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Thermo-Mechanical Analysis of Unidirectional PALF Composites Using Micromechanical Approach

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In the past few years, natural fibres became one of the most widely used materials in place of synthetic fibres to develop composites as it attains some inherent characteristics like renewable resource and biodegradability. Pineapple leaf fibre (PALF) is one of the natural fibre which can be used as reinforcement to develop composites. The objective of the present work is to carry out the analytical study of mechanical and thermal properties of fibre reinforced polymer composites. PALF in unidirectional form is used as reinforcement with varying fibre volume fraction (v_f) ranging from 10%-70% and epoxy as the matrix material to carry out the work. Representative Elementary Volume (REV) based micromechanical analysis is used to determine elastic and thermal properties of composites. The results obtained from this analysis is compared with that of existing analytical methods. The results show the good agreement between the results of finite element analysis (FEA) and analytical methods.

Keywords**:** REV, micromechanical analysis, Pineapple leaf fibre, FEA

1. Introduction

The composite material can be characterized as a material consisting of two or more chemically distinct constituents, separated by an interface. Most composites have two constituents one is reinforcement, and the other one is matrix. The individual parts are independently and autonomously inside the completed structure. The features like biodegradability, renewability, light weight and low cost made natural fibres gain popularity in the field of composites. A number of investigations have been carried out to assess the potential of natural fibres as reinforcement in polymers [1]-[4]. Among the various natural fibres such as jute, sisal, bamboo, coir, banana etc., pineapple leaf fibre (PALF) is one of the most promising one due to its many advantages. But, a very few research has been done on the use of PALF as reinforcement for polymer composites. George et al. [5] made an experimental study on the short PALF reinforced LDPE composites. The influence of orientation, fibre loading and length on the elastic properties of composites have been studied.

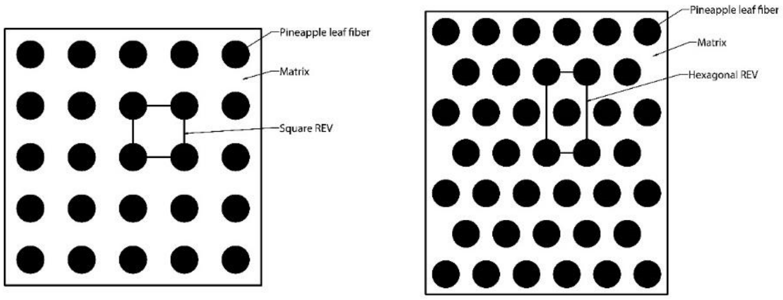
Most of the studies indicate that the mechanical and thermal properties of natural fibre composites are greatly influenced by the many factors related to natural fibres. In order to determine the properties of composites two types of approaches are generally used such as micromechanical approach and macromechanical approach. Micromechanical analysis helps to study the properties of composites at fibre and matrix level whereas macromechanical analysis considers the composite material as homogeneous orthotropic continuum [6]. In micro mechanical analysis, the properties of composites are generally calculated using REV with either square or hexagonal geometry [7-8]. Facca et al. [9] predicted the elastic modulus of different types of natural fibre reinforced HDPE composites by varying the volume fraction of the fibres. Pal et al. [10] predicted the elastic properties of polypropylene fibre based polymer composites by using REV model. Ramani et al. [11] studied the thermal conductivity of composites by finite element method with parallelepiped and spherical fillers. Cao et al. [12] estimated the thermal conductivity of fibre composites through REV with single and multiple fibres by using hybrid FEA based on homogenization technique. The present work is undertaken to study the mechanical and thermal behaviour of unidirectional PALF reinforced polymer composites.

2. Material and Methods

In the present work, epoxy is taken as matrix phase and unidirectional pineapple leaf fibre (PALF) as reinforcement. The matrix and fibres are considered to be homogenous and isotropic. For the ease of analysis, the fibres are considered to be arranged and aligned perfectly. The constituent materials properties are shown in Table 1. For the analysis, fibres arranged in hexagonal and square array are considered. The schematic diagram of the circular fibres arranged in hexagonal and square array is represented in Figure 1. Same schematics is valid for the square fibre. The thermal and elastic properties of the composites are determined by varying the v_f from 0.1 to 0.7.

