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Thermal characteristics of boron nitride filled epoxy composites

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ABSTRACT: **The purpose of this paper is to characterize conductive heat transfer through composite, granular, or fibrous materials. A numerical approach was used to determine the effective thermal conductivity of the composite materials. The solutions of Maxwell and Rayleigh were the first of many attempts to determine the effective thermal conductivityof heterogeneous material.The media are composed of a solid continuous matrix containing similar particles. Later studies on solid-liquid and solid-solid boundaries revealed that a temperature drop occurs when heatflows through a boundary between two phases and, as a consequence, the interfacial thermal resistance should be includedin the heat transfer model. To validate the numerical analysis,BN filled epoxy composites are prepared on a laboratory scale by simple hand layup technique and effective thermal conductivities of these composite samples are measured following ASTM standard E-1530by using the Unitherm™ Model 2022.Calculation is carried out on two and three-dimensional geometric spaces. The results obtained from this calculation were compared to theoretical results found in prior literature.This paper is a review of the most popular expressions for predicting the effectivethermal conductivity of composite materials using the properties and volume fractions of constituent phases. The simulations are compared with K_{eff} values obtained from experiments as well as other theoretical models and it is found that the FEM simulations and K_{eff} values of the theoretical model are fairly close to the measured K_{eff}.**

Keywords: Composites, BN, Effective Thermal Conductivity; FEM simulation, interfacial thermal resistance.

I. INTRODUCTION

The problem of heat conduction in heterogenic materials is mathematically analogous to the problems of electricalconductivity, permittivity and magnetic permeability of such materials.Polymer composites filled with metal and non-metal particles are of interest for many fields of engineeringapplications and important in the technologicaldevelopments. The composites made by incorporation ofpowdery metal fillers into thermoplastic polymers combinethe advantageous properties of the metal and plastics. Thesecomposite materials arise from the fact that the thermalcharacteristics of such composites are close to the propertiesof metals, whereas the mechanical properties and theprocessing methods are typical of plastics. However,polymer composite materials have been found to be extremely useful for heat dissipation applications in electronic packaging. Recent applications of polymers as heat sinks in electronic packaging require new composites with relatively high thermal conductivity. Polymer composites are good electrical and thermal insulators. Commonly used plastics, are electrical insulators with a low thermal conductivity **[1].**Thermal conductivity of the polymers can be improved by either of the two ways i.e. by molecular orientation or by the addition of conductive fillers. It has been seen that the heat transfer is more in the direction of orientation as compared to the direction perpendicular to the orientation **[2].** Improved thermal conductivity in polymers may be achieved either by molecular orientation or by the addition of conductive fillers. There are many potential candidates for solid fillers having both high thermal conductivity and high electrical resistivity such as diamond, beryllia (BeO), boron nitride (BN), aluminum nitride (AlN) and aluminium oxide (Al2O3). Diamond is the ideal solid filler for heat conduction, but it is too expensive and BeO is toxic. The thermal conductivity of Al_2O_3 (30 W/m-K) is much lower than that of AlN or BN.The thermal, electrical and mechanical properties of the composites can be improved by properly selecting the filler components, shapes, sizes and concentrations **[3].**Ceramic filled polymer composites have been the subject of extensive research in last two decades. The inclusion of inorganic fillers into polymers for commercial applications is primarily aimed at the cost reduction and stiffness improvement **[4,5,6].**There are many other fillers in polymeric matrices has been investigated. This includes oxides such as Al_2O_3, ZnO**[7].**

II. MODELS FOR EFFECTIVE THERMAL CONDUCTIVITY FOR COMPOSITES

The theoretical analysis of the heat transfer within the particulate filled polymer has been reported by the authors previously [8]. It is based on the following suppositions: (a) the distribution or dispersion of the solid micro-spheres in the polymer matrix is uniform; (b) the temperature distribution along the direction of heat flow is linear. The expression for effective thermal conductivity of the composite is deduced as:

$$k_{eff} = [1/k_p(1-\frac{6vf}{\pi})^{1/3} + 2(k_p(\frac{4\pi}{3vf})^{1/3} + \pi\left(\frac{2v_f}{9\pi}\right)^{1/3} \times (kg\rho s\rho g - kp))-1]-1 \qquad (1)$$

Here, k_p and k_g are the respective heat conductivities of the polymer and the filler, ρ_p and ρ_g are the effective densities of the polymer and the particulate filler phase respectively, and v_f is the volume fraction of the filler i.e. the BN in the composite.

