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# Finite Element Analysis of Coir/Banana Fiber Reinforced Composite material

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## Abstract
*Natural fiber composites are termed as biocomposites or green composites. These fibers are green, biodegradable, and recyclable and have good properties such as low density and low cost when compared to synthetic fibers. The present work is investigated on the finite element analysis of the natural fiber (Coir/banana) composite material, processed by means of hand lay-up method. Composite beam material is composed of stalk-based fiber of maize and unsaturated epoxy resin polymer as matrix with methyl ethyl ketone peroxide (MEKP) as a catalyst and Cobalt Octoate as a promoter. The material was modeled and resembled as a representative volume element using suitable assumption and analyzed by means of finite element method using ANSYS software for determining the deflection and stress properties. From the results, it has been found that the finite element values are acceptable with proper assumptions, and the prepared natural fiber composite beam material can be used for structural engineering applications.*

## Keywords
*Coir, Fiber, Composite materials, Finite element method, FRP composites*

## I. Introduction
Natural fibers are becoming popular in recent times especially in composites sector because they have lot of advantages over traditional fibers in terms of low cost, low density, biodegradable and easily processed [1,2]. Natural fibers are mainly classified into plant fibers, animal fibers, and mineral fibers as shown in Figure 1. Most commonly, composite materials have a bulk phase, which is continuous, called the matrix, and one dispersed, noncontinuous, phase called the reinforcement, which is usually harder and stronger. The reinforcement material can be of fibers, particulates, or flakes. The concept of composites is that the bulk phase accepts the load over a large surface area and transfers it to the reinforcement, which being stiffer, increases the strength of the composite. In biocomposites, natural fiber act as reinforcement material and the matrix material can be of synthetic polymer or a biopolymer [3]. Natural fibers are cheap, abundant, and renewable and can be produced at low cost in many parts of the developing world. They are strong and stiff, and due to their low densities, it has the potential to produce composites with similar specific properties to those of E-glass fibers [4].

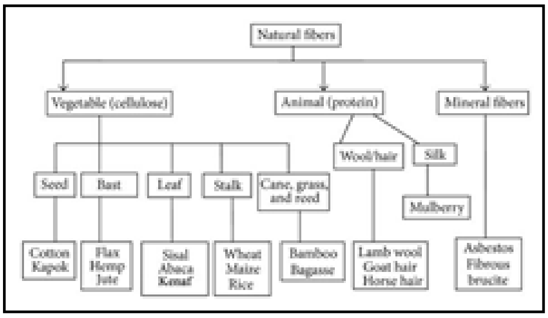


Fig.1: Classification of Natural Fibers

Natural fibre composites (biocomposites) are primarily composed combination of cellulose, hemicellulose, and lignin, which can be derived not only from leaf (e.g., sisal), bast (e.g., flax and hemp), seed (e.g., cotton), and fruit (e.g., coir), but also from other sources such as chicken feathers [1, 2], and these natural fibres offera number of advantages over existing synthetic fibres (e.g., carbon and aramid fibres). From an environmental perspective, natural fibres are biodegradable and are carbon positive since they absorb more carbon dioxide than they produce. Natural fibres also possess a number of advantages in terms of specific material properties as shown in Table 1. The bast and leaf fibres lend mechanical support to the plants stem or leaf, respectively; examples for these kinds of fibres include flax, hemp, jute, and ramie.

Table 1: Few Properties of Natural and Synthetic fibers

| Fibers | Density (g/cm$^3$) | Tensile strength (MPa) | E-modulus (GPa) | Elongation at failure (%) | Moisture absorption |
|---|---|---|---|---|---|
| E-glass | 2.55 | 2400–3500 | 73 | 3 | — |
| Aramid | 1.4 | 3000–3450 | 63–67 | 3.3–3.7 | — |
| Carbon | 1.4 | 4000 | 230–240 | 1.4–1.8 | — |
| Flax | 1.4 | 800–1500 | 60–80 | 1.2–1.6 | 7 |
| Hemp | 1.4 | 550–900 | 70 | 1.6 | 8 |
| Jute | 1.46 | 400–800 | 10–30 | 1.8 | 12 |
| Ramie | 1.5 | 500 | 44 | 2 | 12–17 |
| Coir | 1.25 | 220 | 6 | 15–25 | 10 |
| Sisal | 1.33 | 600–700 | 38 | 2-3 | 11 |
| Cotton | 1.51 | 400 | 12 | 3–10 | 8–25 |