Table 1 Thermal and Mechanical Properties of Epoxy and Pineapple Leaf fibre [2], [13]

Properties	PALF	Epoxy
Density (g/cm^3)	1.52	1.15
Young's modulus (Gpa)	62	3.76
Poisson's ratio	0.07	0.39
Shear modulus (Gpa)	28.97	1.28
Thermal conductivity (W/mK)	0.0273	0.363

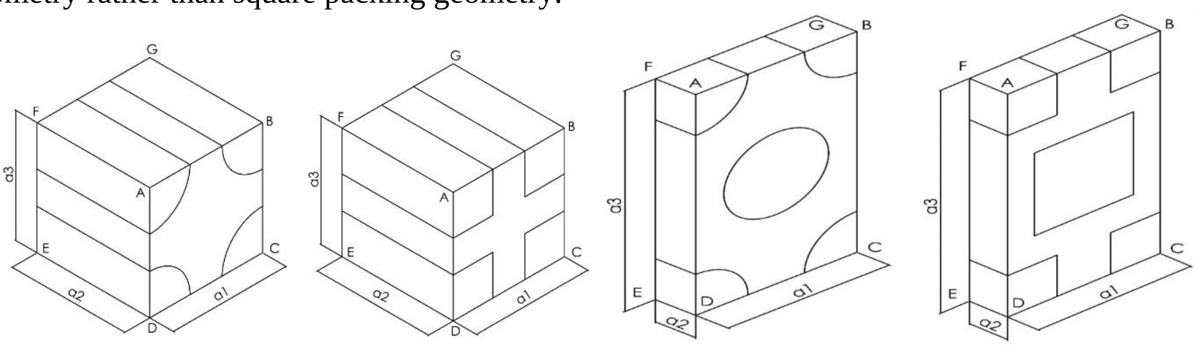


(a) (b)

Figure 1. Fibre arrangement in (a) square REV with circular fibre and (b) hexagonal REV with circular fibre

2. 1. Generation of REV

For ease of analysis, periodic arrangement of fibres is considered for micro-mechanical modelling of composites, where the unit cell or REV can be isolated. The v_f and elastic constants are same for REV and composite. Hexagonal and square array are the commonly used periodic sequences for composite analysis. Figures 2(a) and 2(b) represent square REV with circular and square fibres respectively. Figures 2(c) and 2(d) represent hexagonal REV with circular and square fibres respectively. Generally, more compact composite can be achieved with hexagonal packing geometry rather than square packing geometry.



(a) (b) (c) (d)

Figure 2. Unit cells of (a) square REV with circular fibre, (b) square REV with square fibre, (c) hexagonal REV with circular fibre, and (d) hexagonal REV with square fibre

2. 2. Analytical Methods

To evaluate the properties of a composite, many analytical methods have been developed by many researchers over the years. From these models, some are selected for the analysis. This include rule of mixture, Halpin-Tsai model for analysing elastic properties of composite. Chawla and Hashin models are most commonly used methods for predicting thermal conductivity of unidirectional fibre reinforced composite materials which are used here [14], [15].

2. 3. FEA

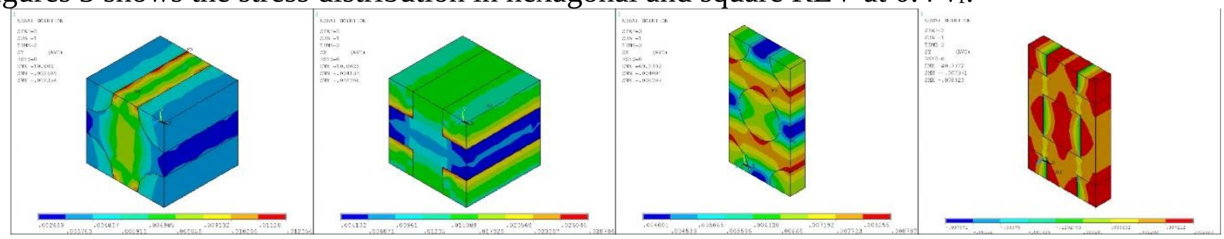
There are many assumptions made for ease of analysis. It is assumed that the arrangement and alignment of fibres in the matrix is regular and the interface between the matrix and fibre is perfectly bonded. It is considered that the composite is free of voids. The axis 1 is aligned with the fibre direction and axis 2 and 3 is perpendicular to direction of fibres. V_f ranging from 0.1 to 0.7 is considered in the analysis. As REV models are considered for analysis, periodic boundary conditions are to be applied. After applying the corresponding boundary conditions for different load steps, various engineering constants were obtained using stress and strain equations of composites.

To predict the transverse and longitudinal thermal conductivity of the composite, steady state heat transfer simulations are done using FEA. For thermal analysis, a temperature difference of 100 K is applied between two opposites faces and rest of the faces are subjected to insulation boundary condition. The heat flux was obtained using the temperature gradient obtained from FEA. The heat conduction law is used to determine the effective thermal conductivity.

3. Results and Discussion

3. 1. Effect of fibre volume fraction on elastic properties of composites

Figures 3 shows the stress distribution in hexagonal and square REV at 0.4 v_f.