III. EXPERIMENTAL DETAILS

Low temperature curing Epoxy LY 556 resin, used as the matrix material and the hardener (HY951) are mixed in a ratio of 10:1 by weight as recommended. Epoxy is chosen primarily of its low density (1.1 gm/cc) and low value of thermal conductivity (0.363 W/m K). Boron Nitride of 100 micron size is reinforced in the resin to prepare the composites. The dough (epoxy filled with BN) is then slowly decanted into the glass molds, coated beforehand with wax and a uniform thin film of silicone-releasing agent. The composites are cast in these molds so as to get disc type cylindrical specimens (dia 20 mm, thickness 5 mm). Composites of 7 different compositions (0, 1.5, 3.36, 5.25, 7.89, 9.07 and 11.5vol %) of BN are made. The castings are left to cure at room temperature for about 24 hours after which the glass molds are broken and samples are released. Unitherm™ Model 2022 is used to measure thermal conductivity of the composites fabricated for this investigation. The test is carried out in accordance with ASTM E-1530 standard.

IV. RESULTS AND DISCUSSION

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 this analysis, three-dimensional physical models with spheres-in-cube lattice arrays have been used to simulate the microstructure of composite materials for five different filler concentrations. Furthermore, the effective thermal conductivities of these epoxy composites filled with BN up to about 11.3% by volume are numerically determined using ANSYS.

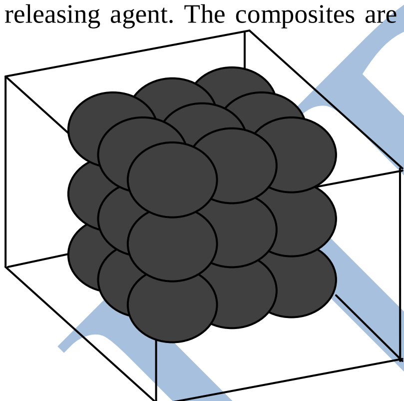


Fig .1. Schematic diagram showing a typical arrangement of BN within the epoxy body

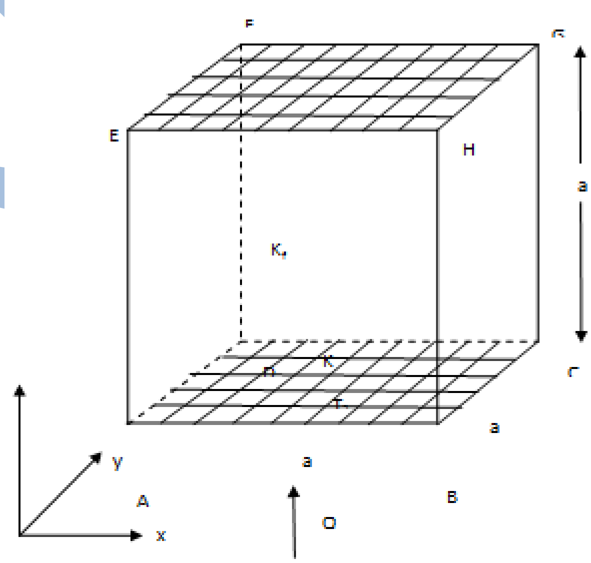
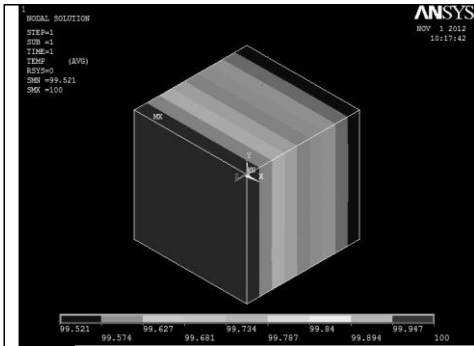


