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Effect of Breakage & Ineffective Length of Fiber on Modulus of FRP

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ABSTRACT

The variation of Modulus E_c as a function of percentage of broken fiber for long aligned fiber composite subjected to longitudinal loading for constant v_f content of 22%. It is observed that as ratio of broken to total fibers decreases Modulus decreases with linearly. Usually as broken fiber increases, the effective reinforcement decrease this reduces contribution of reinforcement in a linear manner. The loss in Modulus increases as percentage of broken fiber increase because reduction factor in fiber contribution R_s is function of β, fraction of broken fiber (ρv), aspect ratio (L/d), maximum shear strength (τ_{max}) which gives less effect at low fraction of broken fiber and therefore the variation of 0-0.3 for fraction of broken fiber cause opposite zone for packages and model, therefore overall loss is obtained is more in case of packages. The comparative results of theoretical Models and FEA packages predicted values of Modulus respectively as a function of percentage of broken fiber for long aligned fiber composite subjected to longitudinal loading with experimental result.

Keywords : Brokenfibers, Aspect ratio, Modulus, FEA, ANSYS, I-DEAS, RVE

I. INTRODUCTION

The 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].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. 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]

II. METHODS AND MATERIAL

1. 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 de-bonding and voids also creates loss in modulus of composite [8].The interfacial bonding influences the tensile modulus through mechanics of ineffective length and broken fiber [5].

2. 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.

3. Effect of Breakage & ineffective length of fiber on modulus of FRP

S. Subramanian [5] also observes that interfacial bonding influences the tensile modulus through mechanics of ineffective length and broken fiber. He assumes the arrangement of fiber in such a way that broken fibers forms a central core and layer of matrix material wrapped around it as shown in Fig. 1. The nearest neighbouringfibers are assumed to be arranged such that it forms co-centric cylinders around the central core of broken fibers. The damaged modulus of central core is calculated as equation 1 by considering different volume fraction of fiber v_f

$E_c = \left(v_f \cdot E_{f'} + (1-v_f) \cdot E_m\right)$ …………**Equation 1**

Considering single fiber with matrix material around it having fiber radius r_f, volume fraction of fiber as v_f and the thickness of matrix layer as d. Further inner core having i broken fibers having core radius r_{f1} and damaged modulus of inner core is calculated by considering new contributing volume fraction of fibersv_f Where $v_f = i\left(\frac{r_f^2}{r_{f1}^2}\right)$

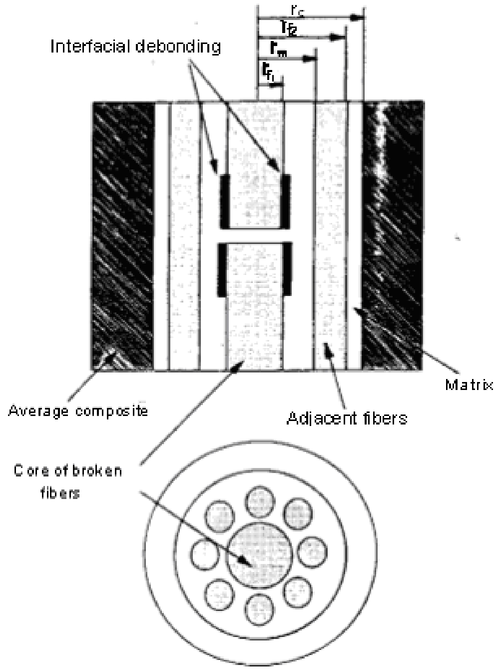

Figure 1. Model of broken fiber at the core cause raises the stresses in adjacent fibers.

Abu Farsakh [7] studied the effect of broken fiber on tensile strength of composite. He observed that the increase in % breakage of fiber decreases the tensile strength of composite thus tensile modulus of composite; again predict tensile strength of graphite/epoxy versus percentage of fiber breakage at different volume fractions as shown in Fig. 2. To estimate the tensile strength he proposed the model which is modification of simple rule of mixture as shown equation 2. Which is derived based on the assumption of eccentric load transfer to hexagonally arrange neighbouringfibers as the core fiber is broken as shown in Fig. 3. The assumption of sharing load of core fiber by adjacent fiber increases the stress level in them causes the reduction factor at the contribution part of fibers.

