academicJournals

Vol. 8(21), pp. 1161-1165, 9 June, 2013
DOI: 10.5897/IJPS2013.3938
ISSN 1992-1950 © 2013 Academic Journals
http://www.academicjournals.org/IJPS

International Journal of Physical Sciences

Full Length Research Paper

Effect of fiber size on elastic constants of hybrid elliptical fiber reinforced lamina

V. Srinivasa Sai[1], V. Bala Krishna Murthy[2]*, M. R. S. Satyanarayana[3] and G. Sambasiva Rao[2]

[1]Department of Mechanical Engineering, DVR and Dr. HS MIC College of Technology, Kanchakacharla, A.P. India.
[2]Department of Mechanical Engineering V. R. Siddhartha Engineering College, Vijayawada, A.P. India.
[3]Department of Mechanical Engineering, GITAM University, Visakhapatnam, A. P. India

Accepted 3 June, 2013

Micromechanical analysis of an fiber reinforced polymer (FRP) lamina consisting of unequal sizes of unidirectional continuous elliptical fibers of two different materials arranged in hexagonal pattern is the present subject. The objective is to observe the change in Young's modulii and Poisson's ratios due to change in volume fractions and ellipse aspect ratio 'a' of individual fibers in a Representative Volume Element (RVE) without altering the total reinforcement share. A three-dimensional finite element model is developed and solved. Two different fiber materials (T-300 and S-Glass) are embedded in hexagonal pattern in a polymer matrix. The problem is simulated in ANSYS software. The converged results are validated using rule of mixtures which works exactly for longitudinal Young's modulus. It is observed that the longitudinal Young's modulus increases with increase in volume fraction of T-300 fiber and does not change due to 'a'. The transverse modulii decrease with increase in size of T-300 fiber and affected by variation of 'a'. Increasing in 'a' increases E_2 and decreases E_3.

Key words: Hybrid, fiber reinforced polymer (FRP), finite element method (FEM), micromechanics, elliptical fiber.

INTRODUCTION

The mechanical properties of an fiber reinforced polymer (FRP) composite depend upon fiber material, its size, shape and arrangement in matrix. Authors of this present work intend to obtain a wide range of mechanical properties of a unidirectional continuous fiber reinforced composite lamina by selecting two different fibers of elliptical cross-section arranged in hexagonal pattern with a provision to change ellipse aspect ratio and size of individual fibers. The brief review of literature relevant to the present topic is presented in the following paragraphs.

Noteworthy works of earlier researchers Eshelby (1957), Hashin (1962), Hill (1963, 1965), Hashin and Shtrikman (1963a) and Hashin and Rosen (1964). Hashin and Shtrikman (1963b) used variational principles to obtain upper and lower bounds for the effective elastic modulii as well as the effective electrical and thermal conductivities of multiphase composites with quasi-isotropic global characteristics. Later on, Milton (1981, 1982) obtained higher-order bounds for the elastic, electromagnetic, and transport properties of two-component macroscopically homogenous and isotropic composites given the properties of the individual constituents. More recently, Drugan and Willis (1996) and Drugan (2003), employed the Hashin–Shtrikman variational principles to analyze two-phase composites with random microstructure. A numerical implementation of this work was carried out by Segurado and Llorca

*Corresponding author. E-mail: vbkmpublications@yahoo.com.

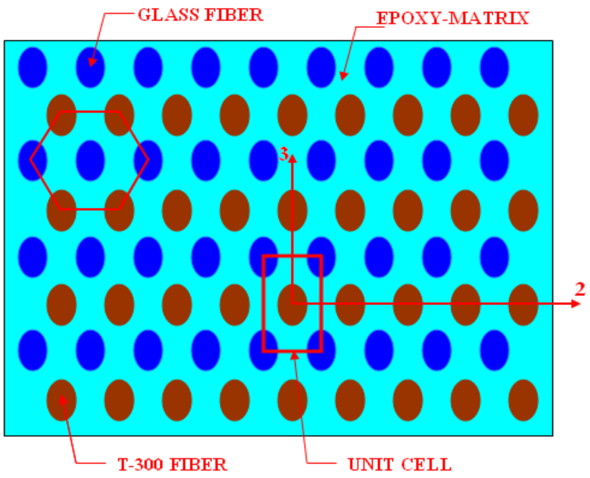

Figure 1. Hybrid composite lamina.