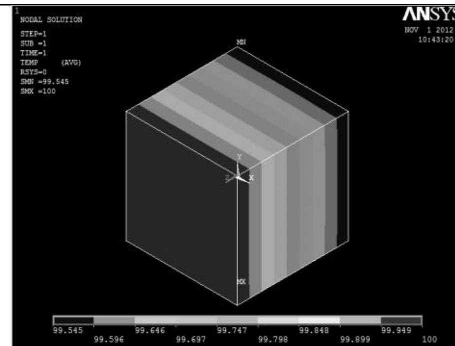
Fig.2. A typical 3-D spheres-in-cube model for the particulate composite

Description of the problem

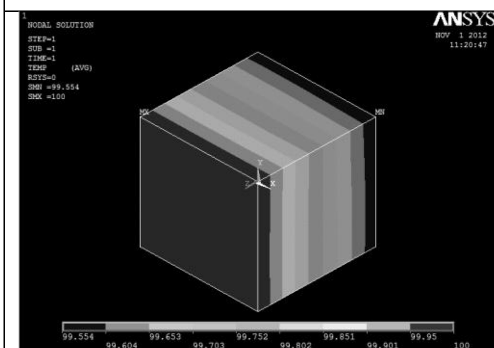
A arrangement of boron nitride within the epoxy body is schematically shown in Fig. 1. Fig. 2 illustrates the heat flow direction and the boundary conditions for the particulate-polymer composite body considered for the analysis of this conduction problem. The temperature at the nodes along the surfaces ABCD is prescribed as T_1 (=100^0C) and the ambient convective heat transfer coefficient is assumed to be 30 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 (Q=0). The temperatures at the nodes in the interior region and on the other boundaries are unknown. These temperatures are obtained with the help of the finite-element program package ANSYS. In this analysis it is 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 and the composite lamina is free from void.

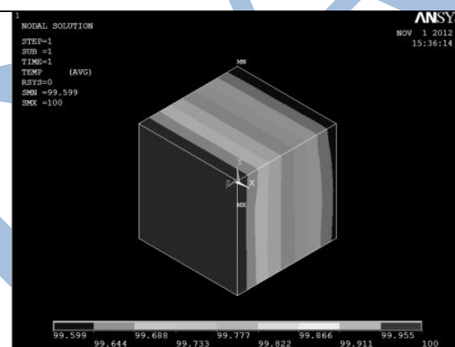


33(a)