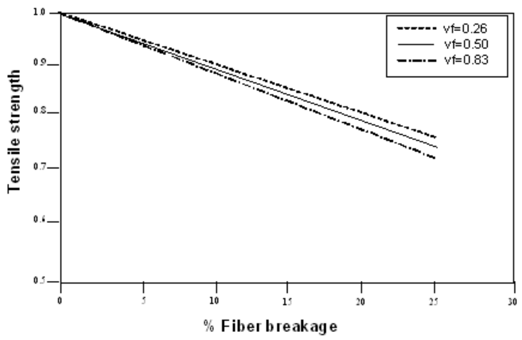

Figure 2. Predicted tensile strength of graphite/epoxy versus percentage of fiber breakage at different volume fractions

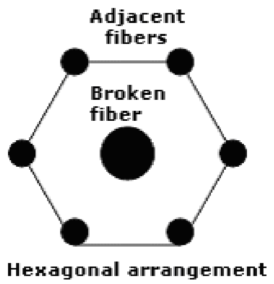

Figure 3. Representing model of broken core fiber transfers the load to adjacent fibers eccentrically.

$$\sigma_c = (1-R_s)\sigma_f v_f + \sigma_m (1-v_f)$$

where **Equation 2**

$$R_s = \frac{\rho_v}{3}\left\{1+\frac{0.7123\tau_{max}\left(\frac{L_e}{d}\right)}{\sigma_f}\left[\frac{E_f v_f}{E_f v_f + E_m(1-v_f)}\right]\right\}$$

$$\left(\frac{L_e}{d}\right) = \frac{3}{2}\frac{1}{(v_f)^{2/3}}\sqrt{\frac{E_f}{G_m}}$$

Where, ρ_v is fraction of broken fiber.

The value of τ_{max} is use d from SAP 90 finite element program

The proposed stress in fiber is given by equation 3.

$$\sigma_{f,max} = 0.35615\tau_{max}\left(\frac{L_e}{d}\right)\left[\frac{E_f v_f}{E_f v_f + E_m(1-v_f)}\right] \quad \textbf{Equation 3}$$

The interphase formed due to ineffectiveness of fiber length also introduces the reduction factor at the contribution place of fiber.

R.F. Gibson [6] Studied the effect of fiber aspect ratio, fiber spacing, visco elastic properties, and stiffness of aligned discontinuous fiber reinforced polymer composite using two approaches: 1. Energy approach: energy stored in fiber and matrix and energy is dissipated Due to interfacial shear stresses were calculated 2. Derivation of expression for elastic stiffness of discontinuous composite Based on average fiber stress and force balance between fiber& matrix both approaches were studied to verify the optimum fiber aspect ratio. He reported agreement of his results with various theories for believing that parameters like fiber aspect ratio, volume fraction, fiber matrix, and modulus ratio & Influences the shear stress distributed at interface. Loss in modulus reported as equation 4, where the reduction factor is function of fiber length only**.**

$$E_c = E_f\left(1-\frac{\tanh\beta l_e/2}{\beta l_e/2}\right)v_f + E_m v_m \ldots \textbf{Equation 4}$$

He derived the expression for optimum length of fiber for maximum damping as equation 2.7.

$$\left(\frac{l}{d}\right)_{opt} = 3.28K \quad \ldots\ldots\ldots\ldots\ldots \textbf{Equation 5}$$

Where,

$$K = \left(\frac{E_f'}{G_m'}\right)^{\frac{1}{2}}\frac{\left[\ln\left(1/cv_f^{1/2}\right)\right]^{\frac{1}{2}}}{2\sqrt{2}}$$

$$c^2 = 2\sqrt{3}/\pi = 4/\pi$$

He also referred Cox equation 6 for stress in fiber

$$\sigma_f = \varepsilon E_f'\left\{1-\frac{\cosh\left[\beta\left(\frac{l_e}{2}-x\right)\right]}{\cosh\frac{\beta l_e}{2}}\right\} \quad \ldots\ldots \textbf{Equation 6}$$

For hexagonal & square array of fiber the shear stress reported as equation 2.9.

$$\tau = r_0^2 E_f \varepsilon\beta \sinh[\beta\left(\frac{l_e}{2}\right)-x] \ldots\ldots\textbf{Equation 7}$$

Where, $\beta^2 = \left(\frac{G_m}{E_f}\right)\frac{2}{r_0^2\ln\left(\frac{R}{r_0}\right)}$

4. Objectives of Present Work

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

(i) To develop a moldas shown in Fig. 4 and press set up for preparing specimens using jute as reinforcement and polyester resin as a matrix material.

(ii) To study the effect of fiber breakage 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.

