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Prediction of Elastic Properties of Glass Fiber Reinforced Epoxy Composites by Micromechanical Analysis

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ABSTRACT

Recently, fiber reinforced polymer composites have a wide range of applications as a class of structural materials because of their advantages such as ease of fabrication, relatively low cost of production & superior strength as compared to neat polymer resins. The representative volume element (RVE) plays a central role in the mechanics and physics to calculate the effective properties of heterogeneous materials. The aim of the present work is to determine the elastic properties of glass fiber reinforced epoxy composite by varying the volume fraction of fiber. The properties of the composite are determined by finite element analysis (FEA) of the RVE with necessary boundary conditions using ANSYS. In order to validate the FEA model, the numerical results of elastic properties are compared with the analytical methods. It has been observed that elastic properties predicted by the finite element analysis agree well with the existing analytical predictions.
Keywords: Composite, FEM, Representative Volume Element, Volume Fraction

I. INTRODUCTION

Now-a-days composite materials have gained popularity due to their specific properties like strength, stiffness, toughness, high corrosion resistance, high wear resistance, high chemical resistance, reduced cost. Fiber reinforced polymer (FRP) composites are used in almost every type of advanced engineering structure, with their usage ranging from aircraft, helicopters and spacecraft through to boats, ships and offshore platforms and to automobiles, sports goods, chemical processing equipment and civil infrastructure such as bridges and buildings[1]. There are many factors which is influencing on the performance of composites. Among various properties, the elastic properties of a unidirectional fiber-reinforced composite have been dependent upon the factors like fibre volume fraction and individual properties of the constituent fibre and matrix materials [2]. Several models for the prediction of elastic properties of FRP composites have already been proposed by researchers. Ahmed and Vijayarangan [3] studied the elastic property of jute-glass fiber based hybrid composites using experimental and classical lamination theory. Gommer et al. [4] investigated the elastic properties of knitted fabric reinforced composites. The effective elastic moduli of the composite are determined by finite element analysis of the representative volume element (RVE) [5]. Sai et al. [6] developed finite element modal and solved for the micromechanical prediction of Young's moduli and Poisson's ratios of a hybrid FRP lamina. Pal et al [7] predict the elastic properties of polypropylene composite by using RVE modal.

Although a great deal of work has already been done on elastic properties of fiber reinforced polymer composites, however determination of elastic properties of glass fiber reinforced epoxy composites using FEA of the RVE is hardly been reported. To this end, the present study is undertaken to evaluate the effect of volume fraction on the elastic properties of glass fiber reinforced epoxy composites using FEA. Finally, the results of FEA are compared with the results of some analytical methods.

II. METHODS AND MATERIAL

Micromechanical Model

Micromechanics are the study of composite materials taking into account the interaction of the constituent materials in detail [8]. In a real unidirectional fiber reinforced composite the fibers are arranged randomly and it is difficult to model random fiber arrangement. In present work composite material considered has cylindrical fibers of infinite length, embedded in an elastic matrix. The schematic diagram of the unidirectional fiber composite where the fibers are arranged in the hexagonal array is shown in Figure 1

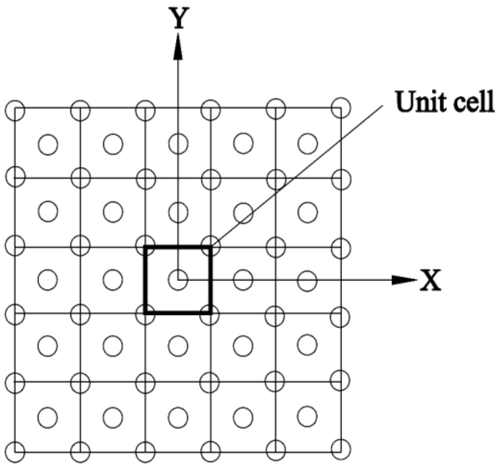

Figure 1 : Arrangement of Fibers in Hexagonal Array

A regular three-dimensional arrangement of fiber in a matrix was adequate to describe the overall behaviour of the composite, was modelled as a regular uniform arrangement as shown in Figure 2. This model assumed that the fibre was a perfect cylinder in a cube. By varying the cylinder diameter with different volume fractions range from 0-70% the model is developed in ANSYS. The element used for the present analysis is SOLID 186 based on three-dimensional elasticity theory and is defined by 20 nodes having three degrees of freedom at each node. The dimensions of FE model are taken as same units in x- y- and z- directions respectively.

