Prediction of Micromechanical Behaviour of Elliptical Frp Composites

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Abstract - One of the tools using to evaluate longitudinal and transverse properties of composite materials is Micromechanics method. The present work deals with the evaluation of longitudinal and Transverse Young's modulus and corresponding Poisson's Ratio's of elliptical fiber which are reinforced in epoxy matrix. The finite element method is used to perform the micromechanical analysis of the composite material. The effects of volume fraction on the mechanical properties of composite materials are estimated. The problem is modelled by using Three-dimensional finite element method with governing boundary conditions. The aspect ratio of the elliptical fiber is taken as 1.5 and the reinforcement volume fraction is varied from 0.1 to 0.5. The finite element software ANSYS has been successfully executed to evaluate the material properties.

Keywords- Micromechanics, ANSYS, Aspect ratio

I. INTRODUCTION

The Mechanics of Materials deals with stresses, strains and deformations in engineering structures subjected to mechanical and thermal loads. A common assumption in the mechanics of conventional materials such as steel and aluminum is that they are homogeneous and isotropic continua. For a homogeneous material, properties do not depend on the location and for an isotropic material; properties are same in all the directions. Fiber reinforced composites on the other hand are microscopically inhomogeneous and orthotropic. As a result the mechanics of fiber reinforced composites are far more complex than that of conventional materials. In the present investigation an effort has been made to quantify the effect of mismatch in the Young's modulus ratio in fiber and matrix materials on the longitudinal and transverse mechanical properties of the composite.

A good number of publications are available on this topic, which indicates the importance and necessity of the micromechanics analysis of the fiber reinforced composites.

II. LITERATURE REVIEW

Zheng-Ming Huang [1] has implemented a micromechanics model to simulate the overall thermal – mechanical properties of a fibrous composite out of an elastic deformation range. This micromechanics model is called the bridging model. Appropriately calibrated with experimental data can therefore inform composite design by identifying suitable constituent materials, their contents, and their geometrical arrangements.

Alfredo Balaco de Morais [2] investigated that, a closed form of micro mechanical equation for predicating the transverse modulus E2 of continuous fiber reinforced polymers. The equation was derived from a relatively simple mechanics materials analysis of a repeating square cell. Theocaris [3] calculated the effective transverse elastic modulii for fiber reinforced composites by a numerical homogenization approach. Akser [4] used Finite Element Analysis to investigate the effect of thermal and transverse mechanical loading on the SiC/Ti-6 Al-4V composite system. The effect on the stress field of a carbon coating on the Sic fibers is also investigated. Robertson [5] has performed the parametric study of various fiber-matrix interface conditions. Analysis methods included both a simplified one dimensional mathematical model and a Finite Element Analysis using MSC/NASTRAN.

Anifantis [6] studied that, variations in topology, material properties and adhesion characteristics, the micro mechanical stress states developed within fibrous composite that contain a heterogeneous interface region has been predicted numerically. The formulation of a generalized computational simulation developed to treat specific features of these materials yields stress predications using a finite-element approximation. Tandon [7] has evaluated the interfacial normal strength in unidirectional SCS-0 / epoxy composites by using single fiber specimens. These model specimens are incrementally loaded in tension to failure with a specially built loading device mounted on the straining stage of a microscope. Asp [8] investigated that the failure initiation in polymer-matrix composites loaded transverse to the fibers by a numerical parametric study where effects of constituent properties, interface properties and thickness are examined. Failure initiation in the matrix is only studied, interfacial debonding is not considered.

Qing Wang [9] has presented in situ strain measurement is performed at a submicron scale using a newly developed micromechanics technique SIEM (Speckle Interferometer with Electron Microscopy). The global mechanical response of metal-matrix composite and transverse tension is related with the micro mechanical behavior of the interface. Nimmer [10] investigated that, analytical models are presented and are used to explore the mechanics of transversely loaded and high temperature composites with a thermally induced residual stress field and vanishingly weak fiber-matrix interface strength. The specific interest in this investigation is the existence of a distinctive, bilinear characteristic of the transverse stress strain curve for composite of moderate fiber volume fraction in which the coefficient of thermal expansion of the matrix is larger than the fiber and the interface strength is vanishingly weak. The effects of fiber and matrix properties, interface friction and fiber volume content are examined. Sun [11] established a vigorous mechanics foundation for using a Representative Volume Element (RVE) to predict the mechanical properties of unidirectional fiber composites. The effective elastic modulii of composite are determined finite- element analysis of the RVE.