The surfaces of natural fibres are uneven and rough which provides good adhesion to the matrix in a composite material. The specific mechanical properties of natural fibres have high significance for their utilization in composites. In natural fibre-reinforced composites, fibre acts as reinforcement and exhibits high tensile strength and stiffness. The mechanical properties of reinforcement (fibres) have direct relation with the tensile strength and stiffness of the composite. The selection of suitable reinforcing fibres follows certain criteria such as, thermal stability, fibre-matrix adhesion, long time behavior, elongation at failure, and moreover price and processing costs. The majority of biocomposites presently used are in the automotive, construction, furniture, and packaging industries. The techniques used to manufacture biocomposites are based largely on existing techniques for processing plastics or composite materials. These include press moulding, hand lay-up, filament winding, pultrusion, extrusion, injection moulding, compression moulding, resin transfer moulding, and sheet moulding compound methods.
Composite materials used for structural purposes often have low densities, resulting in high stiffness to weight and high strength to weight ratios when compared to traditional engineering materials [5]. In addition, the high fatigue strength to weight ratio and fatigue damage tolerance of many composites also makes an attractive option. Composite mechanical properties are strongly influenced by the mechanical properties, distribution of the fibers, and matrix, and well as the efficiency of stress transfer between these two

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components [6]. Polymer composites are widely used in many major engineering structural applications. The matrix serves for mainly two important purposes; namely, it bonds the fibrous phase, and under an applied force, it deforms and distributes the stress to the high-modulus fibrous constituent [7]. The ultimate properties of the composites depend on many properties such as constituents, size, and shape of the individual reinforcing fibres or particles, structural arrangement and distribution, relative amount of each constituent, and the interface between matrix and reinforcement [8, 9].

## II. Methodology

Fiber composites consist of fiber and matrix phases, and the mechanical behavior of the composites is much determined by the fiber and matrix properties. Microstructures such as fiber shape, fiber array, and volume fraction of fibers are also more important in determining the mechanical properties [10]. Micromechanical models have been used to predict the properties starting from the intrinsic properties and their constituents, and these models show that the fibre strength is not being completely employed as a result of poor fibre matrix interfacial adhesion and fiber length.

The material id modelled using certain assumptions and analysed for mechanical properties with finite element method software (ANSYS). The composite material is assigned as unidirectional composite by assuming some properties that are given below. Some of the assumptions used for the analysis work have been gathered by literature.

1. Fibers are not porus.
2. Material properties of all the constituents are attributed as isotropic material for both voolumes.
3. Fibers are uniform in properties with diameter.
4. Interphase bonding is maintained between fiber and matrix.
5. Perfect bond between fiber and matrix and no slippage.
6. Fibers are arranged in unidirectional manner and perfectly aligned.
7. Composite material is free of voids.

The composite material consists of fibres aligned in unidirectional manner and modelled as a regular uniform arrangement. It is assumed that the fiber and matrix materials are linearly elastic. A unit cell is adopted for the analysis. The measure of the volume of fiber relative to that total volume of the composite is taken from the cross- sectional areas of the fiber relative to the total cross-sectional area of the unit cell. This fraction is considered as an important parameter in composite materials and is called fiber volume fraction ($V_f$).

### Material Properties

The materials properties that were used for the calculation of the Elastic properties of the resin/banana composite are listed in table 8.1. The properties of resin are taken from experimental results and banana properties from commercially available grade.

Table 2: Material Properties of constituents for FEA

| S.No | Material | Young's Modulus E (MPa) | Poisson's Ratio |
|---|---|---|---|
| 1 | Epoxy Resin | 35000 | 0.35 |
| 2 | Coir Fiber | 4500 | 0.3 |
| 3 | Banana fiber | 3480 | 0.3 |

### Finite Element Model

In the study of the Micromechanics of fiber reinforced materials, it is convenient to use an orthogonal coordinate system that has one axis aligned with the fiber direction. The 1-2-3 Coordinate system shown in Figure 3 is used to study the behavior of unit cell. The 1 axis is aligned with the fiber direction, the 2 axis is in the plane of the unit cell and perpendicular to the fibers and the 3 axis is perpendicular to the plane of the unit cell and is also perpendicular to the fibers. The isolated unit cell behaves as a part of large array of unit cells by satisfying the conditions that the boundaries of the isolated unit cell remain plane.