5. Experimental Methodology

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

Breakage in fiber

This stage of investigation deals with the effect of breakage on Modulus of composite. The intentional breakage is applied by cutting known number of fiber bundles to vary the ratio of broken fibers to total fibers. All the fibers are kept long continuous with maintaining 0° with direction of loading while broken fibers are cut exactly at middle of specimen. The ratio of broken to total no of fiber bundles (b/t) is varied from 30 % to 75 %. The volume fraction [22%] of fiber and other parameters are kept constant during this stage of investigations. Specimens of broken fiber composite are shown in Fig 5.

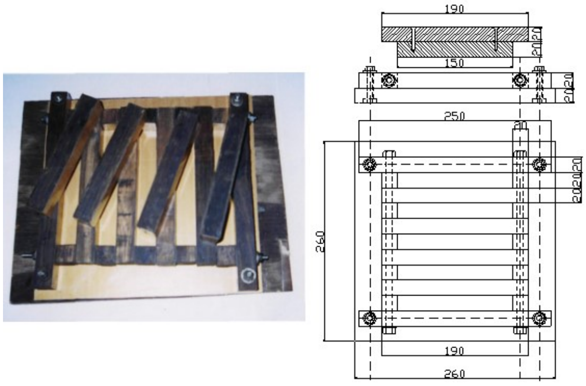

Figure 4. Mold set up

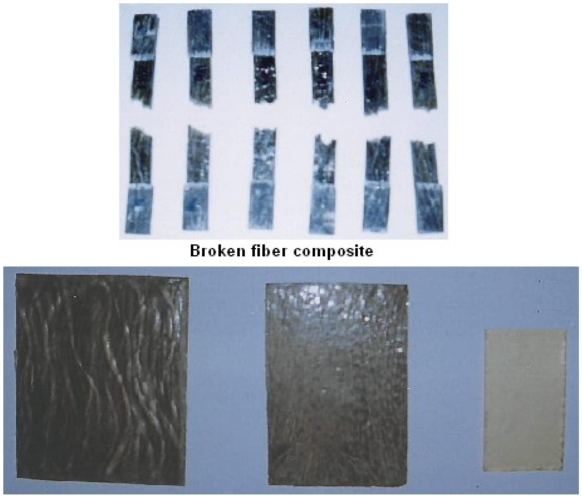

Figure 5. Specimens of Fiber Reinforced Polyester

6. 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.

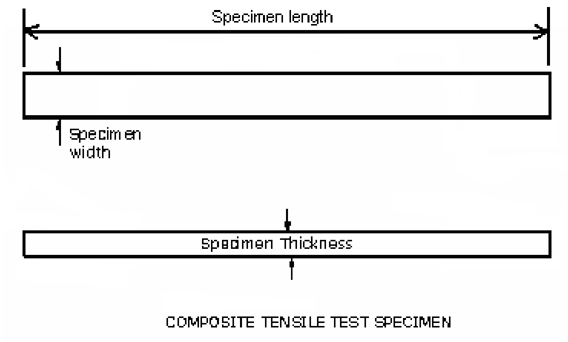

Figure 6. Tensile test specimen

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 8

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)

7. 3D FEA Modelling 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.

8. 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].

9. 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 9.
- 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 9

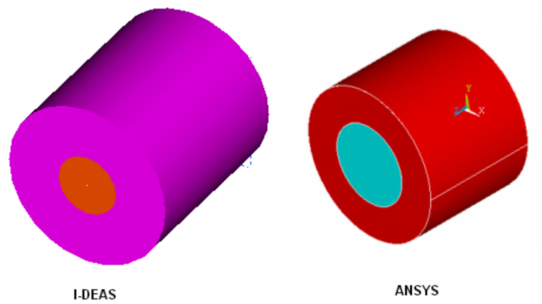

Figure 7. Volume of Composite

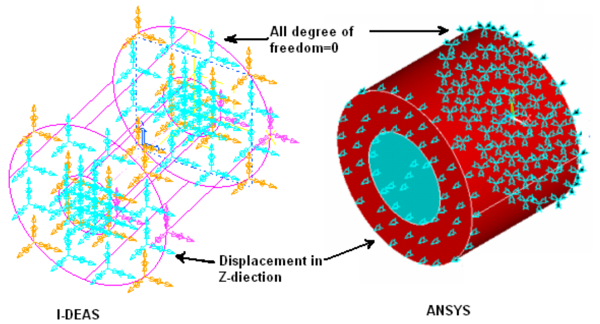

Figure 8. Boundary Conditions

- 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)	1.038×10^{10}	2.285×10^9
Shear modulus G	4.513×10^9	8.34×10^8