The aim of the current work is to predict longitudinal modulus (E_1), Transverse modulus (E_2 and E_3) and Poisson's ratios of three different fiber reinforced plastic lamina for a variable volume fraction of reinforcement using micromechanics approach.

III. PROBLEM MODELLING

A. Geometry:

The dimensions of the finite element model are taken as X=100 units, Y=100 units, Z=10 units. The elliptical fiber volume fraction is varying from 10% to 50% and aspect ratio a/b=1.5 Fig (1, 2 & 3).

B. Element Type:

The element used for the present analysis is SOLID 95 of ANSYS which is developed based on three-dimensional elasticity theory and is defined by 20 nodes having three degrees of freedom at each node: translation in the node x, y and z directions.

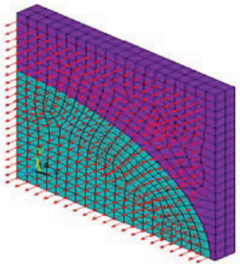

Fig: 1 FE mesh on E_1 model

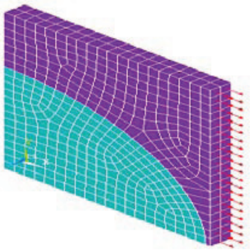

Fig: 2 FE mesh on E_2 model

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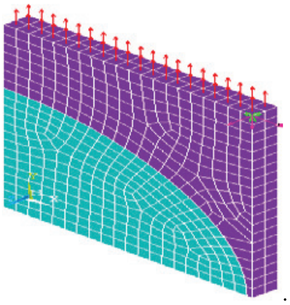

Fig: 3 FE mesh on E_3 model

C. Loading:

Uniform Tensile load of 1 MPa is applied on the area at z = 10 units for E_1. (Fig.1)
Uniform Tensile load of 1 MPa is applied on the area at x =100 units for E_2. (Fig.2)
Uniform Tensile load of 1 MPa is applied on the area at y= 100 units for E_3. (Fig.3)

D. Boundary conditions:

Due to the symmetry of the problem, the following symmetric boundary conditions are used. At x = 0, Ux = 0; At y = 0, Uy = 0; At z = 0, Uz = 0. In addition the following multi point constraints are used. The Ux of all the nodes on the line at x = 100 is same The Uy of all the nodes on the line at y =100 is same. The Uz of all the nodes on the line at z = 10 is same.

IV. MATERIAL PROPERTIES

The material properties to carry out the present work are listed below
AS-4(carbon fiber) :E_1=235(Gpa), $E_2 = E_3$ =15(Gpa), $\nu_{12}=\nu_{13}$=0.2,ν_{23}=0.07,
$G_{12}=G_{13}$=27(Gpa),G_{23}=7(Gpa),
T-300(carbon fiber):E_1=230(Gpa),$E_2=E_3$ =15(Gpa), $\nu_{12} = \nu_{13}$ =0.2, ν_{23} =0.07,
$G_{12}=G_{13}$ =27(Gpa), G_{23} =7(Gpa),
Kevlar49 Aramid: E_1=131(Gpa), $E_2 = E_3$ =7(Gpa), $\nu_{12} = \nu_{13}$ = 0.33, ν_{23} =0.04, $G_{12}=G_{13}$=21(Gpa),G_{23}=7(Gpa),
Epoxy (matrix) : E_1=3100, ν =0.35,

V. VALIDATION

The present finite element method is validated by using analytical equations. The longitudinal Young's modulus is compared with Rule of mixture (ROM). The following table shows the closeness between analytical and FEM results.

