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NUMERICAL ANALYSIS OF TENSILE PROPERTIES OF UNIDIRCECTIONAL COIR FIBER REINFORCED EPOXY COMPOSITE LAMINATE

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Abstract

In this paper numerical analysis of obtaining tensile strength properties of unidirectionally arranged coconut fiber reinforced epoxy composite laminate is discussed. Micromechanical analysis techniques are used to determine the elastic constants which are used as input to determine the stress and strain values. The strength and mechanical properties of the composite laminate can be predicted by knowing the stress strain values by using finite element analysis software. The stress-strain values are determined using empirical models. The empirical results have slight deviation from real time model because of different environmental conditions and this can be validated by performing the experimental testing of the composite laminate. Here the finite element analysis is carried out by considering the composite material as layered element and stress- strain values are computed using ANSYS software.

Key Words: FRP Composite, Coir Fiber, Numerical Analysis

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1. Introduction to FRP Composite

Composite is a structural material composed of mixture of two or more materials which are mixed or bonded together. Fiber reinforced composite (FRP) consists of fibers as reinforcement material embedded in the matrix phase. The matrix holds the reinforcement fibers together to form the required shape of the composite material. The new material obtained will have superior properties than the individual constituent itself and is replacement for few conventional materials.

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1.1 Coir fiber as reinforcement material

Coconut fibers are naturally occurring plant fibers extracted from coconut tree (Cocus Nucifera) which is abundantly available in Southern India. Coconut fiber or coir is the natural fiber of coconut husk where it is a thick and coarse but durable fiber. It is relatively water proof and has resistance to damage by salt water and microbial degradation [1].The husk consists of Coir fiber and a corky tissue called pith. It consists of water, fibers and small amounts of soluble solids. Because of the high lignin content coir is more durable when compared to other natural fibers. With increasing emphasis on fuel efficiency, natural fibers such as coir based composites enjoying wider applications in automobiles and railway coaches & buses for public transport system[2]. There are two types of coconut fibers, brown fiber extracted from matured coconuts and white fibers extracted from immature coconuts. Brown fibers are thick, strong and have high abrasion resistance. White fibers are smoother and finer, but weaker. Coconut fibers are commercially available in three forms, namely bristle (long fibers), mattress (relatively short) and decorticated (mixed fibers). These different types of fibers have different uses depending upon the requirement. In engineering, brown fibers are mostly used [3].

1.2 Epoxy resin as matrix material

Epoxy Resins have terminal epoxy groups and are made by condensation of epichlorohydrin and bisphenol-A. The polymerization/ cross-linking of epoxy resins isinitiated on adding primary or secondary tertiaryamines, amides, anhydrides, etc. Epoxy resins are regarded as campounds which contain more than one epoxy group, capable of beingconverted to cured (thermoset) form with the help of hardened curing agents. Most of the commercially available epoxy resins are formed by the reaction of Bisphenol-A (Diphenylol propane, DPP) and epichlorohydrin in the alkaline medium. Novolac epoxy resins are also commercially available now. The main features of these resins are that they maintain their properties at high temperatures and possess high heat deflection. The main features of these resins are that they maintain their properties at high temperatures and possess high heat deflection temperature (HDT) and high glass transition temperature. The presence of a phenolic backbone provides short-term thermal stability coupled with chemical versatility of epoxide group and also it has led to their manifold newer applications.

2. Micromechanical Analysis

Studying and analysing the mechanical behaviour of a composite material in terms of its constituents is called micromechanical analysis. In this approach we find the average properties of composite ply from the individual properties of the constituents. The average properties are derived by considering the ply to be homogeneous. At this level, one can optimize for the stiffness and strength requirements of a lamina. Rule of Mixtures is a method of approach to approximate

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estimation of composite material properties, based on an assumption that a composite property is the volume weighted average of the phases (matrix and dispersed phase) properties.

