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# Numerical computational of effective thermal conductivity of polymer composite filled with rice husk particle

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***ABSTRACT :****In this paper, a simple 3D finite element model was developed to predict the thermal conductivity of polyester composite filled with micro-sized rice husk particle which is biodegradable and good potential of natural reinforcement element. In 3D finite element model with different size and shape of particle like sphere-in-cube and cubes-in-cube lattice array models are constructed for simulation and estimation of effective thermal conductivity ($K_{eff}$) of polyester composite with rice husk filler concentration varies about 1 to 11%. Finally, the simulation is compared with measured effective thermal conductivity value obtained from other established correlation such as Rule of Mixture, Maxwell models and Russell model. The simulated $K_{eff}$ by ANSYS software showed good agreement with the experiment data. It is further seen that the use of different meshing model for numerical simulation to predicted Keff. The effective thermal conductivity of polyester composite decreases as increases filler concentration.*

***Keywords***: *Effective Thermal Conductivity, Finite element analysis, Polyester Composite, Rice husk*

## I. INTRODUCTION

The use of biodegradable material in advance polymer composite is more popular in previous two decade, these material offer some specific advantage than conventional material. In recent year's biodegradable and environmental safety is more serious area of study. Which move our attention towards biodegradable material, like kenaf, ramie, jute, flax, cotton, bagasse, wood dust, and one more attractive agricultural waste which is available in huge amount is Rice husk. The current annual rice production in India 101.8 million tons and it will be rice husk 20 million tons Rice husk has low thermal conductivity; this characteristic is used in the direction of composite.

A number of studies have been conducted to better utilizations of bio waste material rice husk, in respect to increase the application of rice husk along with polymer material [1-3]. Rice husk are used as filler material in several polymer based composite. Hattotuwa et al. [4] has studies the Mechanical properties of the composites with reference to filler type and filler loading were investigated, unmodified and ground talc and rice husk (RHP) fillers were compounded with polypropylene (PP), two types of fillers, namely RHP and talc were used to prepare PP composites. Natural fiber such as rice husk, wheat -filled polymer composites have attracted great interest due to increasing environmental concerns, and their good mechanical characterize and low costs. They studies, the properties of rice husk flour-filled polypropylene [5].

Analytical approaches for estimating effective thermal properties of general particulate composites in the literature were reviewed in Tsotsas and Martin [6].A recent computational approach by Kumar and Murthy predicts the effective thermal conductivity in a static fluid/solid mixture [7] Various authors have used the computational methods for a direct / inverse identification of effective thermal conductivity ($K_{eff}$) of the polymeric composites. In their work, Telejko and Malinowski [8] proposed that the finite element method (FEM), as an inverse identification tool, can be successfully used for the estimation of thermal conductivity with only a few experimental results. Guoqing Zhang et al. [9] study about that the shape and distribution of fillers, a model predicting the effective thermal conductivity of filled polymer composites is proposed on the basis of the percolation theory. Percolation theory is applicable for characterizing the conduction phenomena that the effective thermal conductivity of composites can increase nonlinearly and rapidly when the percolation network between fillers is formed and developed in polymer matrix.

Ramani and Vaidyanathan [10], they established an automated finite element analysis method to determine the effective thermal conductivity of composites. The variation in type shape and volume of filler and interfacial thermal resistance. Kumlutas¸ and Tavman [11], similarly a finite element model for estimating the effective thermal conductivity of HDPE composites as filler content up to 16% volume, as shape of particle sphere and cubes, further compared the effective conductivity with empirical and experimental results. A 3D finite and element model of sphere in cube in lattice array distribution of epoxy composite pine wood dust as filler was numerical study for obtains effective thermal conductivity and compared with other theoretical methods , Nayak et al.[12]. In the focus of the above conclusion, this paper was investigated the $k_{eff}$ of RHs filled epoxy composite using FEM (ANSYS). 3D models are used to simulate the microstructure of composite materials for various filler concentrations at various filler shape and estimated $K_{eff}$ values are polyester compared with theoretical, empirical and experiment results.

**Thermal Conductivity Models**

In this section brief description of several models for thermal conductivity of composite are discussed prediction of the $k_{eff}$. For two phase mixture many theoretical and empirical models have been proposed. In case of two components composite most simple alternatives would be with the material arranged in either parallel or series with respect to heat flow, which gives upper or lower bounds of $k_{eff}$. For parallel conduction model

$$k_c = (1 - ø)k_m + øk_f \tag{1}$$

Where k: thermal conductivity, c: composite, m: matrix, f: filler ø: volume fraction of filler.
And for series conduction model:

$$\frac{1}{k_c} = \frac{(1 - ø)}{k_m} + \frac{ø}{k_f} \tag{2}$$

The effective thermal conductivity of composite is given by when considered geometric mean model:

$$k_c = k_f^{\phi}.k_m^{(1-\phi)} \tag{3}$$

Maxwell [13] obtained an exact solution for the conductivity of randomly distributed and non-intersecting homogenous spheres in a homogenous medium.