(2002). Other significant early results can be found in the work of Budiansky (1965) and Russel (1973). Mori and Tanaka (1973) in their micromechanical approach obtained closed-form expressions for the elastic properties of two-phase composites. Ying and Kin (2002) proposed a simple life prediction model for the hybrid composite.

Most recently Srinivasa Sai et al. (2010, 2011, 2012, 2013a and b) performed micromechanical analysis of hybrid elliptical fiber reinforced composite for the prediction of elastic properties and fiber-matrix interface stresses. The effects of fiber volume fraction and ellipse aspect ratio on the behaviour of hybrid lamina were studied. The present research work is the extension of Srinivasa Sai et al. (2013b) to study the effect of individual fiber volume fractions on Young's modulii and Poisson's ratios of hybrid composite for a constant total fiber percentage of 50.

METHODOLOGY

Hexagonal array of unit cells

Hexagonal arrangement of elliptical fibers of two different materials in alternative rows in a matrix is shown in Figure 1. It is assumed that the fiber and matrix materials are linearly elastic. A unit cell is adopted for the analysis. The fiber volume fraction V_f is calculated as the cross-sectional area of the fibers relative to the total cross sectional area of the unit cell since third dimension is same for all constituents for the unidirectional continuous fiber reinforced composite. A material coordinate system 1-2-3 is assigned as shown in Figure 1 for the analysis of the problem. 1) is the longitudinal direction of the fiber, 2) the in-plane transverse direction and 3) through-thickness or out-of-plane transverse direction.

Finite element model

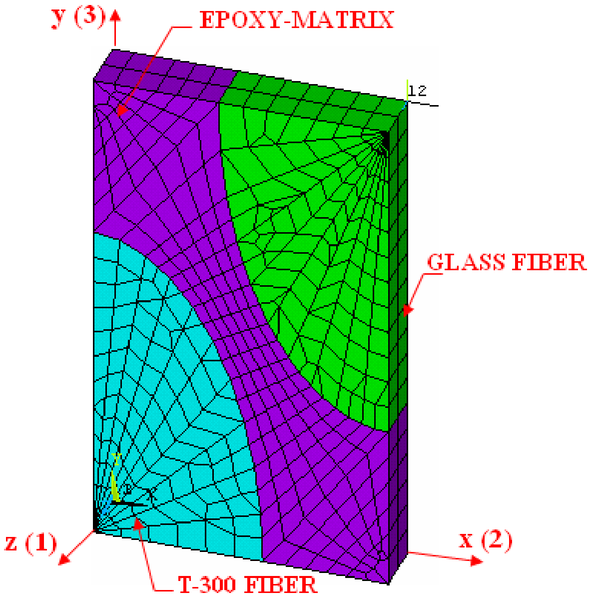

Figure 2. FE mesh on one-eighth portion of the unit cell (one quarter in cross section and half in length direction).

One-eighth portion of the unit cell (that is, one quarter in the cross section and one-half in the longitudinal direction of the fiber) is modeled by taking the advantage of symmetry in geometry, material and loading (Figure 2). The element named SOLID 95 in ANSYS software is used for finite element generation. This is a quadratic brick element having 20 nodes with 3- degrees of freedom (linear displacement components) at each node. This element uses three-dimensional elasticity theory while preparing element matrices. The dimensions of FE model are taken as 50, 86.6 and 10 units in x- y- and z- directions respectively. The dimensions of ellipse are obtained according to the fiber volume fraction and the ellipse aspect ratio ('a'= axis length in 3-direction by axis length in 2-direction).

Boundary conditions and loading

Three perpendicular planes on negative side of coordinate axes are constrained to restrict displacement in normal directions. The opposite faces are constrained to have uniform normal displacement. A uni-axial external load is applied once at a time with respect to the assigned material coordinates in order to use simple Hooke's law to determine Young's modulii. Corresponding Poisson's ratios are also calculated.

Materials

One of the fibers that is, T-300 is orthotropic and other S-Glass fiber and matrix materials are isotropic. The mechanical properties of the constituent materials used in the present analysis are given in Table 1.