Table 1: Mechanical Properties of Coir fiber

SI No.	Physical Property	Value
1	Density	1150 kg/m^3
2	Elastic Modulus (Ef)	5000 Mpa
3.	Rigidity Modulus (Gf)	1892.4 Mpa
4.	Tensile Strength	150 Mpa

Table 2: Mechanical Properties of Epoxy Matrix

SI No.	Physical Property	Value
1	Density	1100 kg/ m3
2	Elastic Modulus (Em)	3100 Mpa
3.	Rigidity Modulus (Gm)	1250 Mpa
4.	Tensile strength	85 Mpa

3. Strength of Materials Approach

In this approach we consider a representative volume element (RVE) of a unidirectional lamina, which consists of the fiber surrounded by the matrix.

Assumptions:

1) The bond between the fibers and matrix is perfect.
2) The elastic moduli, diameters and space between fibers are uniform.
3) The fibers are continuous and parallel.
4) The fibers and matrix follow Hooke's Law i.e. they are linearly elastic
5) The fibers possess uniform strength.
6) The composite is free of voids

Longitudinal Young's modulus (E1) which is the modulus of composite along the fiber direction is given by

$$E_1 = \sigma_1/\varepsilon_1 = E_f * V_f + E_m * V_m$$

Transverse Young's modulus (E2) which is the modulus of composite along the fiber direction is given by

$$E_2 = \sigma_2/\varepsilon_2 = (E_f * E_m) / (V_f * E_m + V_m * E_f)$$

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Major Poisson's Ratio is given by

$$\nu_{12} = \nu_f * V_F + \nu_m * V_m$$

Minor Poisson's Ratio is given by

$$\nu_{21} = \nu_{12} * (E_2/E_1)$$

$$\nu_{23} = \nu_{12} * (1- \nu_{21}) / (1- \nu_{12})$$

In plane Shear Modulus is determined as

$$G_{12} = (G_f * G_m) / (V_f * G_m + G_f * V_f)$$

$$G_{23} = E_2 / 2* (1+ \nu_{23})$$

4. Halphin-Tsai Semi Empirical Models:

Halphin-Tsai model is a mathematical model for the prediction of elasticity of compositematerial based on the geometry and orientation of the fiber and the elastic properties ofthe fiber and matrix. The model is based on the self-consistent field method althoughoften consider to be empirical.The values obtained for transverse Young's modulus and in plane shear modulus through rule of mixture method do not agree well with experimental results. This establishes a need for better modeling techniques. These techniques include numerical methods such as finite element method, finite difference, and boundary element methods, elasticity solution and variational principal models. Unfortunately, these models are available as complicated equations or in graphical form. Due to these difficulties, semiempirical models have been developed for design purposes. The most useful of these semi empirical models include those of Halphin and Tsai, since they can be used over a wide range of elastic properties and fiber volume fractions.

Halphin and Tsai developed their models as simple equations by curve fitting to results that are based on elasticity. The equations are semi empirical in nature since involved parameters in the curve fitting carry physical meaning.

4.1 Longitudinal Young's modulus:

The Halphin-Tsai equation for the longitudinal Young's modulus is same as thatobtained through strength of materials approach, that is,

$$E_1 = \sigma_1/\varepsilon_1 = E_f * V_f + E_m * V_m$$

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4.2 Transverse Young's modulus:

E2, is given by

$E_2/E_m = (1+\xi *\eta *V_f)/ (1-\eta *V_f)$

where $\eta = ((E_f/E_m)-1)/ ((E_f/E_m) +\xi)$

ξ is called reinforcing factor which depends upon fiber geometry, packing geometry and loading conditions.

For example, for a fiber geometry of circular fibers in a packing geometry of a square array, $\xi = 2$. For a rectangular fiber cross-section of length a, width b in a hexagonal array, $\xi = 2(a/b)$, where b is in the direction of loading.