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

Russell [14] developed one of the early model systems using the electrical analogy. Assuming that the discrete phase are isolated cubes of the same size dispersed in the matrix material and that the isothermal lines are planes, he derived an equation for the effective thermal conductivity of the composite, using a series parallel network:

$$k_c = k_m \left[ \frac{ø^{2/3} + \frac{k_m}{k_f}(1 - ø^{2/3})}{ø^{2/3} - ø + \frac{k_m}{k_f}(1 + ø - ø^{2/3})} \right] \tag{5}$$

## II. EXPERIMENTAL STUDY

Polyester composite sample are prepared by the hand lay-up technique. Unsaturated polyester in liquid form with a density 1.35 gm/cc used as matrix material. Its thermal conductivity at 25°C is 0.345 W/mk. The biodegradable filler is RHs in the form of fine powder, with particle size in the range of 100 µm. The solid density of RHs is 0.6 gm/cc and its thermal conductivity 0.0360 W/mk. 5 sample were prepared with different filler concentration varies from 1(1.88 vol.%),2(4.18 vol.%), 3(6.54 vol.%), 4(9.16 vol.%) and 5(11.3 vol.%). Molding can be done at normal atmospheric temperature and pressure. The resulting samples for thermal conductivity measurement are small cube unit. it is very simple and cost of toll is low, complex items can be produce, sand which construction are also possible, it not need high skilled worker. The Unitherm™ Model 2022 used the guarded heat flow meter method to measure thermal conductivity of polymers, glasses, ceramics, composites, rubbers, and Thermal Conductivity Range 0.1 to 40 W/mK to up to 300°C.

## III. NUMERICAL MODELING

Thermal analysis of composite material was carried out using the finite element software of the program ANSYS. In thermal analysis of FEM Conductive heat transfer is carried out through composite and determines temperature of other surface. In order to make a thermal analysis 3D models have been used to simulate the microstructure of composite materials for various filler shape and concentration. They consist of sphere in a cube lattice array, cubes in lattice array, and ellipsoids with different aspect ratio (i.e. the ratio of length long axis to length of short axis) in cube lattice array sphere as filler fig. (1) Shown 3D models of the composite at 6.54 vol. % of filler in polymer.

Table1. In the FEA of the heat conduction problems, boundary conditions are

| | |
|---|---|
| Ambient temperature | 27°C |

| | |
|---|---|
| Temperature at node along the surfaces ABCD, | $T_1$=100 °C |
| EFGH | $T_2$ |
| Convective heat transfer coefficient of ambient | 2.5 $W/m^2K$ |
| Other surface parallel to the direction of the heat flow are | All assumed adiabatic |

For above boundary condition are shown in fig.(2).The temperature at the nodes in the interior region and on the adiabatic boundaries is unknown. These temperatures are obtained with the FE program package ANSYS. $K_{eff}$ of the composite is calculated by using the results of the thermal analysis.
There are no porosity exits in mixture of matrix and filler.
The discontinuous phase (filler) is uniformly dispersed in the continuous phase (matrix).
Thermally mixture is isotropic.
Negligible contact resistance between the continuous and discontinuous phase.
Steady state condition.

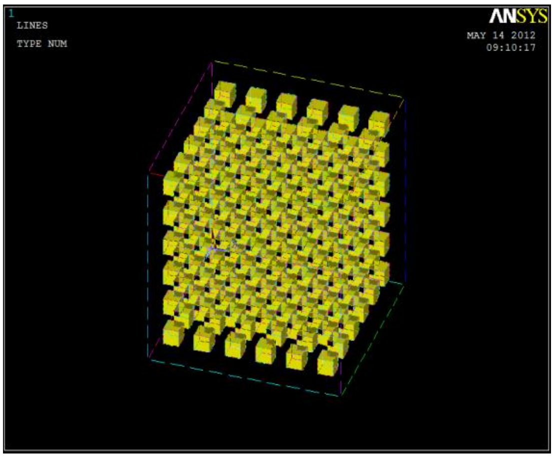



Fig 1. A typical 3-D cube-in-cube model with particle
*Concentration of 11.3 vol. %*

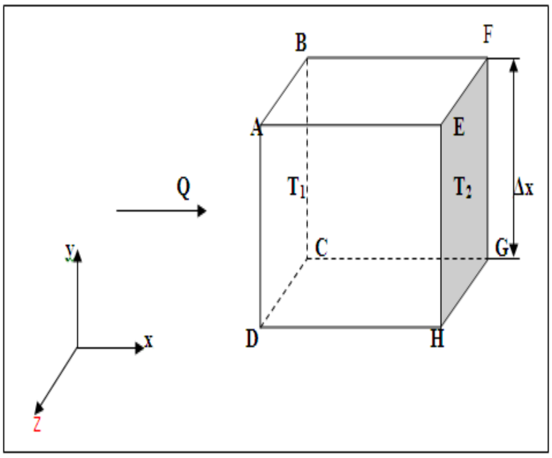



Fig. 2 Boundary condition

## IV. RESULTS AND DISCUSSIONS

The effect of addition of RHs to the matrix on the thermal conductivity of the composite was studied. Actually, in real material, particle filled polyester composites countless filler particle because of small micron scale of composite. A model containing countless filler particle is difficult to modeling in ANSYS. However, in this ANSYS model of composites containing less number of particles. Actual particle filler shape is irregular but we assume that is similar to cube, sphere or ellipsoid.