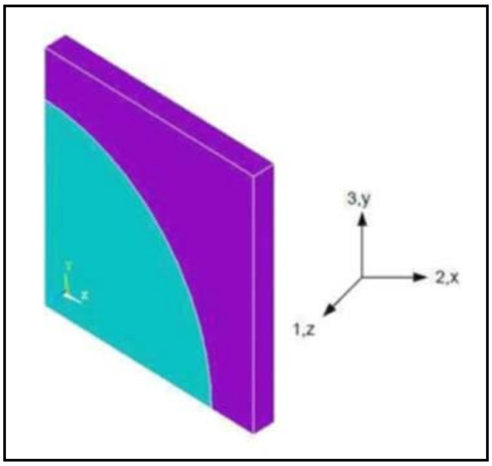



Fig. 2: One fourth portion of Unit cell

Due to symmetry in the geometry, material and loading of unit cell with respect to 1-2-3 coordinate system it is assumed that one fourth of the unit cell is sufficient to carry out the present analysis. The 3D Finite Element mesh on one fourth portion of the unit cell is shown in Figure 4.

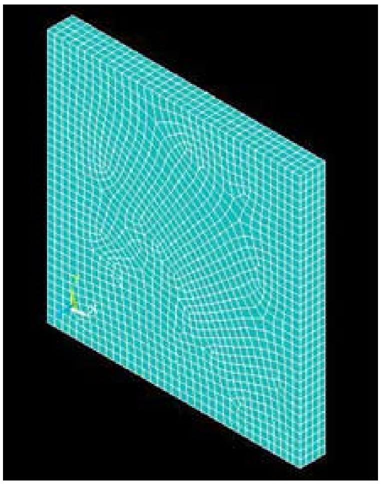


Fig. 3: Finite Element Mesh Model

### Geometry

The dimensions of the finite element model are taken as:
X = 100 units,
Y = 100 units,
Z = 10 units.
The radius of fiber is calculated is varied to the corresponding fiber volume.

### Element Type

The element SOLID 20 node 186 of ANSYS V15.0 used for present analysis is based on a general 3D state of stress and is suited for modeling 3D solid structure under 3D loading. SOLID 20 node 186 is a higher-order version of the 3D 20-node solid element that exhibits quadratic displacement behavior. It can tolerate irregular shapes without as much loss of accuracy. SOLID186 elements have compatible displacement shapes and are well suited to model curved boundaries. SOLID186 has plasticity, creep, stress stiffening, large deflection, and large strain capabilities. The element has 20 nodes having one degree of freedom, i.e., temperature and with three degrees of freedom at each node: translation in the node X, Y, Z directions respectively.

### Boundary Conditions

Due to symmetry of the problem, the following symmetric boundary conditions are used:

At X = 0, $U_x = 0$

At Y = 0, $U_y = 0$

At Z = 0, $U_z = 0$

In addition, the following multi point constraints are used.

- The $U_x$ of all the nodes on the area at X=100 is same.
- The $U_y$ of all the nodes on the area at Y=100 is same.
- The $U_z$ of all the nodes on the area at Z=10 is same.

### Results

In the present work finite element analysis has been carried out to predict the engineering constants of uniform and random distribution fibers in fibre reinforced particulate composite. The results obtained are validated with the results obtained by Rule of Mixtures and Halpin-Tsai.

### Analysis of $E_1$, $E_2$ and $E_3$ values

Tensile modulus, flexural modulus and transverse modulus are analysed with the help of Finite Element Software Named ANSYS 15. The analysis draws the following behaviour with Kenaf fiber and Epoxy matrix at various volume fractions.