(N/m^2)		
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

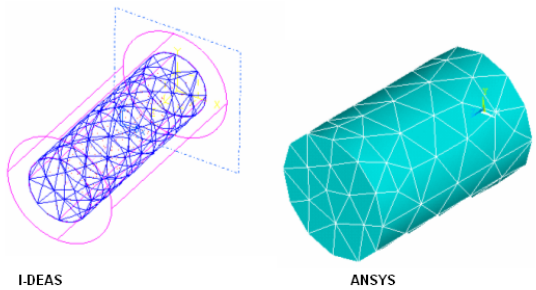

Figure 9. Fiber Meshing

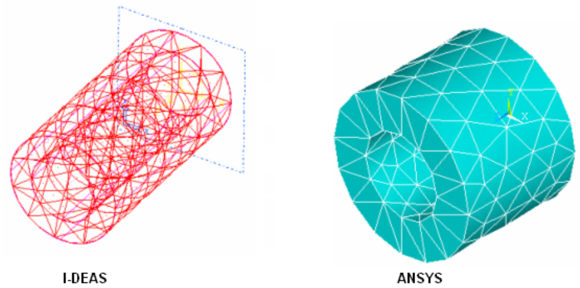

Figure 10. Matrix Meshing

Effect of % of Fiber Breakage Content on Modulus

- In case of fiber breakage, Model divides into two parts. One part is the broken part and another part is the unbroken part as shown in Fig 11.
- The broken part calculation of diameter of fiber is based on that vf_broken as shown in equation 10[7]. Where vf_broken is the contributing volume of fiber at that cross section.

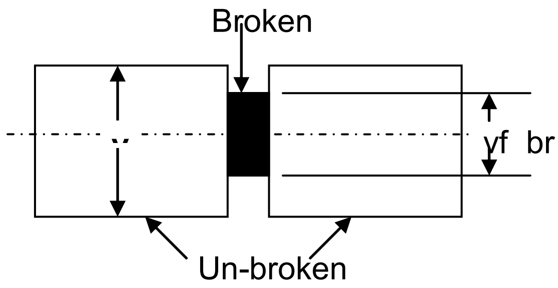

Figure 11. Percentage of breakage in fiber

$$v_{f\_broken} = (1-\rho_v)v_f$$

Assume, d = 100 mm

$$D = \sqrt{\frac{d^2}{v_{f\_broken}}}$$

Now, keeping D as constant and calculate d for different value of percentage of broken fiber by using equation 10.

$$d = \sqrt{D^2 v_f} \text{ ....} \textbf{Equation 10}$$

- While in unbroken part calculation of diameter is based on vf (actual volume fraction of fiber) as same as in case of Longitudinal Loading. Half-Half part is the unbroken on the both side and dimension and fiber content same on both parts so simulation of any one part required thus extruded length of second model is the half of the actual length.
- Following the same methodology for solving the models, the results obtained in broken part for displacement, state of stress in RVE and stresses in individual constituents as shown in Fig 12 to 15 for I-DEAS and Fig 16 to 18 for ANSYS.

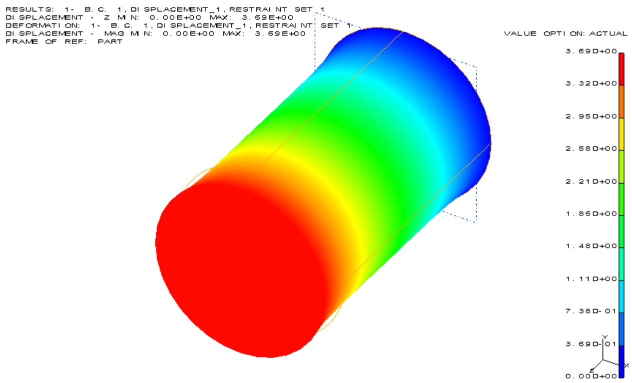

Figure 12. Displacement in Z-Direction (broken part)

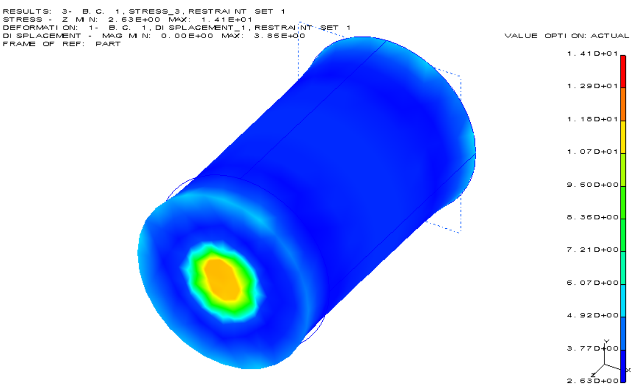

Figure 13. Combine stress of both fiber and matrix (broken part)

