A NUMERICAL STUDY ON ENHANCEMENT OF THERMAL INSULATION CAPABILITY OF POLYESTER BY REINFORCEMENT OF MICRO-SIZED RICE HUSK PARTICLES

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ABSTRACT

A numerical simulation of the heat-transfer process within polyester matrix composites filled with micro-sized rice husk particles is proposed in this paper. A commercially available finite-element package ANSYS is used to for this numerical analysis. Three-dimensional spheres-in-cube lattice array models are constructed to simulate the microstructure of composite materials with rice husk content ranging from about 1 to 12 vol% and the effective thermal conductivities of the composites are estimated. The results show that the effective thermal conductivity (K_{eff}) of the composites decreases with increase in the volume fraction of the rice husk fillers. Finally, the simulations are compared with measured K_{eff} values obtained from other established correlations such as Rule of Mixture (ROM) and Maxwell's model. This study reveals that the incorporation of rice husk particles results in reduction of thermal conductivity of polyester resin thereby increasing its insulation capability. It is found that with incorporation of about 11 vol% of raw rice husk in the polyester resin reduces its thermal conductivity by about 15 %.

Keywords: Polymer Composites; Rice Husk Particles; Thermal Conductivity; FEM Simulation

1. INTRODUCTION

Neat epoxy and polyester resin have low thermal conductivity which can be further reduced by addition of insulating fillers like pine wood dust [1], fiber glass, sugarcane waste [2] etc. Since low cost polymer composite is an active area of materials research, one more attractive material for this purpose can be rice husk (RH) that is available in huge amount as waste product in agriculture. A few studies have been reported on the thermal conductivity of composites beginning in the 1960s [3–7]. There are many experimental as well as numerical and analytical model studies on thermal conductivity of filled polymer composites [8–13].

Progelhof et al. [14] was the first to propose an exhaustive overview on models and methods for predicting the thermal conductivity of composite systems. Mamunya et al. [15] also reported the improvement in electrical and thermal conductivity of polymers filled with metal powders. A numerical approach to predict the effective thermal conductivity of granular or fibrous reinforced composite materials was proposed by Veyret et al.[13]. In their study, using a finite-element formulation, calculation was carried out on three-dimensional geometric spaces.

2. THERMAL CONDUCTIVITY OF TWO-PHASE MIXTURES

Thermal conductivity of the two- phase mixture by the help of many theoretical and empirical models have been introduced to predict the effective thermal conductivity of two-phase mixtures. Comprehensive review articles have discussed the applicability of many of these models [14,16].For a two-component composite, the simplest alternatives would be with the materials arranged in either series or parallel with respect to heat flow, which gives the upper or lower bounds of effective thermal conductivity.

For the parallel conduction model:

$$k_c = (1-\phi)\, k_m + k_f \qquad (1)$$

For series conduction model

$$\frac{1}{k_c} = \frac{(1-\phi)}{k_m} + \frac{\phi}{k_f} \qquad (2)$$

The correlations presented by Eqs. (1) and (2) are derived on the basis of the Rules-of-mixture.

Using potential theory, Maxwell [17] obtained an exact solution for the conductivity of randomly distributed and non-interacting homogeneous spheres in a homogeneous medium

$$k_c = k_m \left[\frac{k_f + 2k_m - 2\phi(k_m - k_f)}{k_f + 2k_m + \phi(k_m - k_f)} \right] \qquad (4)$$

This model predicts fairly well the effective thermal conductivities at low filler concentrations; whereas for high filler concentrations, particles begin to touch each other and form conductive chains in the direction of heat flow, so that this model underestimated the value of effective thermal conductivities in this region.

