The effect of different cross-sectional fiber of the fiber-reinforced composite on prediction of elastic modulus in ansys

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KEYWORDS

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Elastic Modulus,
Different Cross-Sections.

ABSTRACT

This work aims to predict the elastic modulus of the fiber-reinforced polymer composites. A representative volume element (RVE) of size 420x420x420 micron has been created in Solidworks with 10%, 17%, 27%, 40% and 54% of fiber volume. The fiber of circular, square and hexagonal cross-section has been considered in this analysis. The symmetric boundary conditions have been applied to the representative volume element. It has been observed from the ANSYS that the results are not exactly similar to the rule of mixture. The results are varying with a change in the cross-section of the fiber. It is noticed that the elastic modulus is increased when the cross-section changes from circular to square to a hexagon with all said fiber volume. It is attributed due to increase in fiber-matrix surface area and the adhesion. Surprisingly it observed that in hexagonal and square fiber cross section cases the elastic modulus has decreased after 40% of volume fraction.

1. Introduction

This work emphasizes the modelling of fiber-reinforced polymer (FRP) composites wherein the fiber of different cross-sections has been modelled with the polymer matrix. It gives a clear understanding that the differential cross-section of fiber influences the elastic modulus composite structures. The FRPs are being used in multiple industries such as automotive, aerospace, biomedical, production and wind energy. FRP composites are developed with highly strain resistance fiber which is embedded into a softer polymer matrix. This fiber aims to strengthen the material in the direction of fibers in terms of load-carrying capacity and resist the deformation. The directional fiber orientation will result in orthotropic mechanical property in this work and the stress and strain resistance will increase in the direction of fiber.

The different analytical and numerical techniques are being used to predict the mechanical behavior of fiber reinforced composite. These techniques are very simple and then able to apply for different conditions and parameters. These modern techniques are so powerful that can eliminate the expensive and time-consuming mechanical testing of the composite materials. The most utilized model among all researchers for describing mechanical properties are the rule of mixture, Halpin-Tsai model.

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The prediction of mechanical properties of fiber reinforced composite by using finite element analysis is a very popular approach. It is also been observed that the result of finite element analysis for the prediction of mechanical property is almost similar that off experimental analysis [1-2]. This is also been attributed that, an analytical method provides almost accurate prediction of the property of composite materials with simple configurations of the matrix reinforcement compositions [3]. However, if the geometry of matrix reinforcement configuration gets complicated with different types of loading and material properties, the analytical methods provides approximate solution [4-5]. It is pragmatic that, the finite element method has been extensively considered to study arbitrarily oriented fibre reinforced composite as compared with well oriented fibers [6,7,8].

The representative volume elements (RVE) have been generated by orienting fibres randomly as well as well oriented in the polymer Matrix. Sometime this RVE have been generated with short fiber or particulate reinforced with composite and effective mechanical properties are being approximated with finite element techniques and subsequently compared with analytical methods [9,10,11].

The present research work concentrated on the estimation of mechanical engineering property of fiber reinforced composite based on finite element analysis subsequently compared with the available analytical methods. The RVE model has been generated by aligning the fibers in the matrix in a square array as shown in Figure 1. It is considered that the fiber and matrix materials are linearly elastic. This RVE model is considered as a unit cell for the analysis. The volume fraction of fiber is calculated by considering the volume of fiber in the matrix related to the total volume of the composite. This volume fraction is an important parameter in the composite material and is called fibre volume fraction. In this work, the total surface area of fibres in the matrix is also an important parameter and considered for approximating that mechanical properties. The composite is generally composed of two different types of material that is matrix and fiber. Matrix material is composed of polypropylene co ethylene (PPE) and fiber material is composed of polypropylene (PP). The material properties, are considered in this work, has been indicated in the material property Table 1. In the present work, the finite element analysis is carried out using ANSYS version 16.0 running on an Intel i3 processor system.