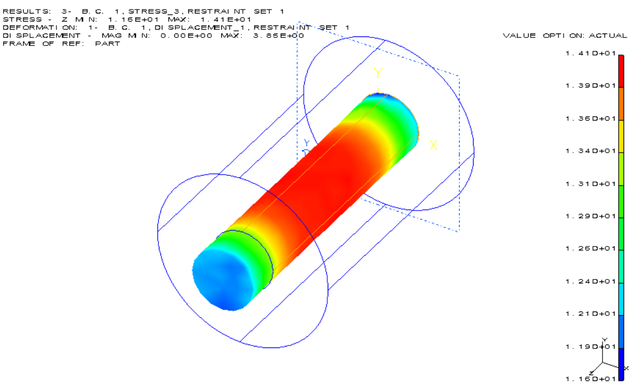

Figure 14. Fiber strength (broken part)

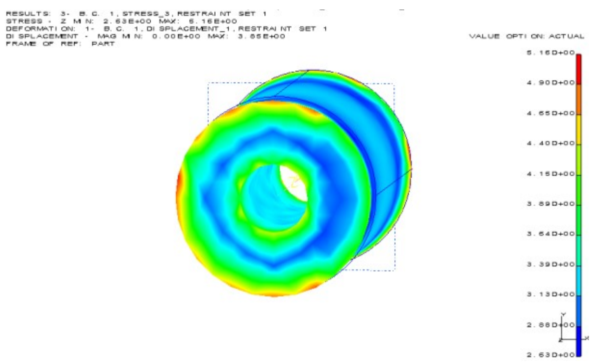

Figure 15. Matrix strength (broken part)

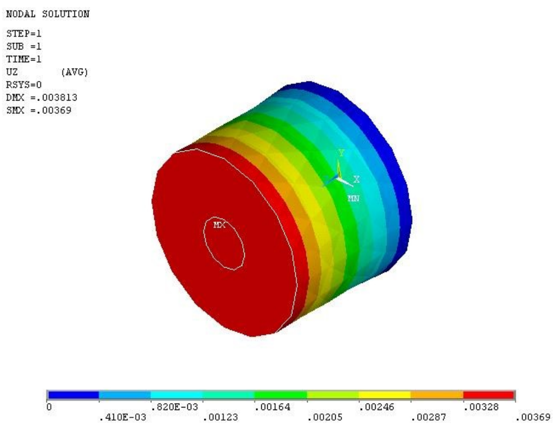

Figure 16. Displacement in Z-Direction (broken part)

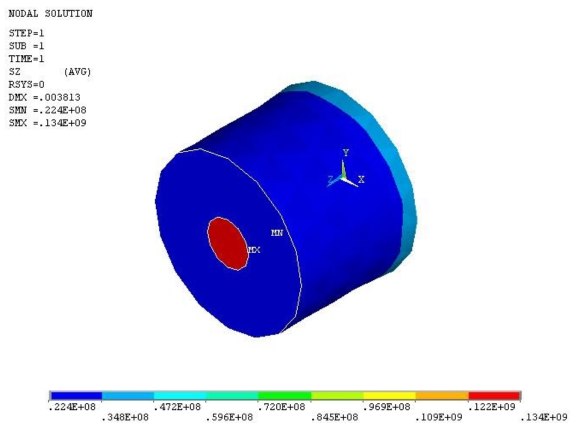

Figure 17. Fiber strength (broken part)

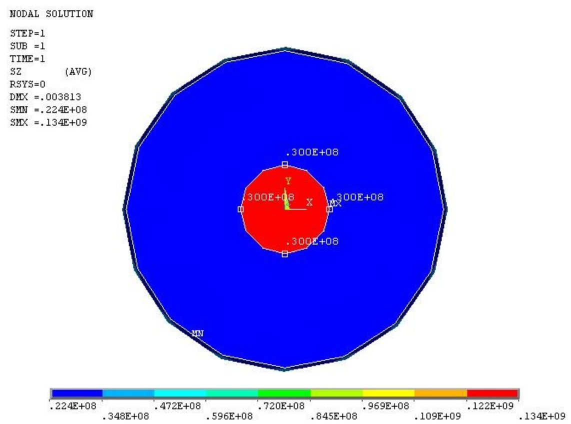

Figure 18. Matrix strength (broken part)

- Similarly, the results obtained in unbroken part for displacement, state of stress in RVE and stresses in individual constituents as shown in Fig 19 to 22 for I-DEAS and Fig 23 to 25 for ANSYS.