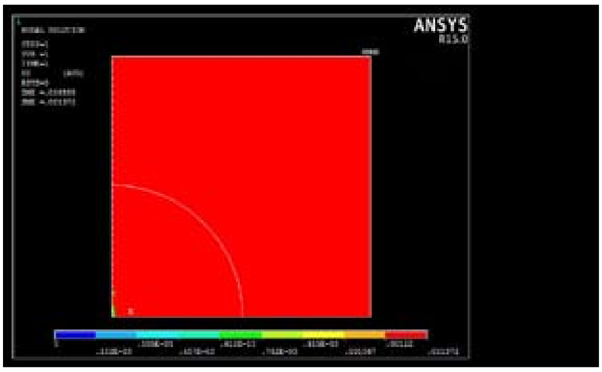



Fig. 4: $E_1$ analysis at 0.05 $V_f$

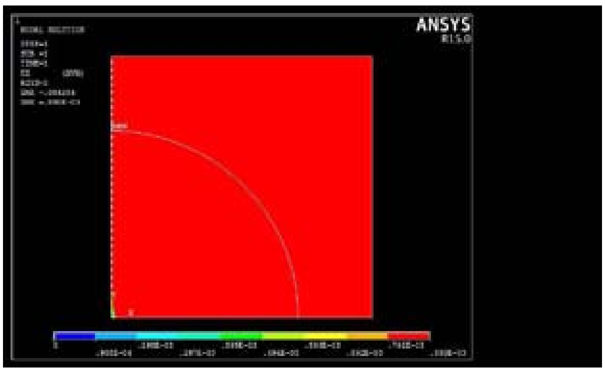



Fig. 5: $E_1$ analysis at 0.1 $V_f$

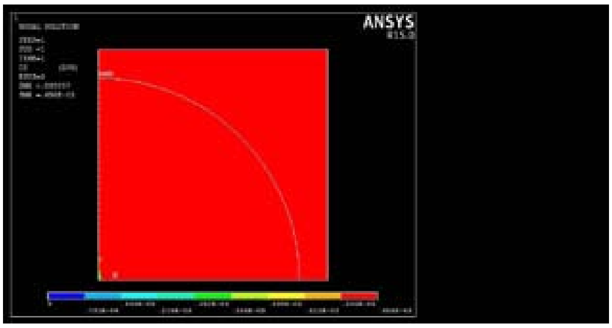



Fig. 6: $E_1$ analysis at 0.15 $V_f$

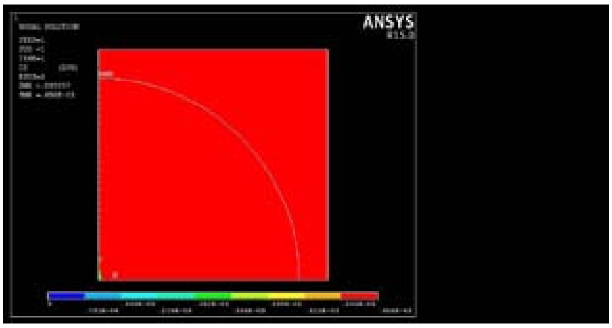



Fig. 7: $E_1$ analysis at 0.2 $V_f$

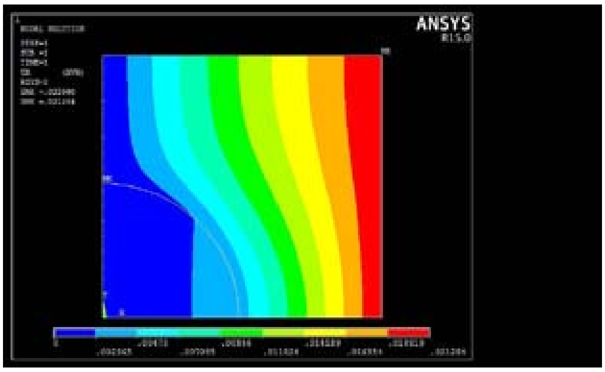



Fig. 8: $E_2$ analysis at 0.05 $V_f$

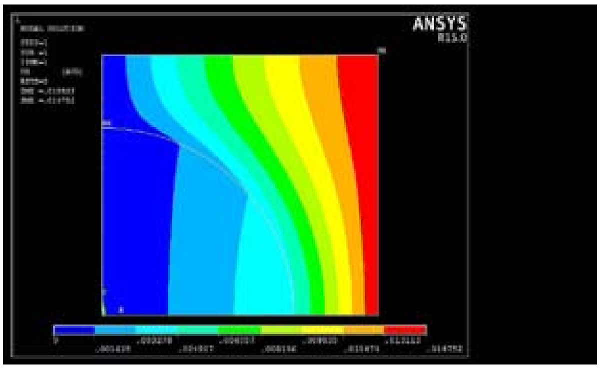



Fig.9: $E_2$ analysis at 0.1 $V_f$