	AS-Carbon/epoxy		T-300/epoxy		Kevlar/epoxy	
Vf	FEM (GPa)	ROM (GPa)	FEM (GPa)	ROM (GPa)	FEM (GPa)	ROM (GPa)
0.1	26.2	26.2	25.79	25.79	15.88	15.89
0.2	49.4	49.4	48.47	48.48	28.67	28.68
0.3	72.6	72.6	71.18	71.17	41.46	41.47
0.4	95.8	95.8	93.87	93.86	54.25	54.26
0.5	119	119	116.58	116.55	67.05	67.05

VI. DISCUSSION ON RESULTS

The 3D FE model is validated by comparing the longitudinal Young's modulus predicted from FEM with the value of from Rule of mixtures, which is accurate for unidirectional continuous fiber reinforced composite lamina, and the results are in very good agreement. From (Fig. 4), it is observed that the value of E_1 increases proportionately with the increase in volume fraction of the fiber. This is due to increase in stiffness of the resulting composite because of the increasing the fiber volume fraction. The same trend is observed for three different fiber (T-300, Kevlar, AS-carbon) reinforced composites. The longitudinal Young's modulus of AS-carbon reinforced composite is high. There is a decrease in ν_{12} and ν_{13} with the increase in Volume fraction (v_f) of the fiber. (Figs. 5&6). This is due to the un-symmetric fiber about longitudinal axis resulting in reduction of 2-3-directional strains. The Kevlar reinforced composite showed high longitudinal strain because of its lower longitudinal stiffness than other two composites. The in-plane transverse young's modulus E_2 is observed to be increasing with respect to increase in the v_f (Fig. 7). The variation of v_{21} and v_{23} are progressively decreasing with respect to increase in the volume fraction of the fiber (Fig. 8 and 9). The out-of-plane transverse young's modulus E_3 is observed to be increasing with v_f (Fig. 10). The values of v_{31} and v_{32} are observed to be gradually decreasing with respect to increase in v_f (Fig. 11 and 12). The reasons explained for longitudinal load are valid in other two cases also.