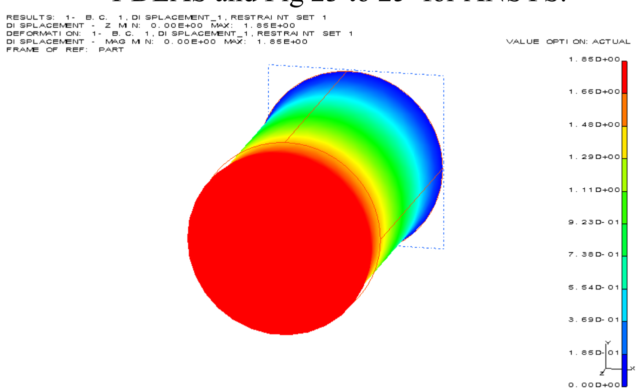

Figure 19. Displacement in Z-Direction (unbroken part)

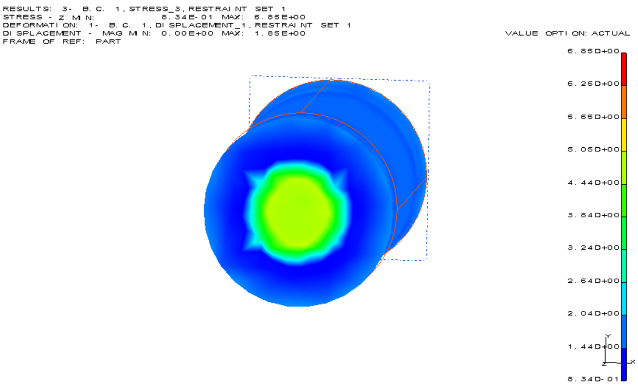

Figure 20. combine stress of both fiber and matrix (unbroken part)

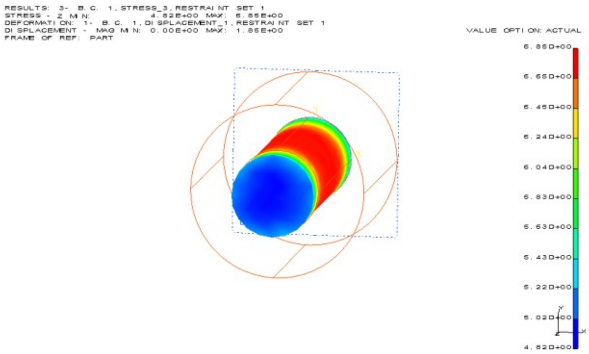

Figure 21. Fiber strength (unbroken part)

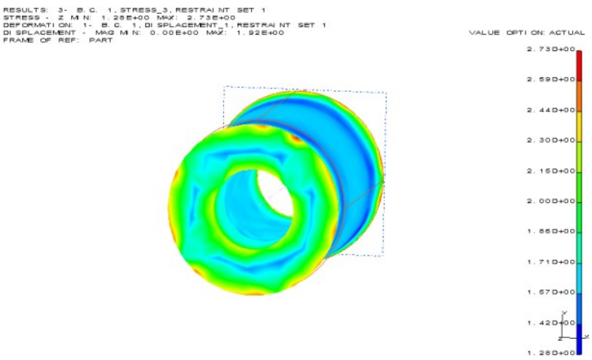

Figure 22. Matrix strength (unbroken part)

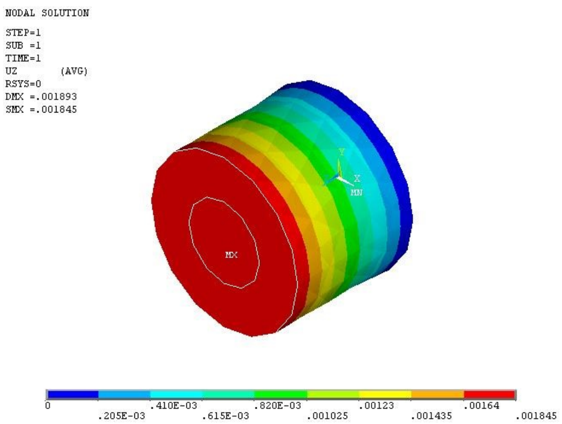

Figure 23. Displacement in Z-Direction (unbroken part)