(a) (b) (c) (d)

Figure 3. Stress gradient in (a) square REV with circular fibre, (b) square REV with square fibre, (c) hexagonal REV with circular fibre, and (d) hexagonal REV with square fibre

Figure 4 shows the effect of v_f on longitudinal modulus of composites analysed by different methods. It is observed from the figure that longitudinal modulus of composites increases with increase in v_f irrespective of the analytical methods and FEA. Generally, with the increase in v_f the stiffness of material increases which may leads to the increase in longitudinal modulus of composites. It is also observed that the results of FEA are in good agreement with the results obtained by the existing analytical methods. Figure 5 shows the variation of transverse modulus of composites with v_f. It can be seen that the transverse modulus increases with the increase in v_f. The results obtained by hexagonal REV are more close to Halpin-Tsai model. Figure 6 shows the variation of In-plane Poisson's ratio with v_f. It is observed that the Poisson's ratio of composites decreases with the increase in v_f. The results obtained by FEA are in good agreement with that of analytical methods. Similarly, Figure 7 shows the effect of v_f on the In-plane shear modulus of composites. It is evident from the figure that the In-plane shear modulus of composites increases with the increase in v_f and the results obtained by hexagonal REV is more close to the Halpin-Tsai model.

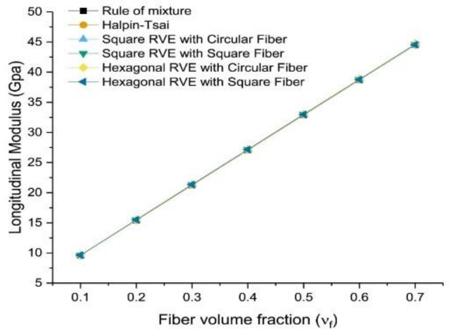


Figure 4. Effect of v_f on longitudinal modulus of composites

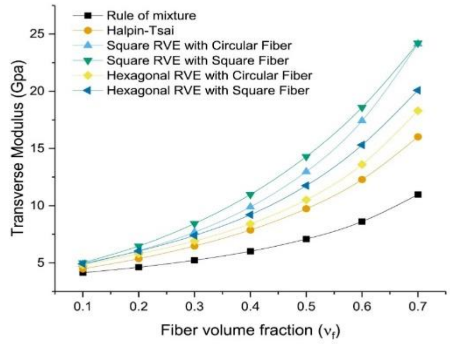


Figure 5. Effect of v_f on transverse modulus of composites

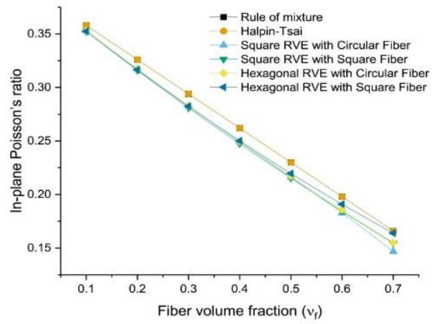


Figure 6. Effect of v_f on In-plane Poisson's ratio of composites

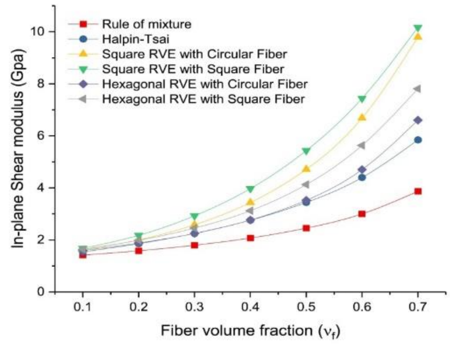
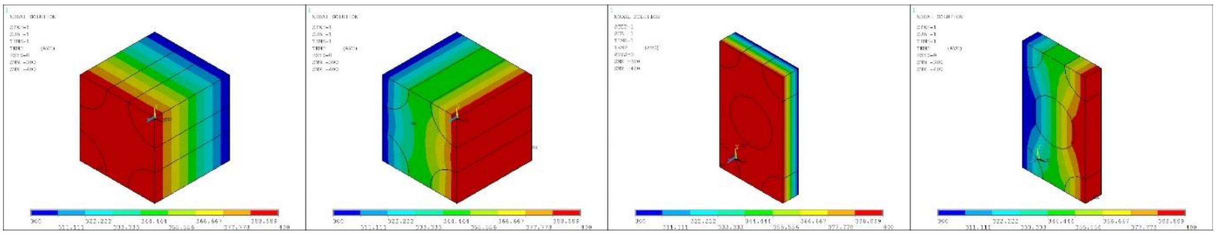


Figure 7. Effect of v_f on In-plane shear modulus of composites

3. 1. Effect of fibre volume fraction on thermal conductivity of composites

Figures 8 shows the longitudinal and transverse temperature gradient in hexagonal and square REV at 0.4 v_f.