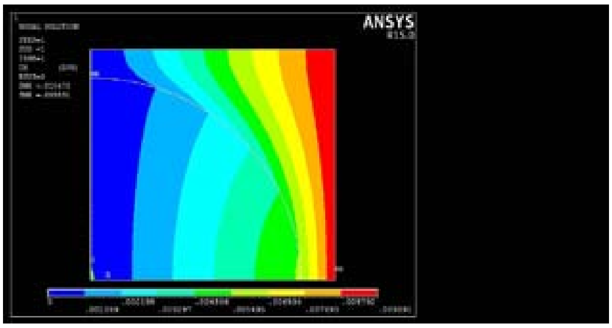



Fig.10: $E_2$ analysis at 0.15 $V_f$

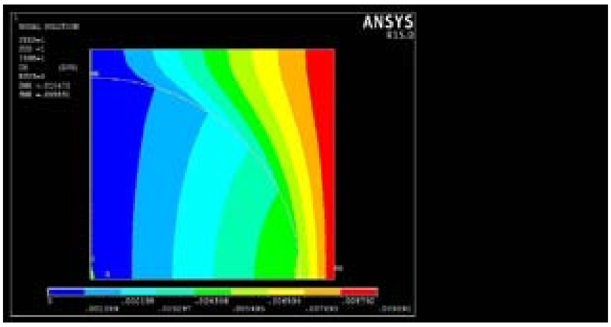



Fig. 11: $E_2$ analysis at 0.2 $V_f$

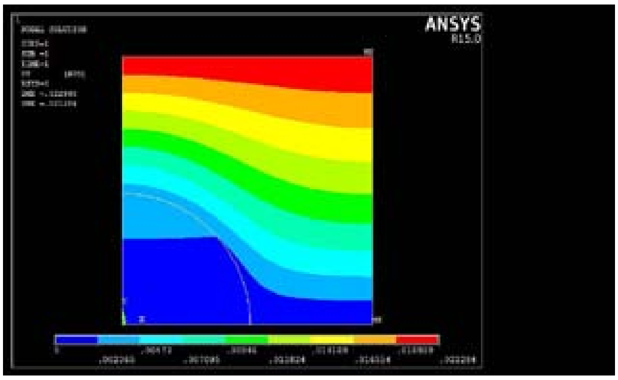



Fig.12: $E_3$ analysis at 0.05 $V_f$

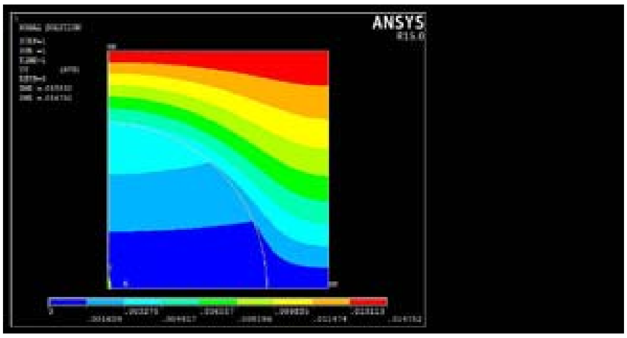



Fig. 13: $E_3$ analysis at0.1 $V_f$

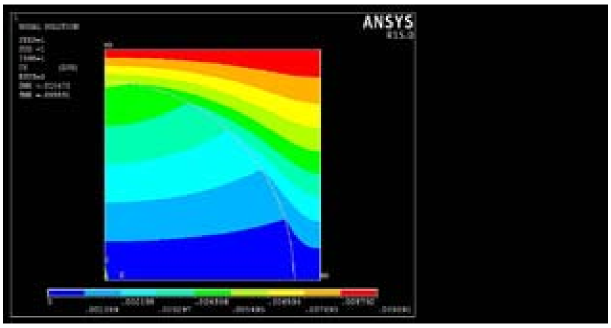



Fig.14: $E_3$ analysis at 0.15$V_f$

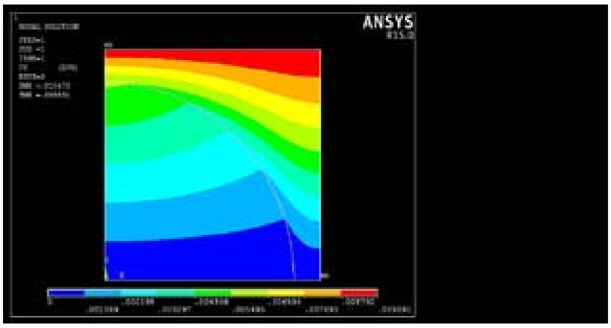
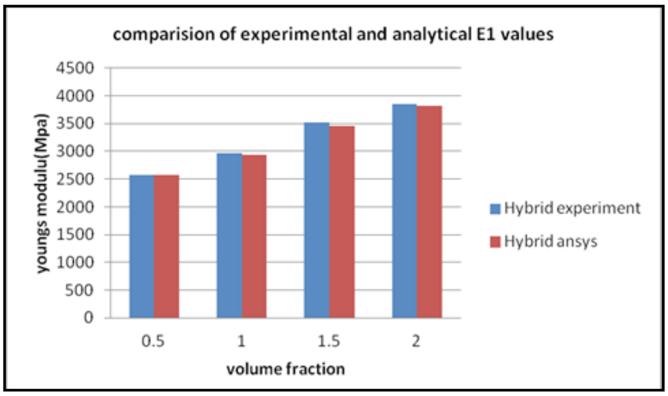