Meshing is main step for discretization of element into nodes, therefore a proper meshing of model give accurate results and also save the analysis time meshing has no physical meaning; it is only a parameter in Finite element analysis. Ten nodes 87 (Solid 87), solid 70, and solid 92 are available for meshing the solid elements in thermal analysis in ANSYS (APDL). That is effect on effective thermal conductivity as shown in fig.(3).in fig the Element edge length 0.001. The Element edge length $3x10^{-5}$of cubes filler shape when fixed The Element edge length of matrix is about 0.0001 will give lower effective thermal conductivity ($k_{eff}$) further reducing the Element edge length will not affected the results. Fig.(3) suggest that Element edge length $3x10^{-5}$ is precise result and further reducing size will require more time for analysis
The temperature distribution within the composite by the FE thermal analysis with cube filler shape at 6.54 vol. % is shown in fig. (4). One end is fixed at 100°C and other end temperature according to its thermal conductivity. The percentage deviation of predicted effective thermal conductivity values for different shape and concentration of filler in polymer composite from corresponding experiment results are shown in fig(5). As seen from figure it conclude that for cubes-in-cube models percentage deviation is less than other filler shape, means this give more closer results as compared with other filler shape.

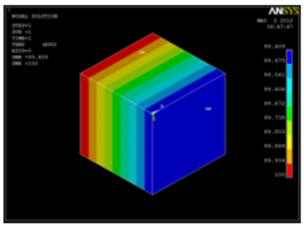


*Fig. 4 Temperature profile for composite with cubes particle Concentration of 6.54 vol.%*

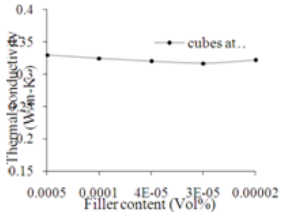
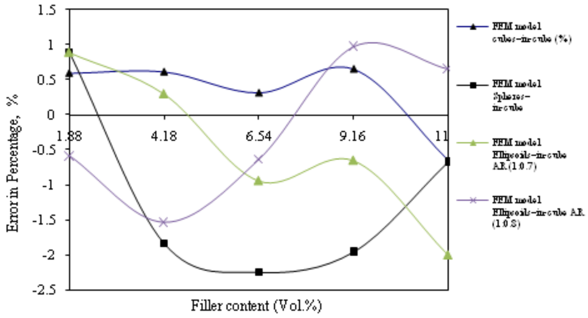



Fig.3 variation of *Keff* with respect to element edge length of cube

Figure (6) indicate the percentage deviation of the predicted value of $K_{eff}$ of various empirical, theoretical and numerical values from corresponding experiment results. Numerical analysis with filler cubes also give less percentage deviation by compared with Maxwell models and Russell models.



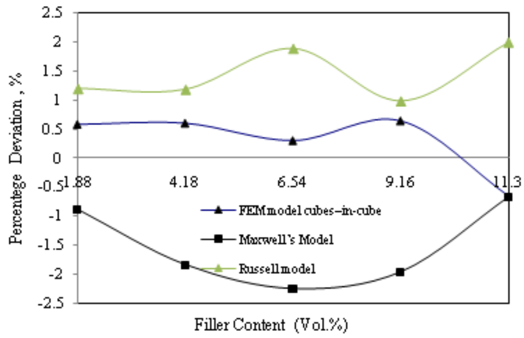




*Fig.5 Percentage deviation of predicted thermal conductivity Values of polyester composites with different filler Shape from corresponding experiment values*
*Fig.6 Percentage deviation of predicted thermal conductivity values of polyester composites with different models from corresponding experiment values*

## V. CONCLUSIONS

The addition of insulated fillers (RHs) particle in polyester matrix is an effective way to increase the thermal insulation of polyester composites with micro-sized RHs particle is increase with as the filler content, as required by several industrial applications. For the investigated conduction filler content up to 11 vol. %, the main conclusions are summarized as follows.

In this study, for RHs particle filled polyester, effective thermal conductivity decrease from 0.345 (W/mK) for pure polyester sample to 0.299 (W/mK) for 11.3 Vol. % filler content, which represents 15% decrease.

Computational may be employed successfully for the $K_{eff}$ estimation of polyester composites. The $K_{eff}$ of polyester composites depends upon the volume fraction of RHs as in the present the higher the RHs content, the lower the $K_{eff}$.

The values of thermal conductivity obtained from FEM (Cubes-in-cube arrangement) are found to be more accurate (close to experimental values) than the calculated values from existing theoretical models such as Rule of mixture, Maxwell's equation, Lewis and Nielsen's model and FEM spheres-in-cube model and Ellipsoid-in-cube model(AR 1:0.8 and AR 1:0.7)

This work may further be extended for the development of computational models with a mixture of different particles distributed within the composite. Yet another investigation may be carried out for irregular shapes of the powdered particles.

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