(a) (b) (c) (d)

Figure 8. Longitudinal and transverse temperature gradient for (a) & (b) square REV with circular fibre and (c) & (d) hexagonal REV with circular fibre respectively

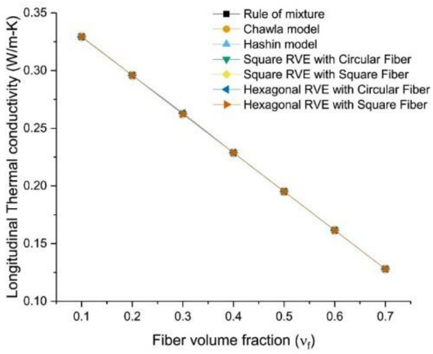


Figure 9. Effect of v_f on longitudinal thermal conductivity of composites

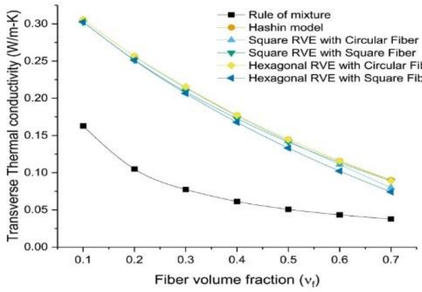


Figure 10. Validation of transverse thermal conductivity with varying v_f

Figure 9 shows the variation of longitudinal thermal conductivity of composites with the v_f by different methods. It is observed from the figure that the longitudinal thermal conductivity of composites decreases with increase in v_f. It is also evident that the results of FEA are in good compliance with the results obtained by other analytical methods. Similarly, Figure 10 shows the effect of v_f on transverse thermal conductivity of composites. From the graph, it is clear that the transverse thermal conductivity of composites decreases with the increase in v_f. The results obtained by FEA are in good agreement with Hashin model.

4. Conclusion

In the present study, the effective thermal and elastic properties of unidirectional PALF reinforced epoxy composites with different v_f have been evaluated using micromechanical approach. The results obtained from FEA are compared with the different analytical methods. The present study leads to the following conclusions:

- The elastic properties of the composites such as In-plane Poisson's ratio and longitudinal modulus predicted by FEA are in good agreement with the analytical methods. However, the In-plane shear modulus and transverse modulus values of composites predicted by FEA are closer to the results obtained by Halpin-Tsai model.
- The longitudinal thermal conductivity values obtained by FEA are in good compliance with the analytical methods. However, the transverse thermal conductivity values predicted by FEA are more close to Hashin model.
- From the study, it is clear that the effective thermal and elastic properties of unidirectional fibre reinforced composites are significantly influence by the v_f.

References

[1]. S. Biswas, Adv. Mater. Res., 1, 221–231 (2013).
[2]. S.B.R. Devireddy and S. Biswas, J. Reinf. Plast. Compos., 35, 1157–1172 (2016).
[3]. V. Mishra and S. Biswas, Procedia Eng., 51, 561–566 (2013).
[4]. S.N. Monteiro, L.A.H. Terrones, and J.R.M. D'Almeida, Polym. Test., 27, 591–595 (2008).
[5]. J. George, S.S. Bhagawan, N. Prabhakaran, and S. Thomas, J. Appl. Polym. Sci., 57, 843–854 (1995).
[6]. J. Aboudi, Appl. Mech. Rev., 42, 193 (1989).
[7]. Z. Hashin and B.W. Rosen, J. Appl. Mech., 31, 223 (1964).
[8]. J. Anurag, S. Biswas, and S. Devireddy, Finite Element Analysis of Mechanical and Thermal Properties of Polymer Matrix Composites, in: Prim. Second. Manuf. Polym. Matrix Compos., CRC Press, Taylor & Francis Group, 121–141 (2007)
[9]. A.G. Facca, M.T. Kortschot, and N. Yan, Compos. Part A Appl. Sci. Manuf., 37, 1660–1671 (2006).
[10]. B. Pal and M. Riyazuddin Haseebuddin, Adv. Mater. Phys. Chem., 02, 23–30 (2012).
[11]. K. Ramani and A. Vaidyanathan, J. Compos. Mater., 29, 1725–1740 (1995).
[12]. C. Cao, A. Yu, and Q.-H. Qin, Int. J. Archit. Eng. Constr., 1, 14–29 (2012).
[13]. K. Abdan, M. Jawaid, Z. Dashtizadeh, M. Asim, M. Nasir, M.R. Ishak, and M.E. Hoque, Int. J. Polym. Sci., 2015, 1–16 (2015).
[14]. R.C. Wetherhold and J. Wang, J. Compos. Mater., 28, 1491–1498 (1994).
[15]. K.K. Chawla, Composite materials: Science and Engineering, Springer-Verlag, (1985).