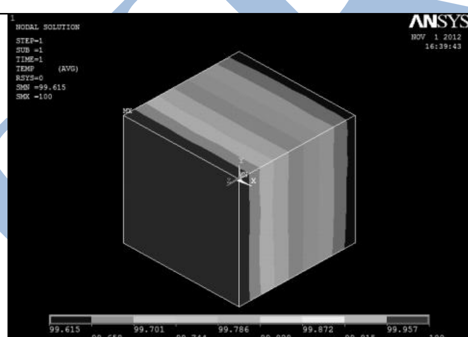


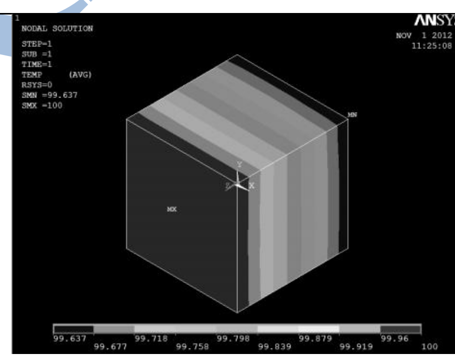
3(a) **3(b)**





3(c) **3(d)**





3(e) **3(f)**

Fig3Temperature profiles for epoxy-BNcomposite with different filler concentrations 3(a) 1.5 vol%
Fig.3(b)Temperature profile for epoxy-BNcomposite with filler concentration of 3.36vol%
Fig.3(c)Temperature profiles for epoxy-BN composite with filler concentration of 5.25vol%,
Fig.3(d)Temperature profiles for epoxy-BNcomposite with filler concentration of 7.89vol%
,Fig.3(e)Temperature profile for epoxy-BN composite with filler concentration of 9.07vol%,
Fig.3(f)Temperature profile for epoxy-BNcomposite with filler concentration of 11.5 vol %

The problem is based on 3D physical model and the filler arranged in a square periodic array are assumed to be uniformly distributed in the matrix.Thermal conductivities of these BN-epoxy composites 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 1.5 vol% within the cube shaped matrix body is illustrated in Fig.1. The temperature profiles obtained from FEM analysis for the composites with particulate concentrations of 1.5, 3.36, 5.25, 7.89, 9.07and 11.5vol

% are presented in Figs 3a, 3b, 3c,3d,3e and 3f respectively.

Table1.Comparison of variation of thermal conductivity of existing models with FEM and experiment values

Sample	BN(vol%)	BN(wt%)	ROM Series Model	Geometric mean model	Maxwell-model(Dk)	Lewis-Nielson model	Experimental	FEM	Proposed model
1	0	0	0.363	0.363	0.363	0.363	0.363	0.363	0.363
2	0.015	3.13	0.37	0.420	0.404	0.411	0.397	0.393	0.377
3	0.0336	6.88	0.372	0.440	0.401	0.420	0.402	0.370	0.360
4	0.0525	10.54	0.384	0.491	0.424	0.458	0.409	0.404	0.367
5	0.0789	15.4	0.395	0.570	0.456	0.516	0.434	0.426	0.375
6	0.0907	18.14	0.399	0.610	0.471	0.547	0.443	0.435	0.379
7	0.0115	21.6	0.415	0.701	0.506	0.619	0.470	0.460	0.390