There fore

In-Plane shear modulus is given by

G_{12} is $G_{12}/G_m= (1+\xi\eta V_f)/ (1-\eta V_f)$

Elastic constants for composite can be tabulated as detailed below.

Table 3: Elastic Constants

Fiber Volume Fraction (%Vol)	Longitudinal Young's Modulus (E1) Mpa		Transverse Young's Modulus (E2) Mpa		Shear Modulus (G12) Mpa	
	Strength of Material's Approach	Halphin-Tsai Model	Strength of Material's Approach	Halphin-Tsai Model	Strength of Material's Approach	Halphin-Tsai Model
5	3195	3195	3160	3502.87	1271.58	1275.8
7.5	3242.5	3242.5	3190.94	3739.86	1282.65	1288.92
10	3290	3290	3222.45	4006.47	1293.92	1302.17
12.5	3337.5	3337.5	3254.6	4308.6	1305.39	1315.56
15	3385	3385	3287.38	4653.95	1317.06	1329.08

Table 4: Poisson's Ratios

Fiber Volume Fraction (%Vol)	Major Poisson's Ratio ν12	Minor Poisson's Ratio ν21	Minor Poisson's Ratio ν23
5	0.3725	0.3684	0.3749
7.5	0.3838	0.3776	0.3876
10	0.3950	0.3869	0.4002
12.5	0.4063	0.3962	0.4132
15	0.4175	0.4055	0.4261

5. FINITE ELEMENT ANALYSIS OF LAMINATE PLY:

A structure made of composite materials is generally a laminate structure made of various laminas stacked on each other. Knowing the macro mechanics of a single lamina, one develops the macro mechanics of a laminate. A lamina (also called a ply or layer) is a single flat layer of unidirectional fibers or woven fibers arranged in a matrix. A laminate is constructed by stacking a number of such laminas in the direction of the lamina thickness. Mechanical structures made of these

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laminates, such as a leaf spring suspension system in an automobile, are subjected to various loads, such as bending and twisting. The design and analysis of such laminated structures demands knowledge of the stresses and strains in the laminate. Also, design tools, such as failure theories, stiffness models, and optimization algorithms, need the values of these laminate stresses and strains. Here, the finite element analysis of laminate is carried out to determine the stresses and strains induced in the laminate under various loading conditions.

Stress- Strain analysis of Coir/epoxy composite is carried out using ANSYS 15.0 software and SHELL 281 element is used for the analysis. Fiber volume fractions are varied considerably for different loading conditions to obtain desirable results.

Longitudinal tensile test can be simulated using finite element analysis for the composite laminate. A simple rectangular cross-sectional area of required dimensions is created and the real constants like number of layers, layer thickness and fiber orientations are provided for the Shell element used for the analysis. In this longitudinal tensile test, all fibers are oriented in 0 degrees with respect to the laminar axis. Model is constrained at the fixed end by all degrees of freedom and a tensile load is applied at the free end.

