Mechanical and Thermal Properties of Coir Fiber Reinforced Epoxy Composites Using a Micromechanical Approach

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Abstract:
Now-a-days, the natural fiber reinforced polymer composites are widely used due to their many advantages such as light weight, low density, ease of fabrication, renewability, biodegradability, nontoxicity and low cost of production. Prediction of various properties of fiber reinforced polymer composites is a challenging task for current simulation techniques, so does the need to understand the numerical simulation of such materials. The objective of the present works it to study the elastic and thermal properties of coir fiber reinforced epoxy composites with different fiber parameters using a micromechanical approach. The three-dimensional micromechanical models based on finite element method with representative volume element (RVE) are employed to predict the mechanical and thermal properties of composites from the constituent material properties. An attempt has been made in this work to develop a cost-effective and user-friendly composite material with better mechanical and thermal properties. The result obtained from the finite element analysis has been compared with the results of existing analytical approaches and found good agreement. It has been also been observed that the properties of composites are significantly affected by a number of parameters such as volume fraction of the fiber, geometry of fiber and RVE.
Keywords**:** Polymer composites; Coir fibers; Finite Element Analysis; Mechanical property, Thermal property.

1. Introduction

In the past few decades, research interest has been shifted from monolithic materials to fiber reinforced polymer (FRP) composites. FRP composites have a wide variety 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. It has been observed that the natural fibers from renewable natural resources offer the potential to act as a reinforcing material for polymer composites alternative to the use of glass, carbon and other man-made fibers. Among various fibers, coir is most widely used natural fiber due to its advantages like easy availability, low density, low production cost and satisfactory mechanical properties. The mechanical and thermal properties of FRP composites is a challenging task requiring expertise in a wide range of fields ranging from quantum mechanics to continuum mechanics depending on the length scale that is being studied. Generally, the analysis of composite materials can be done from two distinct levels: macromechanical approach and micromechanical approach. In macromechanical approach, each layer of the composites is considered as a homogeneous, orthotropic, and elastic continuum [1]. Based on the known properties of the individual layers, the macromechanical analysis involves study of the interaction of the individual layers of the laminate and their effect on the overall properties of the laminate. Although, the macromechanical analysis has the advantage of simplicity, it is not possible to find the stress/strain states in the fiber and matrix level. In contrast, in the micromechanical approach, the fiber and matrix materials are distinctively considered to predict the overall response of the composite as well as the damage propagation and damage mechanisms in the composite [2]. The representative volume element (RVE) or representative unit cell can be used in the micromechanics to calculate the effective properties of composites materials [3]. A great deal of work has been done on the different methods to predict the mechanical and thermal properties of composites. Prediction of boron and aluminium based composite properties from a RVE with square and hexagonal geometry has been reported [4]. Micromechanical analysis of unidirectional FRP composites with square and hexagonal unit cells has been reported to evaluate the effective material properties [5, 6]. Islam and Pramila [7] predicted the effective transverse thermal conductivity of fiber reinforced composites by using finite element method. Springer and Tsai [8] studied the composite thermal conductivities of unidirectional composites and expressions are obtained for predicting these conductivities in the directions along the filaments and normal to them.

The present work describes the analytical and numerical study of a class of FRP composites made from epoxy matrix reinforced with unidirectional coir fibers. A unit cell methodology with square packing geometry is considered for the present analysis to evaluate the elastic and thermal properties of composite based on finite element analysis.

2. Materials and Methods

2.1 Materials

The unidirectional coir fiber as reinforcement and epoxy as matrix material is taken for the present study. The fiber and matrix materials are considered as isotropic and homogeneous. The properties of the constituent materials are presented in Table 1. In a real unidirectional FRP composite, the fibers are generally arranged randomly and it is difficult to model random fiber arrangement. Therefore, the fiber with circular and square cross section is considered for the present analysis. By varying the volume fraction of fiber from 10 % to 40 % the elastic and thermal properties of composite material are determined. The detailed designation and composition of composites is given in Table 2.

Table 1: Properties of the constituent materials

Properties	Coir fiber	Epoxy
Density (g/cm^3)	1.2	1.15
Youngs Modulus (GPa)	6	3.14
Thermal Conductivity (W/m-K)	0.047	0.363

Table 2: Detailed designation and composition of composites

C1	Epoxy (100 wt%)
C2	Epoxy (90 wt%) + Coir (10 wt%)
C3	Epoxy (80 wt%) + Coir (20 wt%)
C4	Epoxy (70 wt%) + Coir (30 wt%)
C5	Epoxy (60 wt%) + Coir (40 wt%)

2.2 Finite Element Modeling

A three-dimensional micromechanical RVE model has been developed by varying volume fraction of fiber from 10% to 40% by using finite element software package ANSYS. Three-dimensional fiber composite materials can be represented as a periodic array of RVE. The RVE has the same elastic constants and fiber volume fraction as the composite. The periodic fiber sequences commonly used are the square array and the hexagonal array [9]. For the present study, the square array of fiber arrangement has been considered. The periodic boundary conditions were applied to the RVE models [9]. For simplification, there are few assumptions considered for the present analysis such as fibers which are arranged in a particular pattern in a matrix. The composite is free of voids and other irregularities, all fibers are uniformly distributed in the matrix and perfectly aligned, and the interface between the fiber and matrix is perfectly debonded.