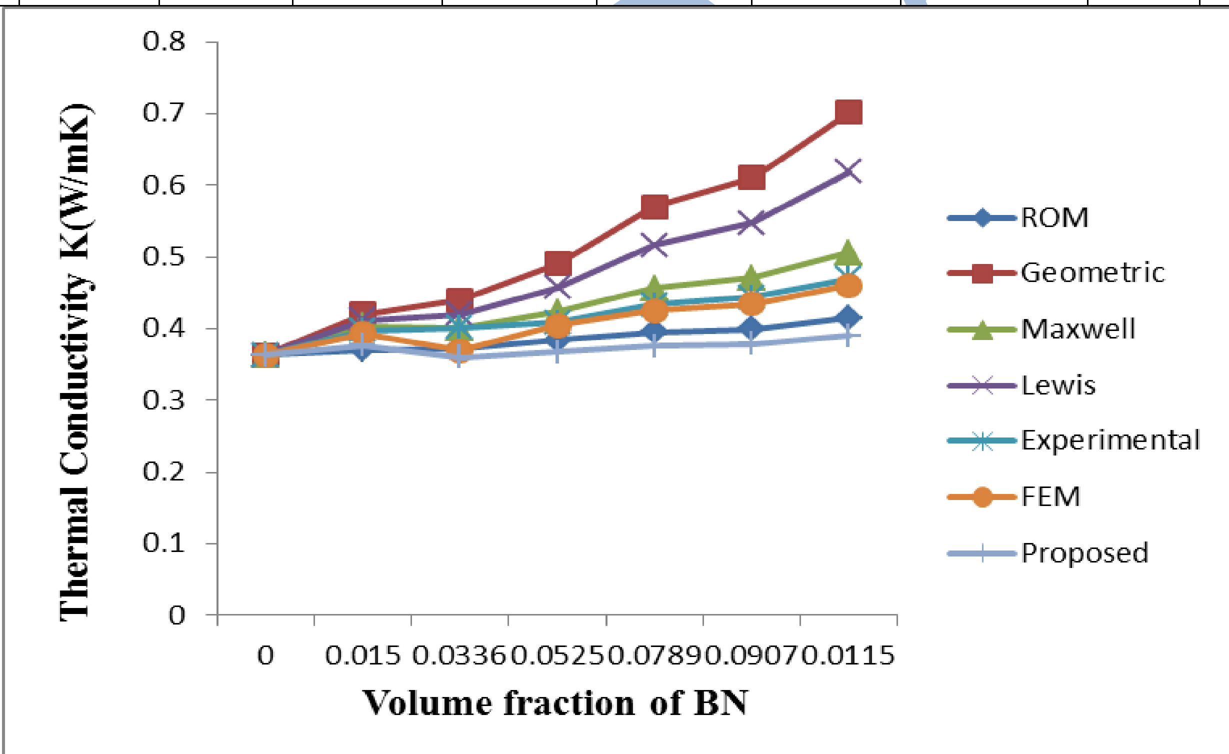


Fig 4.Variation of effective thermal conductivity with BN content: Comparison of theoretical and measured values

V. CONCLUSIONS

Fabrication of epoxy based composites filled with Boron Nitride by hand-lay-up technique is possible. Incorporation of BN results in increase of thermal conductivity of epoxy resin and there by improves its conduction capability. With addition of 11.5 vol% of BN (100 micron size), the thermal conductivity increases by about 72% as compared to neat epoxy resin. For any given content of BN filler, the larger size will achieve higher thermal conductivity. Also, the higher percentage of BN will achieve higher thermal conductivity. The BN particles show a percolation behavior at a volume fraction above 25vol% and at that point the thermal conductivity increases swiftly. This is the critical concentration at which BN particles start contacting with each other and hence the actual size of the agglomerates becomes larger. With light weight and improved conduction capability BN filled epoxy composite can be used for applications such as electronic packages,applications include microwave components, electronic parts, semiconductor, prototypes, high temperature furnace fixtures, and supports,food container, space flight and aviation industry etc.

REFERENCE

[1]. R. Pal, “On the Lewis-Nielsen model for thermal/electrical conductivity of composites”, Composite: Part: Applied science and manufacturing, Vol.39 (5), 718-726, 2008.

[2]. Tavman, “Thermal anisotropy of polymers as a function of their molecular orientation”, Experimental Heat Transfer, Fluid Mechanics, and Thermodynamics, 1562-1668, 1991.

[3]. P. Procter, J. Solc, Improved thermal conductivity in microelectronic encapsulate, IEEE T Compon Hybr, 14(4) (1991) 708–713.42

[4]. Eun-Sung Lee, Sang-Mock Lee, Daniel J. Shane field and W. Roger Cannon, Enhanced Thermal Conductivity of Polymer Matrix Composite via High Solids Loading of Aluminum Nitride in Epoxy Resin, J. Am. Ceram. Soc, 91 [4] (2008) 1169-1174. 3

[5]. R.N. Rothon, Mineral fillers in thermoplastics: filler manufacture, J. Adhes., 64 (1997) 87–109. 11

[6]. R.N. Rothon, Mineral fillers in thermoplastics: filler manufacture and characterization, Adv. Polymer. Sci. **139** (1999) 67–107.12

[7]. L. Sim, S. R. Ramanan, H.Ismail, K. N. Seetharamu and T. Goh, “Thermal characterization of Al_2O_3 and ZnO reinforced silicone rubber as thermal pads for heat dissipation purposes”, *Thermochim. Acta* , Vol.430(1-2), 155-165, 2005.

[8]. Dawson, D.M. and Briggs, A. (1981). Prediction of the Thermal Conductivity of InsulationMaterials, Journal of Materials Science, 16(12): 3346-3356.