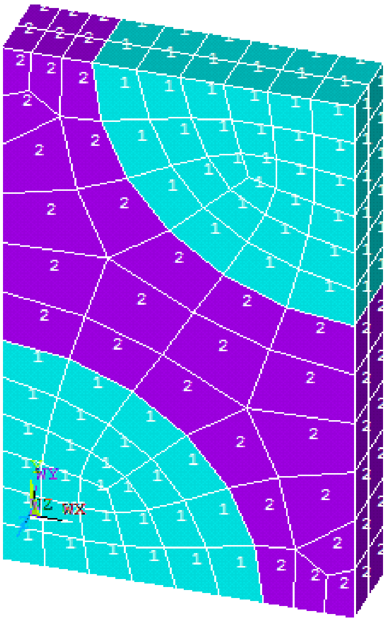

Figure 2 : Meshed model of representative volume element

The constituent materials used in this investigation are glass fibre and epoxy resin, [9] whose properties are given in Table 1. Where u1, u2 and u3 are displacements in the 1, 2 and 3 directions respectively, and a1 = 1 µm, a2 = 4 µm and a3 = 6.928 µm are geometric parameters shown in Figure 3. Symmetry boundary conditions applied on the planes 1 = 0, 2 = 0 and 3 = 0 represent the rest of the body. Uniform displacements δ1, δ2 and δ3 applied on the planes 1 = a1, 2 = a2 and 3 = a3 ensure the repeatability of the microstructure and the compatibility of the displacement fields. The stress and strain diagrams of the representative volume element are shown in Figure 3-4.

TABLE I: Material properties of composite.

Property	Glass fiber	Epoxy
Young’s modulus (GPa)	74	3.76
Poisson’s ratio	0.2	0.39
Shear modulus (GPa)	29.75	1.362

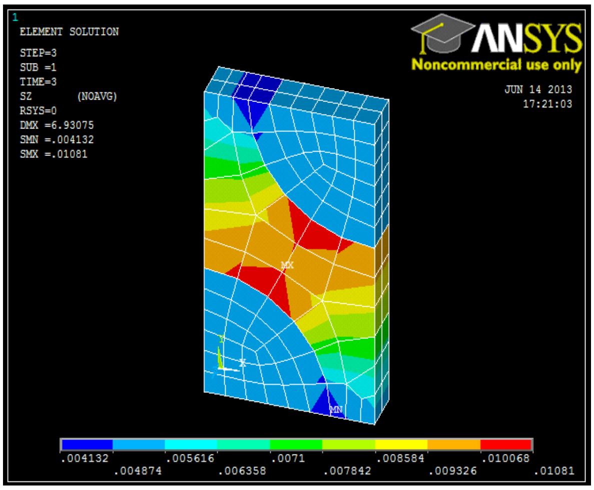

Figure 3 : Counter of stress in representative volume element

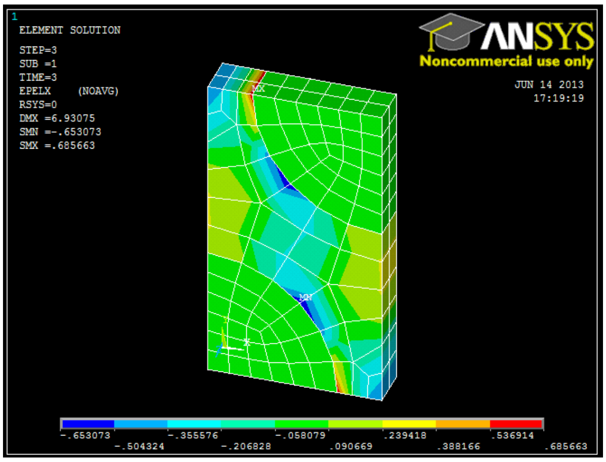

Figure 4 : Counter of strain in representative volume element.

III. RESULTS AND DISCUSSION

Longitudinal modulus of composite is the ratio of longitudinal stress to the longitudinal strain. Figure 5 shows the effect of fiber content on the longitudinal modulus of composites using FEA, rule of mixtures, periodic micro structure and Halpin-Tsai techniques. It can be observed from the figure that the longitudinal modulus increasing with increase in volume fraction of fiber and there is a good agreement of finite element model with other analytical methods.