The steady state heat transfer simulations are done by using the finite element analysis to predict the thermal conductivity of composites along both the longitudinal and transverse direction. The thermal boundary conditions are applied for the analysis. One wall (parallel to the fiber direction) is kept at a temperature of 120ºC, while the corresponding wall is kept at 30ºC to maintain a temperature difference of 90ºC for the calculation of longitudinal thermal conductivity. All other surfaces are subjected to insulation boundary conditions. Similarly, one wall (perpendicular to the fiber direction) is kept at a temperature of 120ºC, while the corresponding wall is kept at 30ºC to maintain a temperature difference of 90ºC for the calculation of transverse thermal conductivity. All other surfaces are subjected to insulation boundary conditions. Using the temperature gradients the heat flux is obtained from ANSYS software. The effective thermal conductivity is established from the fundamental heat conduction law, found by Fourier's, which states that the heat flux is proportional to the temperature gradient [10].

2.3. Analytical Methods

In order to validate the finite element results, three well existing analytical methods such as rule of mixture [9], Halpin-Tsai [11], Lewis and Nielsen [12] models have been used for the current study.

3. Results and Discussion

3.1. Effect of Volume Fraction on the Elastic Properties of Composites

The longitudinal and transverse modulus coir fiber reinforced epoxy composites are determined using finite element analysis and compared with the existing analytical techniques. Generally, the longitudinal modulus is the response of composites during the application of load parallel to the fiber direction. It can be defined as the ratio of longitudinal stress to the longitudinal strain. The effect of fiber content on the longitudinal modulus of coir fiber reinforced epoxy composites is shown in Figure 1. It can be observed from the figure that the longitudinal modulus of composites increases with the increase in fiber volume fraction and found a good agreement between the finite element results and analytical methods specifically with the rule of mixture model.

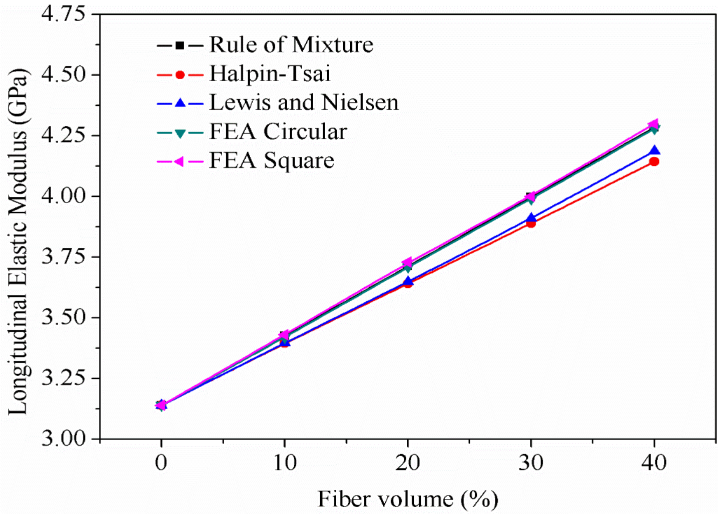

Figure 1: Effect of fiber volume on longitudinal elastic modulus of coir fiber reinforced composites

The transverse modulus is the response of composite during the application of load perpendicular to the fiber direction. It can be defined as the ratio of transverse stress to the transverse strain. The effect of fiber volume fraction on the transverse modulus of coir fiber reinforced epoxy composites is shown in Figure 2. It is observed from the figure that the transverse modulus of composites increases with the increase in fiber volume fraction. It is also evident from the figure that the finite element results are agree well with the results obtained from Halpin-Tsai model as compared to other two models.

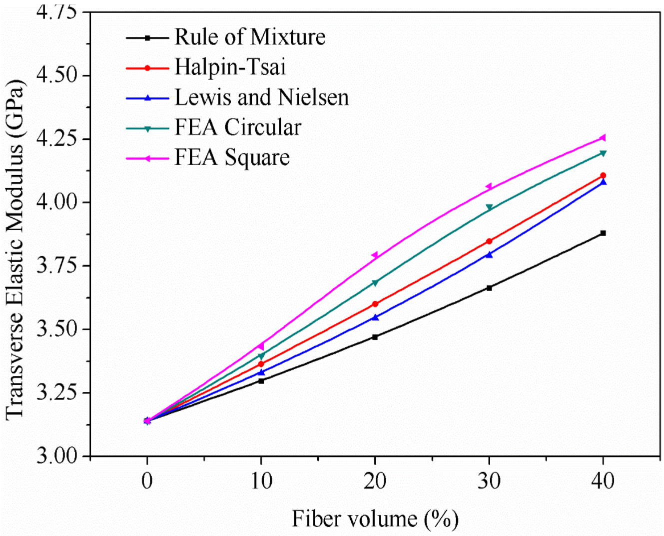

Figure 2: Effect of fiber volume on transverse elastic modulus of coir fiber reinforced composites