Table 1

Material Properties	Polypropylene co ethylene (PPE) Matrix	Polypropylene (PP) Fiber
Longitudinal Modulus E_1	1.05 Gpa	4.5 Gpa
Transverse Modulus E_2	1.05 Gpa	4.5 Gpa
Poisson's Ratio	0.33	0.2

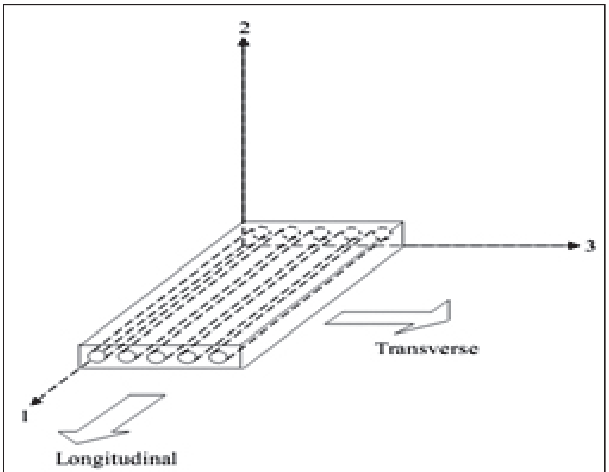


Fig. 1

2. Mathematical Modelling

Rule of mixture is a method to approximate the mechanical property of fiber reinforced composite which is derived from the mechanics of materials approach. The mechanics of mature approach is based on certain assumptions that a composite property is the volume weighted average of the matrix and dispersed phases properties.

2.1. Assumptions made for the present analysis were

The bond between fibers and matrix is perfect

The diameter of fiber and space between fibers are uniform.

The fibers are continuous and parallel.

The Hooke's law is followed for fibers and matrix.

The fibers possess uniform strength.

The composite is free of voids.

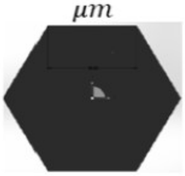
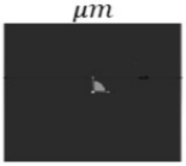
This RVE model consists of fiber of different cross-section which is indicated in the table 2 and the matrix material. It is valid for transversely isotropic symmetry. The defining parameters are elastic constant and the volume fraction of the phases of fiber and Matrix. This model can predict four elastic constants i.e E_z , E_x, v_{xz}, G_{xz}. The orientation of fiber in the matrix where Z is in 1 direction and X, Y are in 2 and 3 direction respectively as shown in Figure 1.

Empirical formula to predict elastic modulus as follows:

Longitudinal Young's Modulus: $E_z = E_f V_f + E_m V_m$

Transverse Young's Modulus: $\frac{1}{E_x} = \frac{V_f}{E_f} + \frac{V_m}{E_m}$

Table 2

Fiber	Volume of fibers (μm^3)	Volume of Matrix (μm^3)	no of fiber in matrix	Volume fraction of fiber	contact surface area with matrix (sq mm)
Dia d=50 μm 	$\frac{\pi}{4}d^2$* no of fiber * length of fiber (420 μm)	420 μm * 420 μm * length of fiber (420 μm)	9	10	594
			16	18	1055
			25	28	1649
			36	40	2374
			49	54	3231
edge s= 28 μm 	$\frac{3}{2} * \sqrt{3}s^2$* no of fiber * length of fiber (420 μm)	420 μm * 420 μm * length of fiber (420 μm)	9	10	635
			16	18	1129
			25	28	1764
			36	40	2540
			49	54	3457
edge, s= 44 μm 	s*s* no of fiber * length of fiber (420 μm)	420 μm * 420 μm * length of fiber (420 μm)	9	10	665
			16	18	1182
			25	28	1848
			36	41	2661
			49	54	3622

Where

E_m - Young's Modulus of Matrix

V_m Volume fraction of Matrix

E_f Young's Modulus of Fiber

V_f Volume fraction of Fiber

3. Finite Element Model

In this study, a model has been developed in ANSYS directly. Orthogonal frame of reference has been assigned on this unit model where in one axis say 'Z' is aligned with the fiber direction as soon in Figure 1. This isolated unit is known as represented volume element (RVE) behaves as a unit cell of the large array of the composite with the consideration of satisfying the condition in such that the surfaces of the unit cell remain plane. This RVE 3D unit has thought of for analysis in ANSYS to extract the elastic properties of the composite.