Fig.15: $E_3$ analysis at0.2$V_f$

Table 1.2 :Comparison values of E1 for all fiber configurations

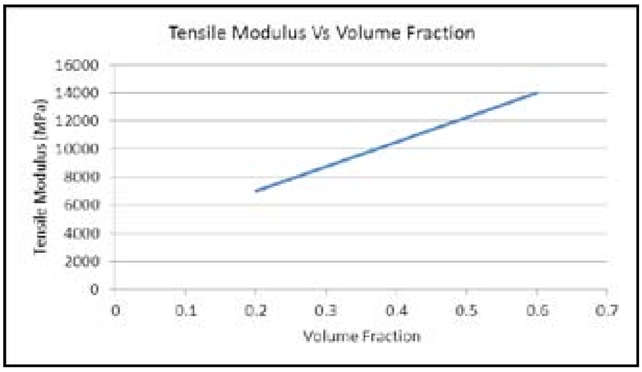
| S.No | Fiber Volume Fraction | Coir Tensile Modulus ($E_1$) (MPa) | | Banana Tensile Modulus ($E_1$) (MPa) | | Hybrid Tensile Modulus ($E_1$) (MPa) | |
|---|---|---|---|---|---|---|---|
| | | Experiment | Ansys | Experiment | Ansys | Experiment | Ansys |
| 1 | **0.05** | 2245 | 2244.9 | 1858 | 1858 | 2581 | 2580.5 |
| 2 | **0.1** | 2669 | 2668.7 | 2218 | 2217.5 | 2961 | 2940.3 |
| 3 | **0.15** | 3021 | 3020.6 | 2619 | 2618.7 | 3513 | 3449.7 |
| 4 | **0.2** | 3248 | 3247.5 | 2913 | 2912.6 | 3845 | 3820.6 |



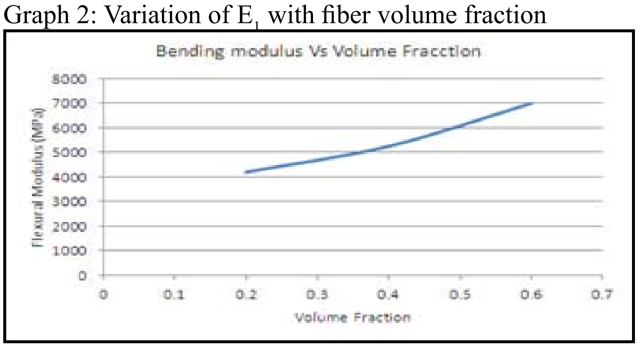

Graph 1: Comparison plot of tensile modulus for different fiber configurations.

**Uniform distribution of fiber (coir/banana) in an FRP composite**

The variation of different engineering constants of a uniform distribution of Kenaf fiber/Epoxy composite with respect to the different volume fractions is shown.




Graph 2: Variation of $E_1$ with fiber volume fraction




Graph 3: Variation of $E_2$ with fiber volume fraction

The variation of longitudinal Young's modulus ($E_1$) with respect to volume fraction of fiber is observed. The response of E1 of composite material is increasing in linear manner with the variation of fiber content ($V_f$). This is due to the improvement in stiffness of resulting composite material. The variation of Transverse modulus

($E_2$) following the same trend as that of longitudinal modulus but in nonlinear way.

## Conclusion

From the FEM Analysis, it is confirmed that there is a possibility of reducing the stress concentration in the matrix and fiber interphase by increasing the fiber content. More stress deviation in the fiber, matrix and the interphase regions of the composite leads to changes of fiber de-bonding. Finite element method software simulation reveals that there is need to have certain assumptions for the perfect bonding and also to define interphase properties. In the present method, the model is validated using some assumptions because natural fibers are anisotropy, porosity and the interphase, whose volume will vary with different conditions and fiber arrangements. Hence the obtained values are Predicted values.

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