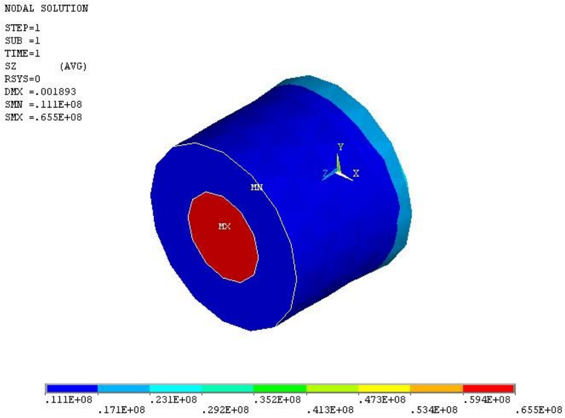

Figure 24. Fiber strength (unbroken part)

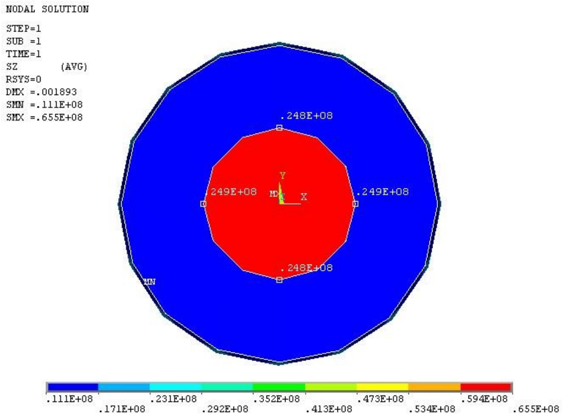

Figure 25. Matrix strength (unbroken part)

Calculation procedure of Modulus of FRP is by using equation 11.

$$E_c = E_{f\_broken} V_{f\_broken} + E_{f\_unbroken} V_{f\_unbroken} + E_m V_m$$

$$E_{f\_broken} = \frac{\sigma_{f\_broken}}{\varepsilon}$$

$$E_{f\_unbroken} = \frac{\sigma_{f\_unbroken}}{\varepsilon}$$

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

σ_{f_broken} is the maximum fiber strength at broken part

$\sigma_{f\_unbroken}$ is the maximum fiber strength at unbroken part

ε is the experimental strain of composite

Equation 11

III. RESULTS AND DISCUSSION

The characteristics of FRP material using Jute and Polyester is as a constituent. The experimental results obtained for breakage in fiber bundles attempted during the course of work is described below

EFFECT OF % of Fiber Breakage Content on Modulus

1. Fig. 26 shows the variation of Modulus E_c as a function of percentage of broken fiber for long aligned fiber composite subjected to longitudinal loading for constant v_f content of 22%. It is observed that as ratio of broken to total fibers decreases Modulus decreases with linearly. Usually as broken fiber increases, the effective reinforcement decrease this reduces contribution of reinforcement in a linear manner which is quite in tune with the observation made by Abu [7].

2. Fig.27 and 28 shows the comparative results of theoretical Models and FEA packages predicted values of Modulus respectively as a function of percentage of broken fiber for long aligned fiber composite subjected to longitudinal loading with experimental results. It is obvious that theoretical and package simulations 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 29 shows the loss in Modulus as a function of percentage of broken fiber. The loss in Modulus increases as percentage of broken fiber increase because reduction factor in fiber contribution R_s is function of β, fraction of broken fiber (ρ_v), aspect ratio (L/d), maximum shear strength (τ_{max}) which gives less effect at low fraction of broken fiber and therefore the variation of 0-0.3 for fraction of broken fiber cause opposite zone for packages and model, therefore overall loss is obtained is more in case of packages.. The loss predicted by FEA packages is high compare to theoretical model. The losses observed as (23.74-33.16) % in Abu-Farsakh model and in FEA packages, (31.70-35.45)% in I-DEAS and (30.38-34.40) % in ANSYS as fiber breakage varies from 30 to 75 %.
4. Fig. 30 shows the loss constants m and c for different models and FEA packages. In Abu-Farsakh model constant m is high and cis low compare to software packages I-DEAS and ANSYS. Loss constant m is positive for theoretical model and software packages means loss increases as fiber breakage increase. Loss constant c is also positive means over prediction of modulus.