The behavior of 3D unit cell depends on the complexity of the geometry, the contact surface of the fiber and matrix, the elastic property of the materials, the loading conditions and the initial boundary conditions. In this modelling, the fibers are aligned in a single direction and the cross-section of the fibers have been change for different model. In this type of modelling, the properties are depending on the direction of fibers. Composite with directional fiber in the square area can be considered as transversely isotropic because the properties of the fiber reinforced composite are same in all plan with normal to the fiber direction.

A regular three-dimensional matrix of 420 x420 x 420 has been created as shown in Figure 2. The

Table 3

X -ve Face			X +ve Face			Y -ve Face			Y +ve Face			Z -ve Face			Z +ve Face		
X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
0	No Con-straints	No Con-straints		No Constraints		No Con-straints	0	No Con-straints		No Con-straints		No Con-straints	No Con-straints	0	No Con-straints	No Con-straints	0.05

Table 4

Section	V_f	Contact Surface Area	ROM	E_z	% of error	ROM	E_x	% of error
Circular	10	594	1395	1417	-22	1301	1215	86
	18	1055	1636	1670	-34	1454	1341	113
	28	1649	1981	2011	30	1627	1542	103
	40	2374	2430	2391	39	1922	1728	194
	54	3231	2913	2862	51	2035	2057	-22
Hexagon	10	635	1395	1442	-47	1301	1140	161
	18	1129	1636	1634	2	1454	1331	123
	28	1764	1981	2030	-49	1627	1561	66
	40	2540	2430	2459	-29	1922	1864	58
	54	3457	2913	2322	591	2035	1842	193
Square	10	665	1395	1413	-18	1301	1228	73
	18	1182	1636	1637	-1	1454	1364	90
	28	1848	1981	2026	-45	1627	1616	11
	40	2661	2430	2446	-16	1922	1941	-19
	54	3622	2913	2558	335	2035	2079	-44