RESULTS

The finite element software ANSYS is successfully executed for the analysis. The elastic properties are

Table 1. Mechanical properties of the constituent materials.

Property	T-300 fiber	S-Glass fiber	HM polymer matrix
E_1 (GPa)	220.60	85.50	5.17
E_2 (GPa)	13.79	85.50	5.17
E_3 (GPa)	13.79	85.50	5.17
v_{12}	0.20	0.20	0.35
v_{23}	0.25	0.20	0.35
v_{13}	0.20	0.20	0.35
G_{12} (GPa)	8.96	35.62	1.91
G_{23} (GPa)	4.83	35.62	1.91
G_{13} (GPa)	8.96	35.62	1.91

Table 2. Validation of E_1 (MPa).

V_{f1} + V_{f2}	ROM	FEM	% Variation
5+45	52090	52129	0.076
10+40	58845	58884	0.067
15+35	65600	65640	0.061
20+30	72355	72396	0.056
25+25	79110	79150	0.051
35+15	85865	85905	0.046
40+10	92620	92660	0.043
45+5	99375	99413	0.039

evaluated using the normal strains in 1, 2 and 3 directions calculated from the normal deformations of the unit cell obtained from finite element analysis. The displacements in x, y and z directions, U_x, U_y and U_z respectively of the finite element model are obtained from the finite element solutions. The corresponding normal strains are determined from the displacements. The longitudinal Young's moduli and Poisson's ratios due to the longitudinal load are determined from the following expressions.

$$E_1=\sigma_1/\varepsilon_1 \quad v_{12}= - \varepsilon_2/ \varepsilon_1 \quad v_{13}= - \varepsilon_3/ \varepsilon_1$$

where 1(z), 2(x) and 3(y) are longitudinal, in-plane transverse and out-of-plane transverse directions respectively of the composite lamina. Remaining properties are obtained in similar fashion for in-plane and out-of-plane transverse loads. The results are obtained for hybrid lamina with varying volume fractions of individual fibers for a total fiber volume fraction of 50%.

Validation

The converged finite element results are validated for the longitudinal Young's modulus using rule of mixtures (ROM) which is an exact theoretical approach for unidirectional continuous fiber composites. The results are presented in Table 2 for various arrangements of fibers for 'a'=0.5. V_{f1} and V_{f2} are the volume fractions of T-300 and S-Glass fibers respectively. A very close agreement is observed between the FE and analytical results.

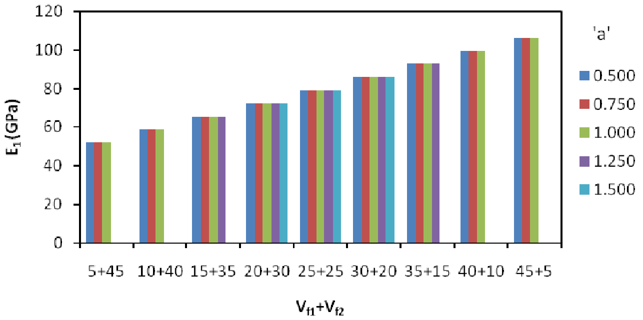

Figure 3. Variation of E_1 with respect to varying fiber volume fractions for different 'a'.

Analysis

It can be observed that E_1 linearly increases with respect to change in individual fiber volume fractions but not affected by 'a' (Figure 3). Which is expected since rule of mixtures does not take shape of fiber into account. v_{12} decreases and v_{13} increases with 'a' at larger rate for lower volume fractions of T-300 fiber and at smaller rate for smaller volume fractions of S-Glass fiber as shown in Figures 4 and 5. At 'a'=0.5 there is no considerable variation in these Poisson's ratios with respect to change in V_f of fibers. However, v_{12} increases up to certain extent followed by a slight drop for other values of 'a', whereas v_{13} variation is opposite to that of v_{12}.