3.2. Effect of Volume Fraction on the Thermal Conductivity of Composites

The longitudinal and transverse thermal conductivity of coir fiber reinforced epoxy composites are determined using finite element analysis and compared with the existing analytical techniques. Generally, the longitudinal thermal conductivity of composite is the property of a material to conduct heat in parallel to the direction of the fibers. Figure 3 shows the effect of fiber volume fraction on the longitudinal thermal conductivity of composites. It is observed from the figure that the longitudinal thermal conductivity of composites decreases with the increase in fiber content. The reason may be due to the low thermal conductivity of coir fibers. It is also evident that the finite element results with square fiber geometry is closer to the Halpin-Tsai and Lewis and Nielsen models, however, the finite element results with circular fiber geometry is closer towards the rule of mixture model.

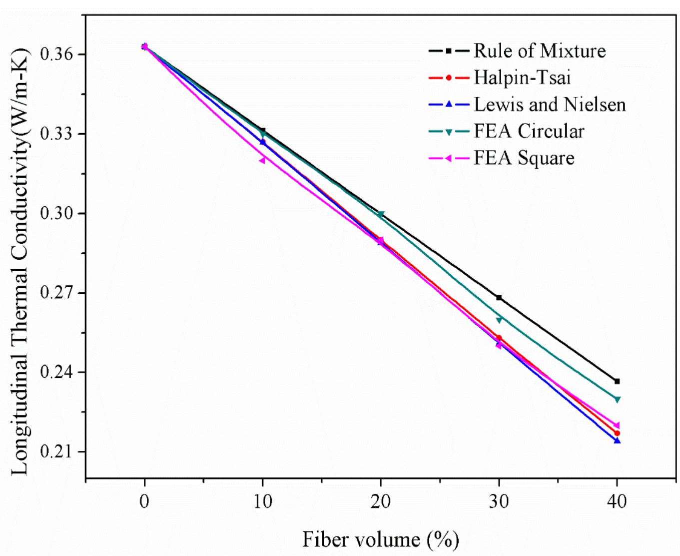

Figure 3: Effect of fiber volume on longitudinal thermal conductivity of coir fiber reinforced composites

Transverse thermal conductivity of composite is the property of a material to conduct heat, in the direction perpendicular to the fibers. Figure 4 shows the effect of fiber content on the transverse thermal conductivity of composites. It is observed from the figure that the transverse thermal conductivity of composites decreases with the increases in fiber volume fraction. Further, it is clear from the figure that the results obtained from finite element analysis are agree well with the Halpin-Tsai models as compared to other two models.

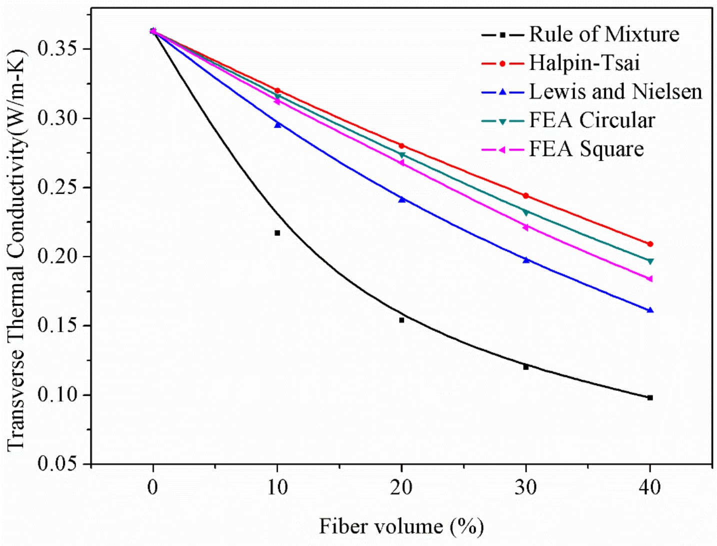

Figure 4: Effect of fiber volume on transverse thermal conductivity of coir fiber reinforced composites

4. Conclusion

The finite element model based on three-dimensional RVE with a square packing geometry is successfully implemented by using the finite element code ANSYS to calculate the elastic and thermal properties of coir fiber reinforced epoxy composites. It has been observed that the longitudinal modulus by the finite element analysis agree well with all the existing analytical predictions specifically with the rule of mixture model. Transverse modulus predicted by the finite element analysis is more close to the Halpin-Tsai model as compared to the other analytical methods. It has been observed that the finite element results with square fiber geometry is closer to the Halpin-Tsai and Lewis and Nielsen models, however, the finite element results with circular fiber geometry is closer towards the rule of mixture model. Similarly, the transverse thermal conductivity predicted by the finite element analysis is more close to the Halpin-Tsai model as compared to the other analytical methods. Therefore, it is concluded that the elastic properties and thermal conductivity of FRP composites are affected by the fiber geometry and volume fraction of the fibers.

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