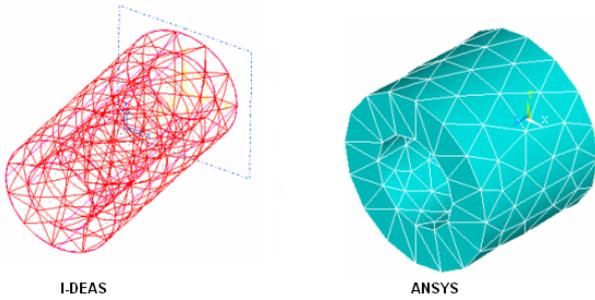


Figure 11. Matrix Meshing

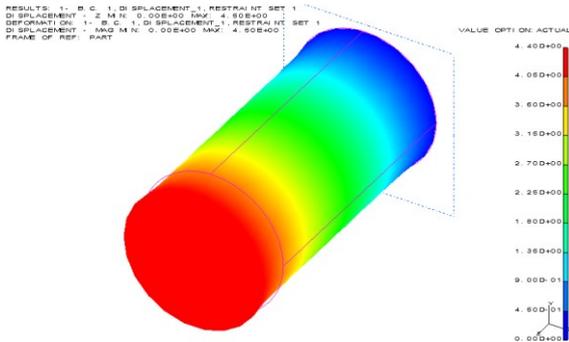


Figure 12. Displacement in Z-Direction

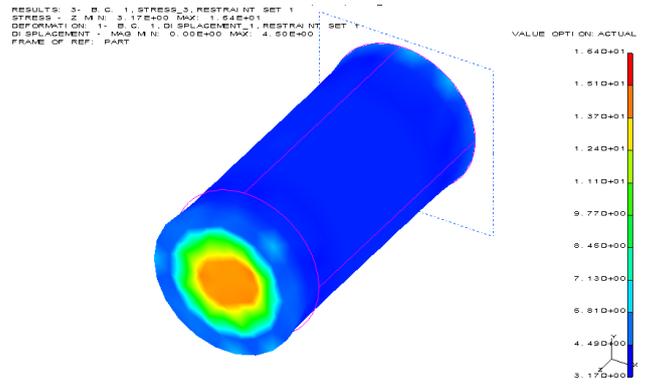


Figure 13. Combine stress of both fiber and matrix

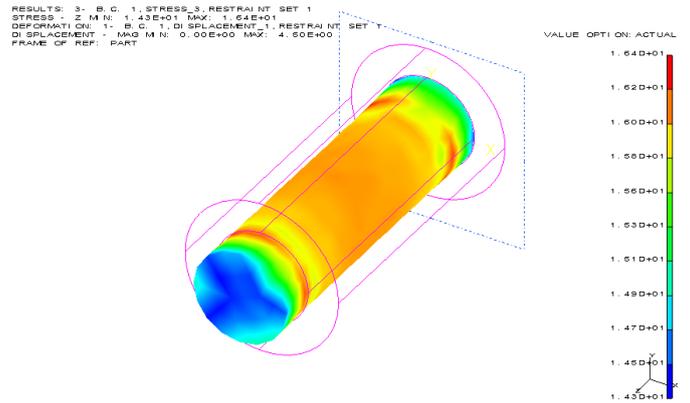


Figure 3. Fiber Strength

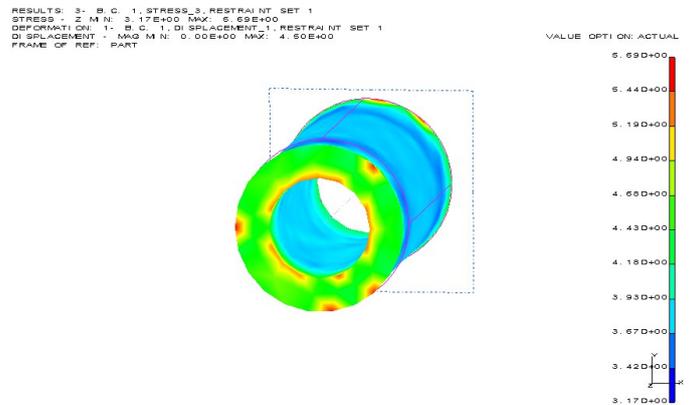


Figure 4. Matrix strength

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MODAL SOLUTION
STEP=1
SUB =1
TIME=1
UZ      (AVG)
RSYS=0
DMX = .004558
SMN = .0044
SMX = .0044