Figures 6 and 7 show the variation of E_2 and E_3 respectively. E_2 and E_3 decease with increasing in size of T-300 fiber and decrease of S-Glass fiber. This is obvious since stiffness of glass fiber is greater than transverse stiffness of T-300 fiber. E_2 increases and E_3 decreases with 'a' at larger rate for small volume of T-300 fiber. Increase in 'a' increases reinforcement effect in 2-direction and decreases in 3- direction due to increase in projected area of ellipse normal to 2-direction. Figures 8 and 9 show the variation of Poisson's ratios v_{21} and v_{31}. These properties decrease with volume fraction changes. With respect to 'a', v_{21} increases at smaller volume fractions of T-300 fiber. At other places and for all values of 'a' these piosson's ratios are not changing

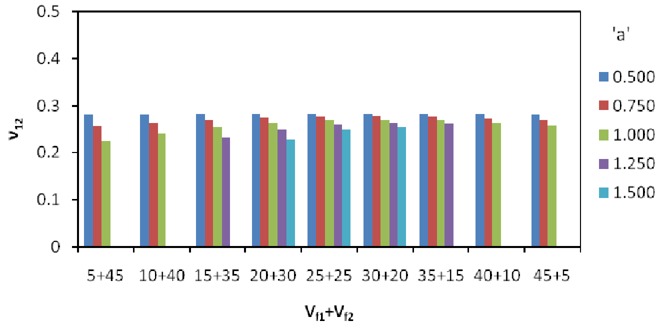

Figure 4. Variation of ν_{12} with respect to varying fiber volume fractions for different ‘a’.

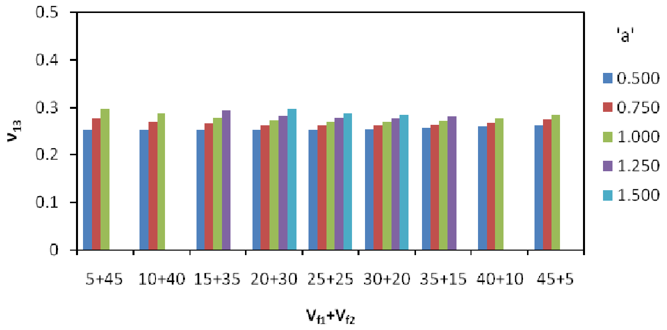

Figure 5. Variation of ν_{13} with respect to varying fiber volume fractions for different ‘a’.

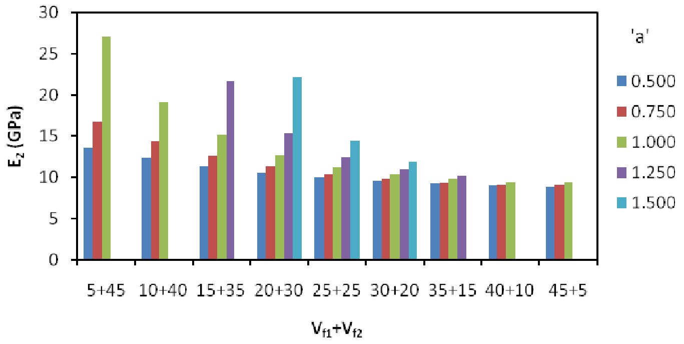

Figure 6. Variation of E_2 with respect to varying fiber volume fractions for different ‘a’.

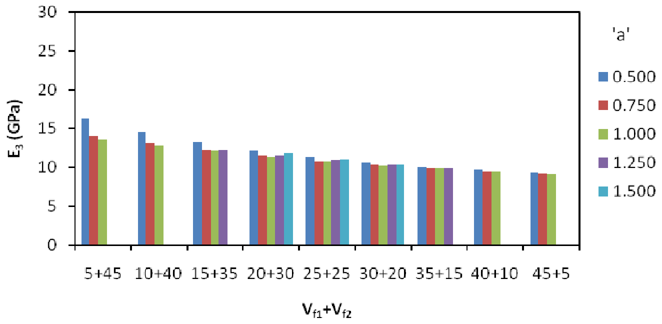

Figure 7. Variation of E_3 with respect to varying fiber volume fractions for different ‘a’.