3. MATERIALS CONSIDERED

- Matrix Material: Polyester resins are relatively fast processing and inexpensive resins used generally for low-cost applications. Isophthalic polyester resins exhibit higher thermal stability, dimensional stability and creep resistance. In general, for a fiber-reinforced resin system, the advantage of polyester is its low cost and its ability to be processed quickly. The cost of the resin is lower than the epoxy resin. Polyester is chosen for this work primarily because it happens to be the most commonly used polymer and because of its insulating nature (low value of thermal conductivity, about 0.345 W/m K).
- Filler material (rice husk): Due to the high thermal insulating properties and lightweight of the rice husk that draw attention towards their alternative application in beyond traditional application. They are the natural sheaths that from on rice grains during their growth. Removed during the refining of rice, these husks have no commercial interest [18]. Rice husk (RH) is generated during the milling of paddy in rice mill. About 78% of paddy is received as rice and reaming 22% is in form of rice husk. The annual rice husk produce in India amounts is generally approximately 120 million tons. It means that total rice husk produced in India is about 26.4 million tons. It is chosen as the filler material in this work mostly for its very low thermal conductivity (0.0359W/m K) and low density (70-110kg/m^3). Moreover, it is renewable, eco-friendly, available at low cost, non-toxic and basically the rice husk is considered as a waste product.

4. Numerical Analysis: Concept of finite element method and ANSYS

The finite element method (FEM),originally introduced by Turner et al. (1956) , is a powerful computational technique for approximate solutions to a variety of ‘‘real-world” engineering problems having complex domains subjected to general boundary conditions. FEM has become an essential step in the design or modeling of a physical phenomenon in various engineering disciplines. A physical phenomenon usually occurs in a continuum of matter (solid, liquid, or gas) involving several field variables. The field variables vary from point to point, thus possessing an infinite number of solutions in the domain. The basis of FEM relies on the decomposition of the domain into a finite number of sub-domains (elements) for which the systematic approximate solution is constructed by applying the variation or weighted residual methods. In effect, FEM reduces the problem to that of a finite number of unknowns by dividing the domain into elements and by expressing the unknown field variable in terms of the assumed approximating functions within each element. ANSYS is general-purpose finite-element modeling package for numerically solving a wide variety of mechanical problems that include static/dynamic, structural analysis (both linear and nonlinear), heat transfer, and fluid problems, as well as acoustic and electromagnetic problems

4. RESULTS AND DISCUSSION

4.1. Numerical analysis

Using the finite-element program ANSYS, thermal analysis is carried out for the conductive heat transfer through the composite body. In order to make a thermal analysis, three-dimensional physical models with spheres-in-cube in a lattice array have been used to simulate the microstructure of composite materials for four different filler concentrations. Furthermore, the effective thermal conductivities of these polyester composites filled with rice husk up to about 11.3 % by volume are numerically determined using ANSYS.

4.2. Description of the problem

In the analysis of this conduction problem, the heat flow direction and the boundary conditions for the particulate-polymer composite body are shown in Fig.1. The temperature at the nodes along the surfaces ABCD is prescribed as T_1 (=100°C) and the ambient convective heat transfer coefficient is assumed to be 2.5 W/m^2-K at room temperature of 27°C. The other surfaces parallel to the direction of the heat flow are all assumed adiabatic. The temperatures at the nodes in the interior region and on the other boundaries are unknown. These temperatures are obtained with the help of finite-element program package ANSYS. In this analysis it is be assumed that the composites are macroscopically homogeneous, locally both the matrix and filler are homogeneous and isotropic, the thermal contact resistance between the filler and the matrix is negligible, the composite lamina is free of voids, the problem is based on 3D physical model and the filler are arranged in a square periodic array and are uniformly distributed in matrix.

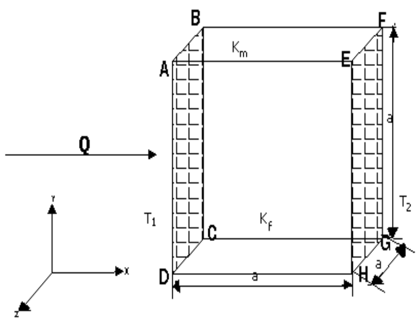

Fig.1 Boundary conditions

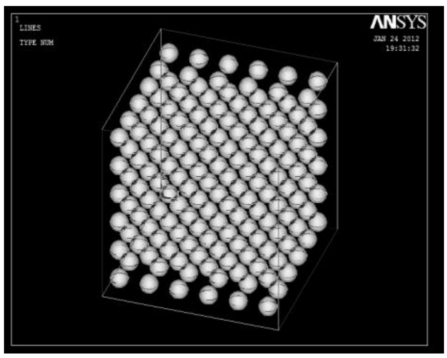

Fig. 2 A typical 3-D spheres-in-cube model (with particle concentration of 11.3vol%)