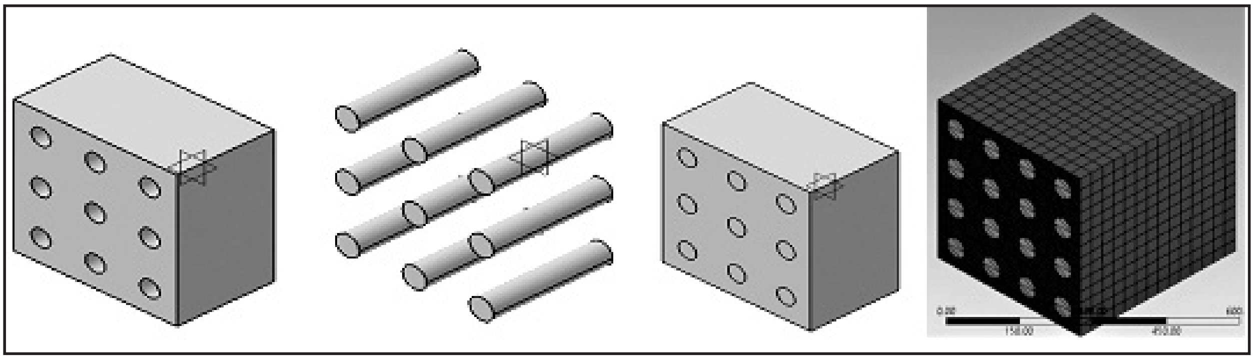
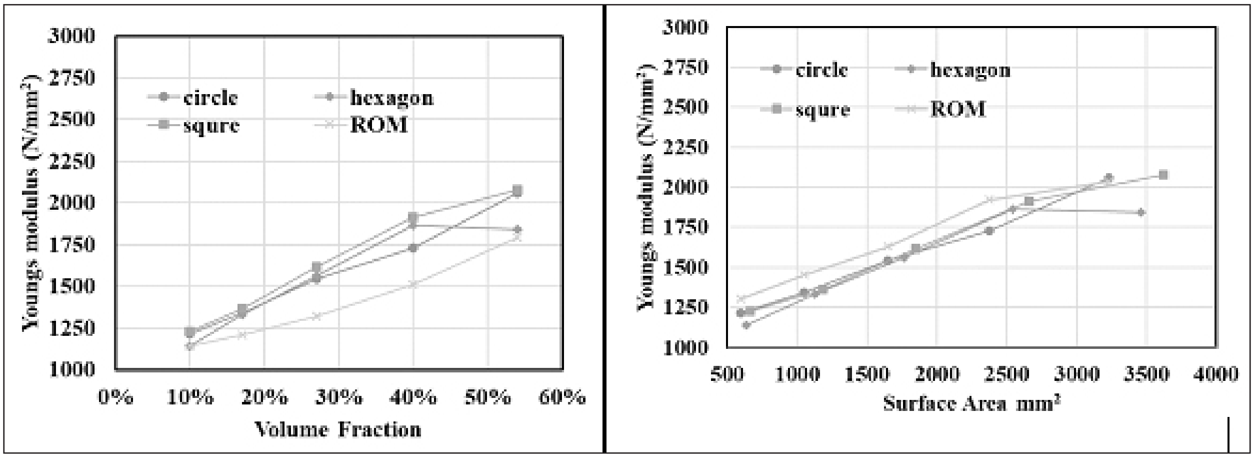
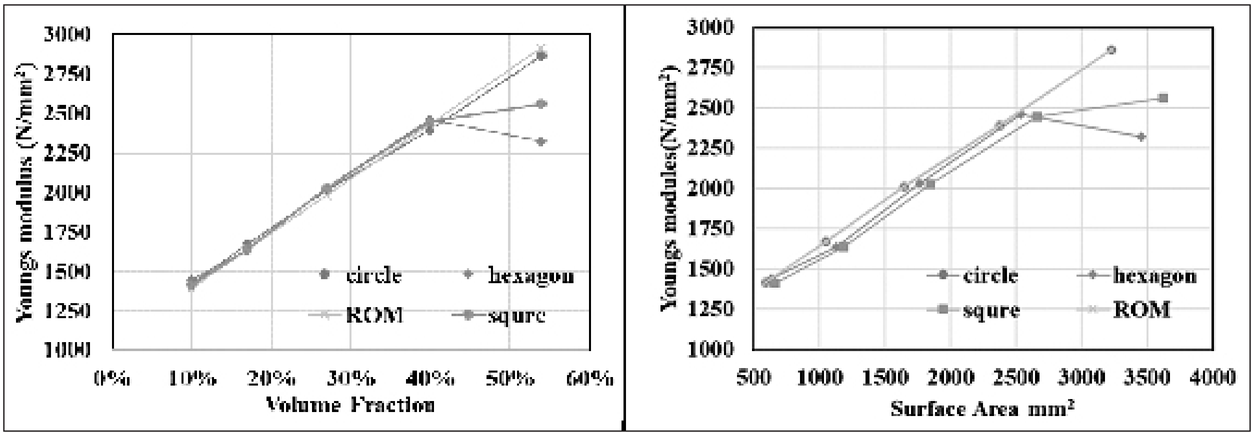


Fig. 2

fibers are aligned into polymer matrix along the direction of Z. The fiber of circular, hexagonal and square cross section has been considered for analysis. In this present work, the volume fraction of fiber is 10%, 18%, 28%, 40%, 54%. and the number of fibers for each volume fraction is 9, 16, 25, 36, 49 taken in RVE respectively. The contact surface area of the fibers with matrix for different cross-section are different but the volume is the same of all kinds of fibers. Table 2 representing number of fibers, volume fraction and contact surface area with matrix in detail. The geometric model of 3D unit cell has shown in Figure 2.