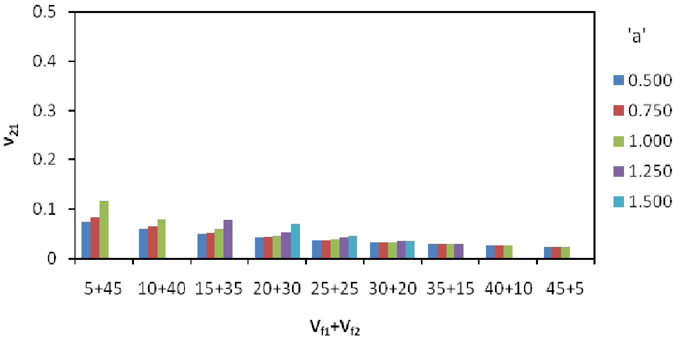

Figure 8. Variation of ν_{21} with respect to varying fiber volume fractions for different ‘a’.

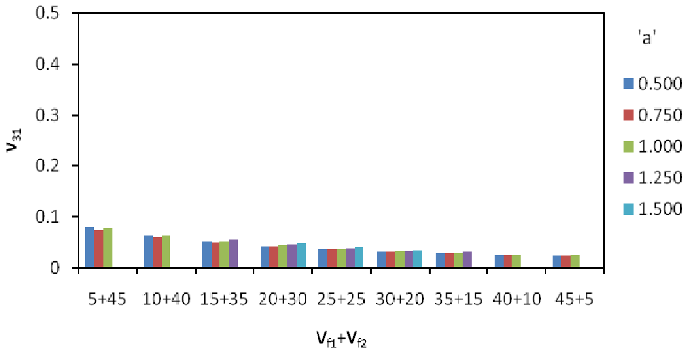

Figure 9. Variation of ν_{31} with respect to varying fiber volume fractions for different ‘a’.

considerably. Figures 10 and 11 show the variation of Poisson’s ratios ν_{23} and ν_{32}. These properties increases up to certain extent and decreases with respect to fiber volume fraction changes. ν_{23} increases with ‘a’ at lower volumes of T-300 fiber followed by negligible changes, whereas ν_{32} decreases with ‘a’. The reasons for the variation of Poisson’s ratios are similar to that explained for variation of Young’s modulii since the strains are taken from the same load cases.

Conclusions

Young’s modulii and Poisson’s ratios are predicted for an elliptical hybrid fiber reinforced composite lamina using three-dimensional finite element analysis. The effect of change in volume fractions of individual fibers and fiber cross-sectional aspect ratio on these elastic properties is studied. It is observed that this study gives a scope to

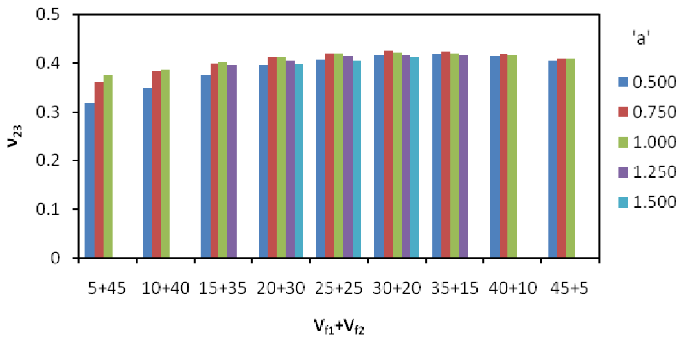

Figure 10. Variation of v_{23} with respect to varying fiber volume fractions for different 'a'.

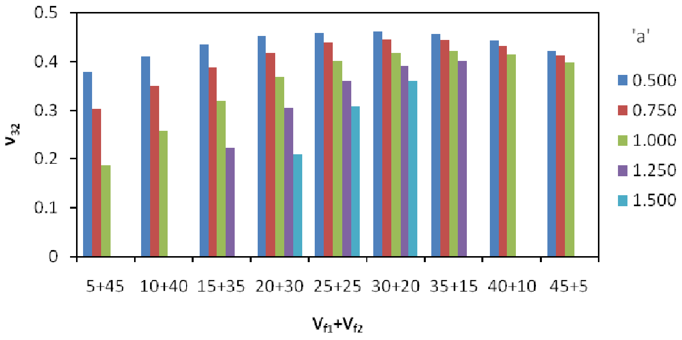

Figure 11. Variation of v_{32} with respect to varying fiber volume fractions for different 'a'.

obtain a wide range of elastic properties for selection of material as per design requirements.