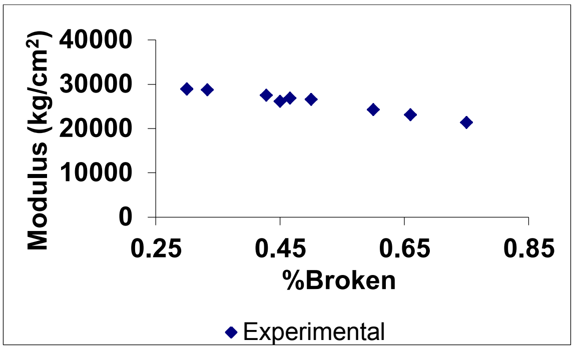

Figure 26. Effect of % of broken fibers on Modulus of continuous aligned fiber composite under longitudinal loading.

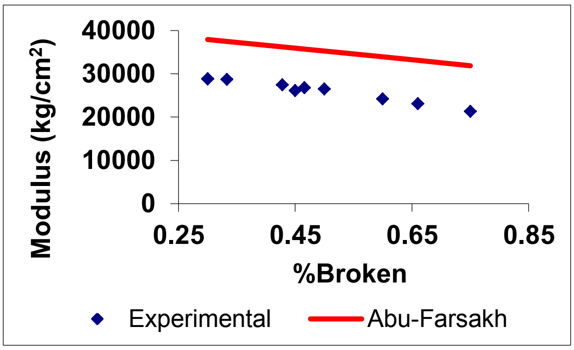

Figure 27. Comparative results of theoretically model predicted Modulus on continuous aligned broken fibers composite under longitudinal loading with experimental results.

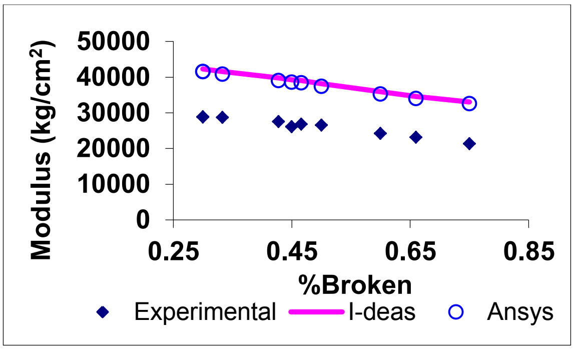

Figure 28. Comparative results of FEA package simulated Modulus on continuous aligned broken fibers composite under longitudinal loading with experimental results.

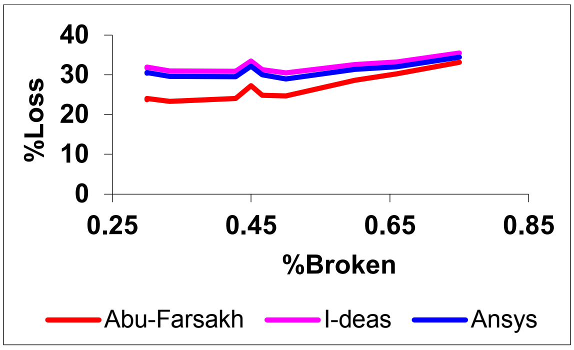

Figure 29. Comparative results of losses in modulus on continuous aligned broken fibers composite under longitudinal loading.

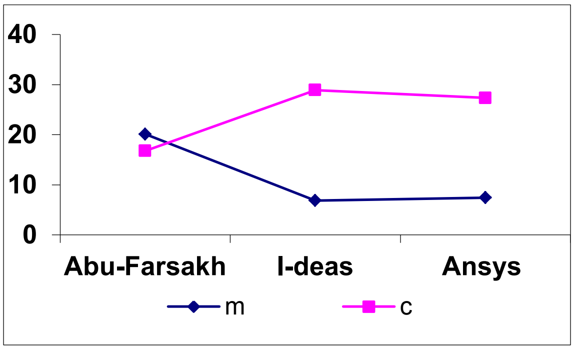

Figure 30. Comparative results of Linearity constants for Models & FEA packages on continuous aligned broken fibers composite under longitudinal loading.

IV. CONCLUSION

Based on the extensive experimental investigations on effect of breakage in fibers under longitudinal loading the following conclusions may be drawn:

The loss in Modulus of composite increases as the amount of broken fiber increases with linearly under longitudinal loading condition. The loss in modulus in terms of % of broken fiber (bf) is as showing in following forms.

a. Abu-Farsakh:%Loss=20.11(bf)+16.77
b. I-DEAS: %Loss=6.87(bf)+28.91
c. ANSYS: %Loss=7.44(bf)+27.35

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