(a) Longitudinal young's modulus



(b) Transverse young's modulus

Fig. 3

4. Specification of Boundary, Initial and Loading Conditions

The symmetric boundary conditions are applied to the model with respect to x y and z directions. The displacements are applied with respect to the condition that is longitudinal loading and transverse loading.

To determine E_z along the fiber direction of the following symmetric boundary conditions applied as indicated in Table 3

5. Result and Discussion

In the fiber reinforced polymer composite, the effective elastic properties are the key parameters in the mechanics of composite material. Determination of these parameters occasionally are difficult to determine through experimentally. Thus, the researchers are frequently use the numerical techniques like finite element analysis to calculate the elastic property of fiber reinforced polymer composite. These numerical techniques usually involve analysis of RVE which is described in this work.

The few critical issue issues have been carefully considered in this representative volume element for carrying out the analysis so that the results are approximated to the value of rule of mixture. The appropriate boundary conditions have been applied to the chosen representative volume element model in such a way so that it mirrors the actual experimental conditions. The symmetric boundary conditions have been applied to all the faces of the representative volume element in all the input conditions like different percentage of volume flexion and different cross-section of fibers.

The Finite element analysis is considered for different fiber volume fractions like 0.10, 0.17, 0.27, 0.40, and 0.54 for circular, hexagonal and square cross-sectional fiber. The number of elements depends on the fiber volume fraction and the different types of elements are used for generating the mesh. The results are tabulated in Table 3 for all volume fraction, contact surface area for circular, hexagonal and square cross-section.

It has been observed during analysis in ANSYS that due to the complex nature of geometry the convergence of longitudinal and transverse elastic modulus does not depend on the fixed mesh size of an element. It is required to change the mesh size by trial and error method for convergence of the analytical young's modulus data to rule of mixture data for a different cross-section of fiber geometry. The analysis data have been tabulated in Table 3 and graphical representation in Figure. 3. It has been observed that for a circular cross-section of fiber the modulus of elasticity is in accordance with the rule of mixture. But for the hexagonal and square cross-section, it has been attributed from Figure 3 that up to 40%, the young's modulus is a good agreement with the rule of mixture. It is further observed that after 40%, the elastic modulus of the hexagonal and square cross-section has been decreased to a certain level. It has also been perceived that a cross-sectional area of square fiber has declined more than that of fiber with a hexagonal cross-section. This is attributed that in 40% volume fraction the total surface area of the hexagonal fiber is 2540 square micrometre and square fiber is 2661 square micrometres as compared to the circular fiber for 40% volume fraction which is 2430 square micrometre. It shows that, as the fiber cross-sectional area increasing, the composite becomes more fragile and resulted in the decline of young's modulus.

6. Conclusion

In this work, three-dimensional representative volume element has been created in the finite element analysis software for carrying out the solution to find out the elastic properties of fiber reinforced polymer composites at different volume fractions and different cross section of fiber. The results from finite element analysis were compared with the rule of mixture formulations. the following outcomes have been observed:

1. The results of elastic moduli E_x E_z have been computed with finite element analysis software and has found that the fiber with circular and square cross section predict a good agreement with the analytical results which is calculated from rule of mixture.
2. Though the sharp edges exist in the square cross-sectional fiber but the contact surface area with the matrix is maximum so the adhesion.
3. The hexagonal cross-sectional fiber is depicted more variation when the volume fraction of fiber is more than 40%.
4. It seems after certain amount of volume fraction like 40% in this study, the stiffness of hexagonal cross-sectional fiber reinforced composite is getting lesser than circular and square fiber.
5. It is observed that, the stress concentration in the hexagonal fiber is more due to a greater number of sharp edges which resulted in decreasing the stiffness after 40% volume fraction.
6. It is also observed that, though the surface area of hexagonal fiber is more with the matrix as compared with the other fibers, the adhesion between the fiber and matrix did not help to increase the stiffness of the fiber reinforced composite.

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