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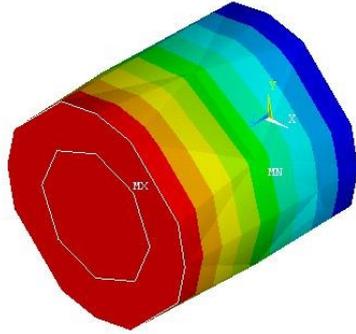


Figure 5 Displacement in Z-Direction

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MODAL SOLUTION
STEP=1
SUB =1
TIME=1
SZ      (AVG)
RSYS=0
DMX = .004558
SMN = .313E+08
SMX = .158E+09

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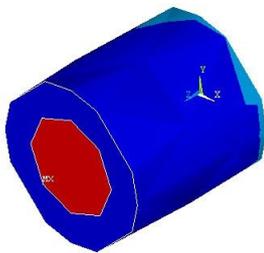


Figure 6. Fiber Strength

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MODAL SOLUTION
STEP=1
SUB =1
TIME=1
SZ      (AVG)
RSYS=0
DMX = .004558
SMN = .313E+08
SMX = .158E+09

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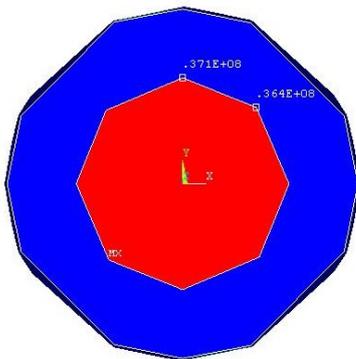


Figure 7 Matrix Strength

- Calculation procedure of Modulus of composite [4] by using equation 5.

$$E_c = E_f v_f + E_m v_m$$

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

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

Equation 5

σ_f is the maximum fiber strength

σ_m is the maximum matrix strength

ϵ is the experimental strain of composite

5. RESULTS

The characteristics of FRP material are using Jute and Polyester as constituents. The experimental results obtained for parameters volume fraction attempted on long continuous fibers is described below

5.1 Effect of Fiber Content on the Modulus for Longitudinal Loading

1. Fig. 18 shows the variation of Modulus E_c as a function of v_f for long continuous fiber composite subjected to longitudinal loading. It is observed that as v_f increases Modulus also increases linearly because the increase in reinforcement tends to increase the Modulus of composite [4, 9, 10].

2. Fig.19 and Fig 20 shows the comparative results of theoretical Models and FEA packages simulated results of Modulus respectively as a function of v_f for the long continuous fiber with experimental results. It is worth to mention that theoretical and packages predictions are on higher side as compared to experimental results. This may be attributed to the presence of voids, ineffective contribution from matrix and fiber other interfacial effects [5], while in theoretical models it is assumed that there is perfect bonding between fiber & matrix and absence voids. Again in FEA package the glue option is used to maintain perfect bonding and voids are not considered during the modeling.

3. Fig 21 shows the loss in Modulus as a function of v_f for the long continuous fiber. The comparison clearly indicates rise in divergence as v_f increase. The divergence of model ROM & Puck is highest and the losses observed (12.2-13.5)% & (15.5-15.4)% as they are independent of strain value. While the divergence is reduced as (0.2-8)% & (0.16-6.68)% in case of I-DEAS and ANSYS as their simulated value are depending on experimental strain value and not only on constituents property. However trend is very much in line with above referred models.

4. The effect of loss variation shown in Fig 22. The value of m indicates rate of increase of loss while c indicates over and under prediction characteristics. The rule of mixture is observed to have low value as compare to Puck model means loss characterise by Puck is steeper, while for packages it is moderate. The rule of mixture & Puck models are over predicting while

packages are slightly under predicting as the results are simulated at experimental strain value.

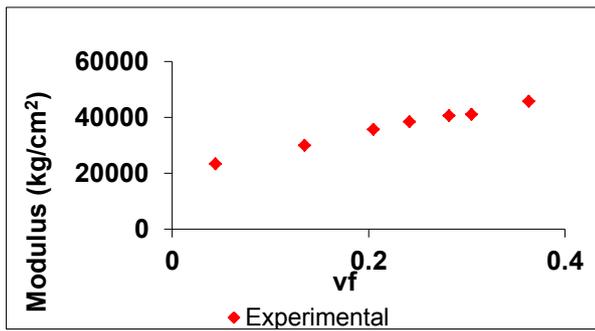


Figure 19. Effect of fiber content on Modulus of long continuous fiber composite under longitudinal loading.