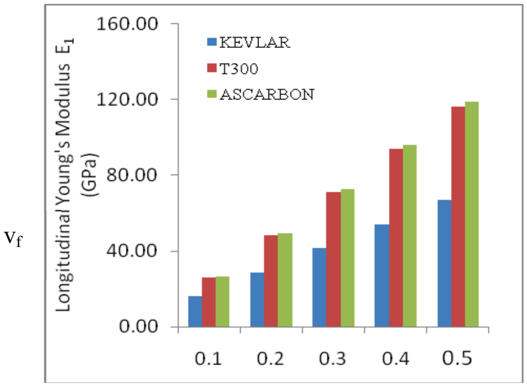

Fig. 4 Variation of E_1 with v_f

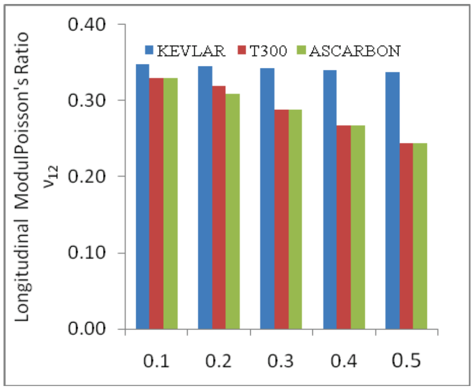

Fig. 5 Variation of v12 with vf

v_f

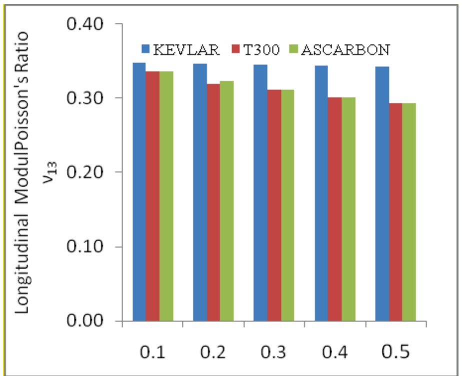

Fig. 6 Variation of v13 with vf

v_f

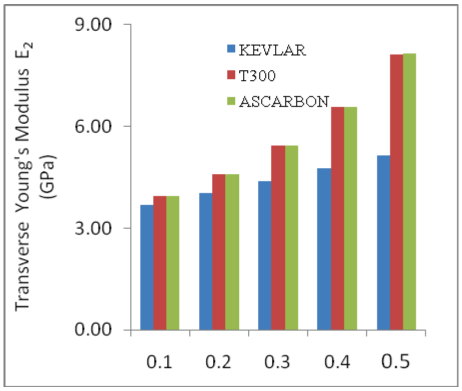

Fig. 7 Variation of E2 with vf

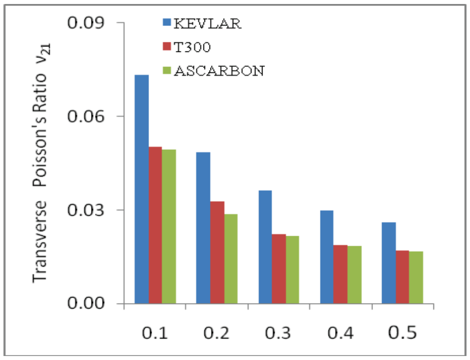

Fig. 8 Variation of v_{21} with v_f

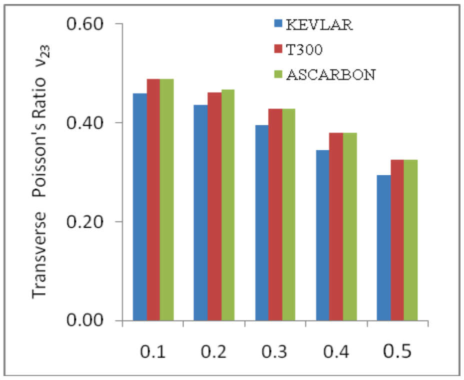

Fig. 9 Variation of v23 with vf

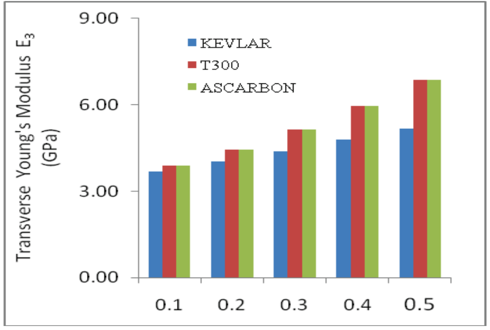

Fig. 10 Variation of E3 with vf

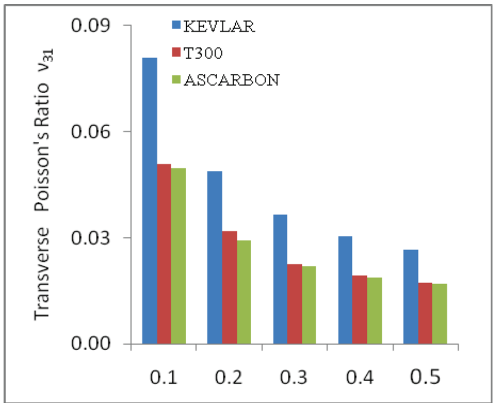

Fig. 11 Variation of v31 with vf

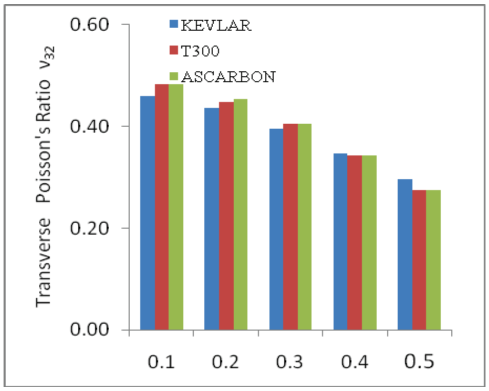

Fig. 12 Variation of ν_{32} with ν_f

VII. CONCLUSION

In the present investigation, the three different fibers with different Young's modulus of on the mechanical properties of a continuous unidirectional elliptical fiber reinforced composite lamina subjected to longitudinal and transverse loading has been studied. The Young's modulii E_1, E_2, E_3 increase with ν_f. AS-carbon reinforced composites are showing good properties than other Kevlar, T-300 composites.

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