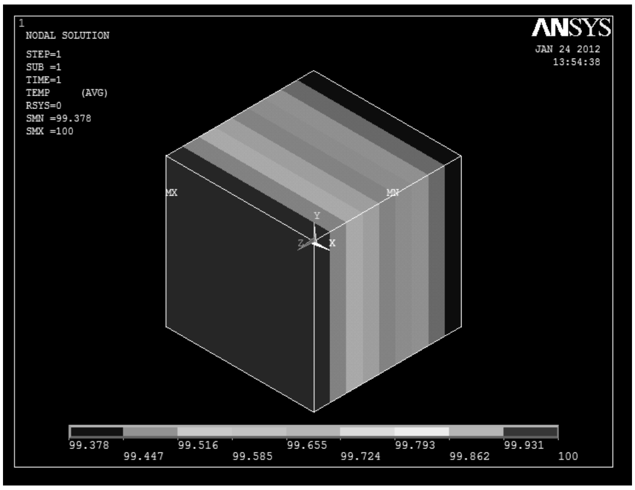

Fig. 3 Temperature profile for composite with particle concentration of 11.3vol%

Table 1. Thermal conductivity values for composites obtained from Rule of mixture, Maxwell’s model and FEM model.

Sample	Rice husk content (vol. %)	Effective thermal conductivity of the composite (W/mK)		
		Rule of mixture model	Maxwell’s model	FEM model
1	0	0.345	0.345	0.345
2	1.41	0.307	0.338	0.334
3	1.88	0.296	0.336	0.331
4	3.35	0.267	0.330	0.321
5	4.18	0.253	0.327	0.319
6	5.23	0.237	0.322	0.312
7	6.54	0.220	0.317	0.309
8	7.53	0.209	0.312	0.305
9	9.16	0.192	0.306	0.300
10	10.26	0.183	0.301	0.295
11	11.3	0.174	0.297	0.293

Thermal conductivities of polyester composites filled with rice husk particles up to 11.3% by volume are numerically estimated by using the spheres-in-cube model. A typical 3-D model showing arrangement of spherical fillers with a particle concentration of 11.3 vol% within the cube shaped matrix body is illustrated in Fig.2. The temperature profiles are obtained from FEM analysis for the composites (spheres-in-cube arrangement) with particulate concentrations of 1.41%, 1.88%, 3.35%, 4.18%, 5.23%, 6.54%, 7.53%, 9.16%, 10.26%and 11.3 vol%. Fig 3 presents such a typical temperature profile diagram. Then the effective thermal conductivities of these rice husk polyester composites are numerically estimated by using the resulting temperature profiles. The numerical results are compared with the Rule of mixture and Maxwell’s model. The simulated values of thermal conductivity of the composites obtained by FEM are presented in Table 1.

It is noticed that while the FEM analysis for spheres-in-cube model can very well be used for predictive purpose in determining the effective thermal conductivity for a wide range of particle concentrations. The difference between the simulated values and the value of thermal conductivity obtain by Rule of mixture and Maxwell's model may be attributed to the fact that some of the assumptions taken for the numerical analysis are not real. It is encouraging to note that the incorporation of rice husk results in reduction of thermal conductivity of polyester resin. With addition of 1.4 vol. % of rice husk, the thermal conductivity reduces by about 3.18 % and with addition of 11.3% of rice husk it is reduced by about 15 %.

5. CONCLUSIONS

This numerical investigation on thermal conductivity of rice husk filled polyester composites has led to the following specific conclusions:

1. Successful fabrication of polyester based composites filled with micro-sized rice husk by hand-lay-up technique is possible.
2. Finite element method can be gainfully employed to determine effective thermal conductivity of these composite with different amount of filler content.
3. Incorporation of rice husk results in reduced of thermal conductivity of polyester resin. With addition of 1.41 vol.% of rice husk, the thermal conductivity reduced by about 3.18 % and with addition of 11.3 vol.% of rice husk the thermal reduced reduces by about 15%.
4. This new class of rice husk filled polyester composites can be used for applications such as thermal interface material and electrical cable insulation.

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