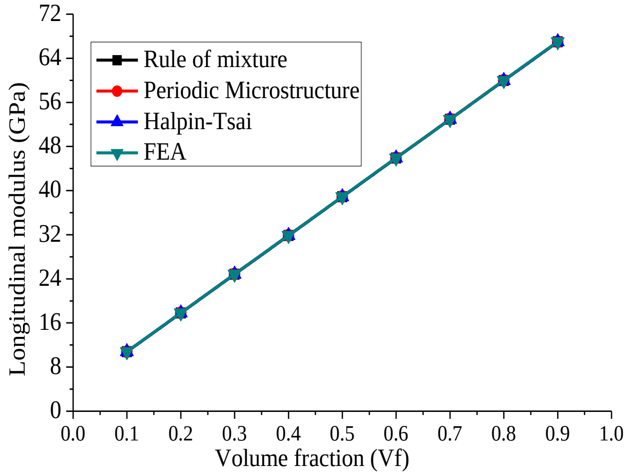

Figure 5 : Longitudinal modulus validation with different volume fraction

Transverse modulus of composite is the ratio of transverse stress to the transverse strain. Figure 6 shows the effect of fiber volume fraction on transverse modulus of composites using finite element analysis and three analytical methods. It is clear from the figure that the transverse modulus increases with increase in fiber volume fraction. In analytical method the periodic microstructure results are closely agreed with the finite element results compare to the rule of mixture and Halpin-Tsai method.

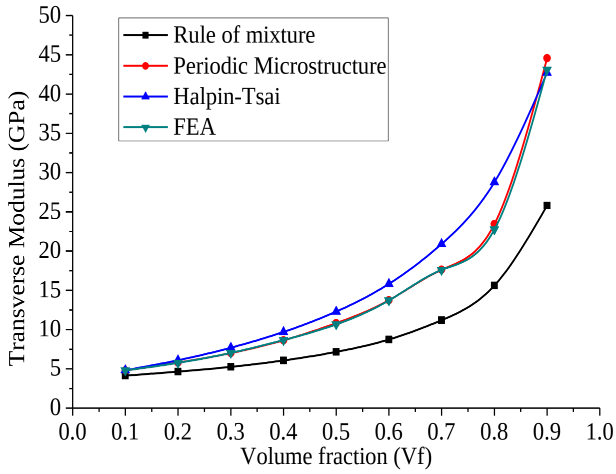

Figure 6 : Transverse modulus validation with different volume fraction

Figure 7 shows the effect of fiber volume fraction on the in plane Poisson's ratio of composite. It is evident from the figure that the major Poisson's ratio decreases with increase in fiber volume fraction as expected. However as far as comparison of the methods, finite element results are closely agreed with the rule of mixture and periodic microstructure compared to the Halpin-Tsai methods.

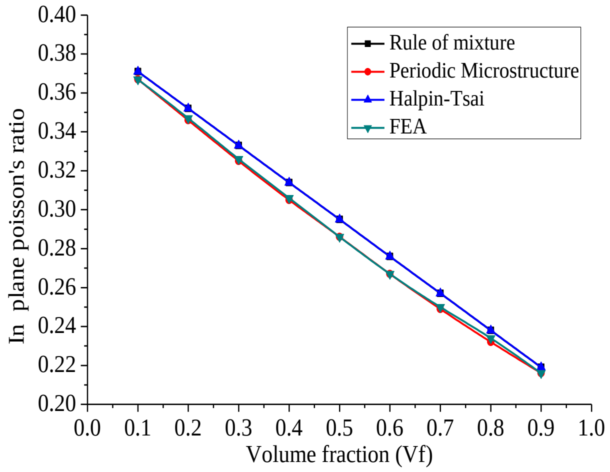

Figure 7 : In plane Poisson's ratio validation with different volume fraction.

IV. CONCLUSION

In this study, the evaluated results for the elastic properties of glass fiber reinforced epoxy composite using analytical and numerical methods the following conclusions can be drawn:

- Effect of fiber volume fraction on the longitudinal modulus, transverse modulus, inplane Poisson's ratio, inplane shear modulus and interlaminar shear modulus of composites is studied. It has been observed that the fiber volume fraction significantly influencing the elastic properties of composites.
- Various analytical methods like rule of mixture, periodic microstructure and Halpin-Tsai methods are discussed to determine the elastic behaviour of composite materials.
- Representative volume element model has successfully applied for the finite element analysis using ANSYS software. The numerical results agreed with the existing analytical predictions.

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