REFERENCES

ANSYS Reference Manuals, 2008.
Budiansky B (1965). On the elastic modulii of some heterogeneous materials, J. Mech. Phys. Solids 13:223–227.
Drugan WJ, Willis JR (1996). A micromechanics-based non local constitutive equation and estimates of representative volume element size for elastic composites. J. Mech. Phys. Solids, 44(4):497–524.
Drugan WJ (2003). Two exact micromechanics-based non local constitutive equations for random linear elastic composite materials, J. Mech. Phys. Solids, 51(9):1745–1772.
Eshelby JD (1957). The determination of the elastic field of an ellipsoidal inclusion, and elated problems. Proc. Roy. Soc. A241:376–396.
Hashin Z (1962). The elastic moduli of heterogeneous materials, J. Appl. Mech, 29:143.
Hill R (1963). Elastic properties of reinforced solids, J. Mech. Phys. Solids, 11:357–372.
Hill R (1965). A self-consistent mechanics of composite materials, J. Mech. Phys. Solids, 13:213–222.
Hashin Z, Shtrikman S (1963a). A variational approach to the theory of elastic behavior of multiphase materials, J. Mech. Phys. Solids, 11:127–140.
Hashin Z, Shtrikman S (1963b). Conductivity of polycrystals, Phys. Rev. Lett.130(1):129–133.
Hashin Z, Rosen BW (1964). The elastic moduli of fiber-reinforced materials, J. Appl. Mech. 31:223–232.
Milton GW (1981). Bounds on the electromagnetic, elastic, and other properties of two- component composites, Phys. Rev. Lett. 46:542–545.
Milton GW (1982). Bounds on the elastic and transport properties of two-component composites, J. Mech. Phys. Solids, 30:177–191.
Mori T, Tanaka K (1973). Average stress in matrix and average energy of materials with misfitting inclusions, Acta Metall. Mater. 21:571–574.
Russel WB (1973). On the effective moduli of composite materials: effect of fiber length and geometry at dilute concentrations, Zei ang Math. und Physik, 24:581–600.
Segurado J, Lorca LJ (2002). A numerical approximation to the elastic properties of sphere-reinforced composites, J. Mech. Phys. Solids, 50(10):2107–2121.
Srinivasa Sai V, Bala Krishna Murthy V, Satyanarayana MRS, Sambasiva Rao G, Phani Prasanthi P (2010). Prediction of Micromechanical Behaviour of Hybrid Elliptical Fiber Einforced Lamina For Longitudinal Load, Int. J. Appl. Eng. Res. 5(2):293–304.
Srinivasa Sai V, Bala Krishna Murthy V, Satyanarayana MRS, Sambasiva Rao G (2011). Prediction of Micromechanical Properties of Hybrid Elliptical Fiber Reinforced Lamina, Int. Conf. Futuristic Trends Mater. Energy Syst. (FTME -2011) organized by Mechanical Engineering Department of V. R. Siddhartha Engineering College, Vijayawada, India, pp. 77-81.
Srinivasa Sai V, Bala Krishna Murthy V, Satyanarayana MRS, Sambasiva Rao G (2012). Prediction of Interfacial Stresses in a Hybrid Elliptical Fiber Reinforced Lamina Subjected to Out-of-Plane Transverse Load, Int. J. Eng. Res. Ind. Applications, 5(IV):71-81.
Srinivasa Sai V, Bala Krishna Murthy V, Satyanarayana MRS, Sambasiva Rao G (2013a). Prediction of Micromechanical Behaviour of Hybrid Elliptical Fiber Reinforced Lamina for In-Plane Transverse Load, Int. J. Math. Sci. Eng. Applications, 7(I):91-100.
Srinivasa Sai V, Bala Krishna Murthy V, Satyanarayana MRS, Sambasiva Rao G (2013b). Mechanical Properties of Hybrid Elliptical Fiber Reinforced Lamina with equal Fiber Volume Fractions, Int. J. Current Eng. Technol. 3(1):102-107.
Ying S, Kin L (2002). Environmental fatigue behavior and life prediction of unidirectional glass–carbon/epoxy hybrid composites, Int. J. Fatigue, 24:847–859.