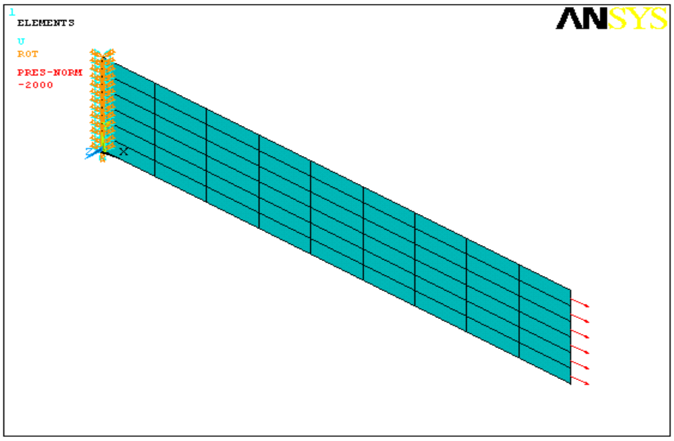

Figure1: Boundary and loading conditions for tensile test

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5.1 STRESS VS STRAIN GRAPHS FOR DIFFERENT FIBER VOLUME FRACTIONS

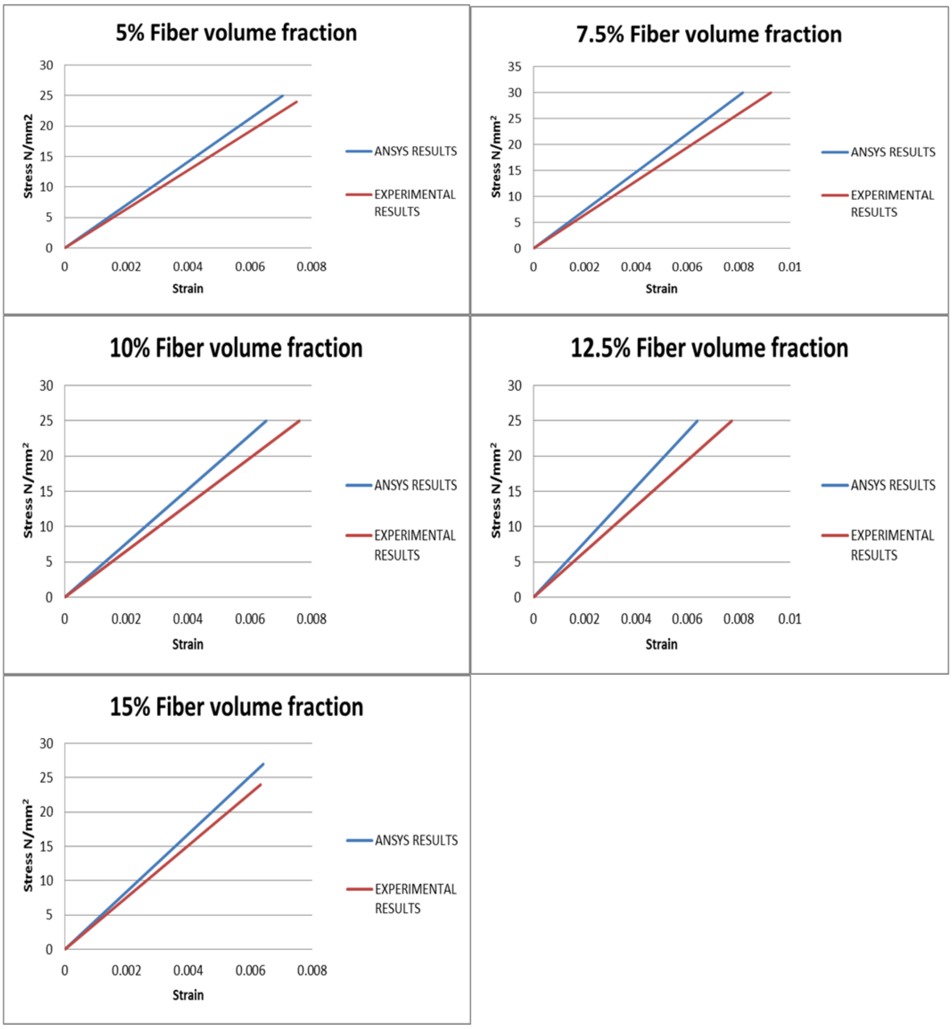

Figure2: Stress-Strain graph for different fiber volume fractions

6. Conclusion

From the results we can conclude that finite element analysis can be used as one of the methods to determine the composite properties. The advantage of finite element over the experimental method is that specimen model may not be prepared and broken. Hence cost of manufacturing a specimen for testing can be avoided. Small deviations are observed in the comparison due to presence of residual stress, voids, and inclusions in the specimen also due to moisture absorption by the specimen when it is experimentally tested. Hence the values of elastic properties and overall strength of composite determined by experimental testing will be comparatively less compared to finite element analysis.

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