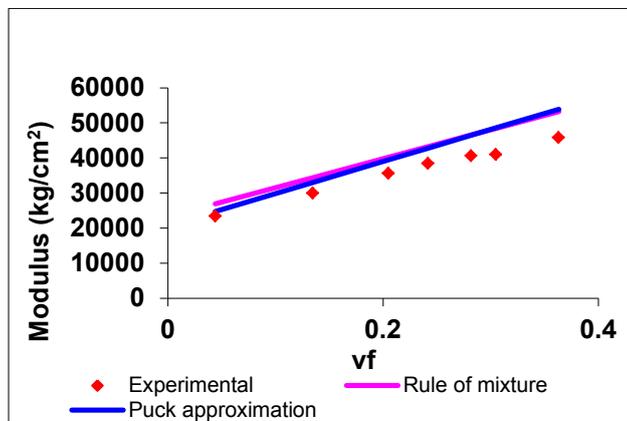


Figure 20. Comparative results for modulus predicted by theoretical models with experimental results considering long continuous fibers.

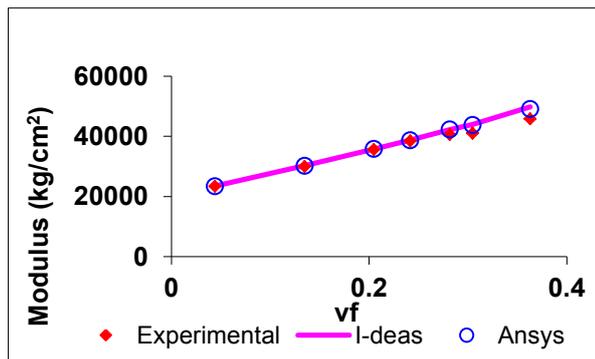


Figure 8 Comparative results simulated by FEA packages with experimental results for long continuous fiber composite.

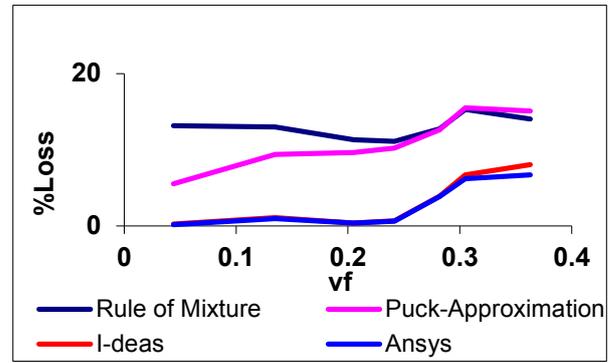


Figure 9 Comparative results of losses in modulus on long continuous fiber composite.

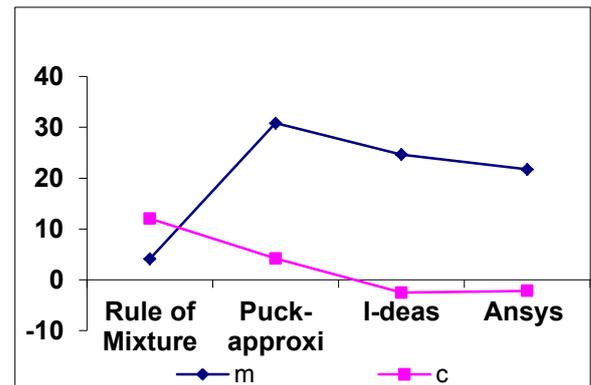


Figure 10 Comparative results of linearity constants for long continuous fiber composite.

IV. CONCLUSION

Based on the extensive experimental investigations on effect of fiber content for long continuous fibers, the following conclusions may be drawn:

1. The loss in Modulus of long continuous fibers composite increases slight linearly under longitudinal loading condition as the volume fraction of fiber increases. The loss in modulus in terms of volume fraction of fiber (v_f) observed as linear function as follows:

- a. Rule of Mixture: $\%Loss=4.10 v_f+ 12.03$
- b. Puck-approximation: $\%Loss=30.83v_f+ 4.20$
- c. I-DEAS: $\%Loss=24.64v_f- 2.54$
- d. ANSYS: $\%Loss=30.83v_f- 2.19$

V. FUTURE SCOPE

Prediction of the end property is critical task in case of fiber reinforced plastics materials. However the

consideration of interphase effect in predictive models can lead towards better convergence. The approximation of interphase property may be used in simulation packages for better simulation results.

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