The 5th PSU-UNS International Conference on Engineering and Technology (ICET-2011), Phuket, May 2-3, 2011
Prince of Songkla University, Faculty of Engineering
Hat Yai, Songkhla, Thailand 90112

A STUDY ON THERMAL CONDUCTIVITY OF ALUMINUM NITRIDE FILLED POLYMER COMPOSITES

Alok Satapathy[1]*, Lucy Mohapatra[1], Debasmita Mishra[1], Amar Patnaik[2]

[1] National Institute of Technology, Rourkela 769008 India
[2] National Institute of Technology, Hamirpur 177005 India
*Authors to whom correspondence should be addressed via email: satapathy.alok@gmail.com

Abstract: *In this paper, finite element method (FEM) is implemented to determine the effective thermal conductivity of aluminum nitride (AlN) particulate filled epoxy matrix composites. A commercially available finite-element package ANSYS is used for this numerical analysis. Three-dimensional spheres-in-cube and cubes-in-cube lattice array models are constructed to simulate the microstructure of composite materials for various filler concentrations varying in the range of 1 to about 12 vol%. This study shows that the incorporation of aluminum nitride particles results in enhancement of conductivity of epoxy resin and thereby improves its heat conduction capability.*

Key Words: ***Polymer composite, Aluminum nitride, Thermal conductivity, Finite-element method.***

1. INTRODUCTION

Epoxy or polyester resin systems are used for encapsulating a variety of electronic components because of their high thermal stability, moisture resistance and low cost. But unfortunately, the cured epoxy or polyester resins have poor thermal properties like high coefficient of thermal expansion and low thermal conductivity [1]. The high thermal expansion coefficient of epoxy resin is lowered with the addition of ceramic powder filler like fused silica or quartz. But silica-filled epoxy resins are less desirable for the encapsulation of silicon integrated circuit (IC) chips because of silica's low thermal conductivity; hence higher thermal conductivity fillers are being developed. Since recent applications of polymers as heat sinks in electronic packaging require new composites with relatively high thermal conductivity, it is important to enhance the conductivity of the polymers [2]. Improved thermal conductivity in polymers may be achieved either by molecular orientation or by the addition of conductive fillers. There are many possible 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 aluminum oxide (Al_2O_3) etc. Diamond is the ideal solid filler for heat conduction, but it is too expensive and BeO is toxic. The theoretical thermal conductivity of Al_2O_3 (30 W/mK) is much lower than that of AlN or BN. BN has two crystal structures, hexagonal or cubic. The thermal conductivity of BN is very much different depending on the structures, while AlN has a single thermal conductivity value and is more commercially available than BN [2].

Considerable work has been reported on the subject of heat conductivity in polymers by Hansen and Ho [3], Peng and Landel [4], Choy and Young [5], Tavman [6], etc. But most of these studies were confined to the thermal behaviour of neat polymers only and not to their composites. Reports are available in the existing literature on experimental as well as numerical and analytical studies on thermal conductivity of some filled polymer composites. The fillers most frequently used are aluminum particles, copper particles, brass particles, short carbon fiber, carbon particles, graphite and magnetite particles. Progelhof et al. [7] were the first to present an exhaustive overview on models and methods for predicting the thermal conductivity of composite systems. Recently Nayak et.al [8] have also reported on the modified thermal conductivity of pine wood dust filled epoxy based composites.

In view of the above, the present work is undertaken to investigate numerically and experimentally the thermal conductivity of epoxy matrix composites filled with aluminum nitride particles. Since this work aims at developing some kind of a light, cheap and conducting material, epoxy emerged as the first choice for the matrix material. Epoxy is chosen primarily because it happens to be the most commonly used polymer. This paper thus reports the estimation of the equivalent thermal conductivity of these AlN filled epoxy composite system using finite element method.

2. METHODOLOGY

The determination of effective properties of composites is of paramount importance for functional design and application of composite materials. One of the important factors that influence the effective properties and can be controlled to an appreciable extent is the microstructure of the composite. Here, microstructure means the shape, size distribution, spatial distribution and orientation distribution of the reinforcing inclusion in the matrix. Although most composite possess inclusion of random distributions, great insight of the effect of microstructure on the effective properties can be gained from the investigation of composites with periodic structure. System with periodic structures can be more easily analyzed because of the high degree of symmetry embedded in the system.

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 T1 (=100^{0}C) and the ambient convective heat transfer coefficient is assumed to be 25 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.

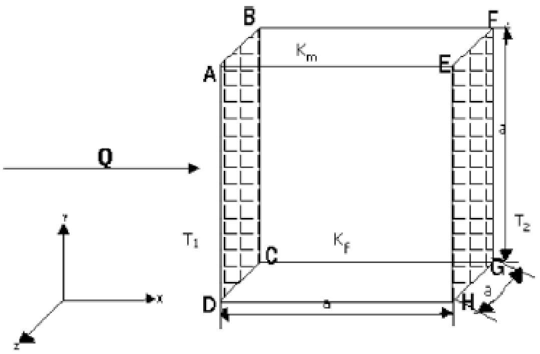

Fig. 1 *Boundary conditions*

Using 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 and cubes-in-cube lattice arrays have been used to simulate the microstructure of composite materials for four different filler concentrations. Furthermore, the effective thermal conductivities of these epoxy composites filled with aluminium nitride up to 11.3 % by volume are numerically determined.

3. RESULTS AND DISCUSSION

The temperatures at various nodes within the composite body are obtained with the help of finite-element program. 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, the composite lamina is free of voids and the filler particles are arranged in a square periodic array/uniformly distributed in matrix.

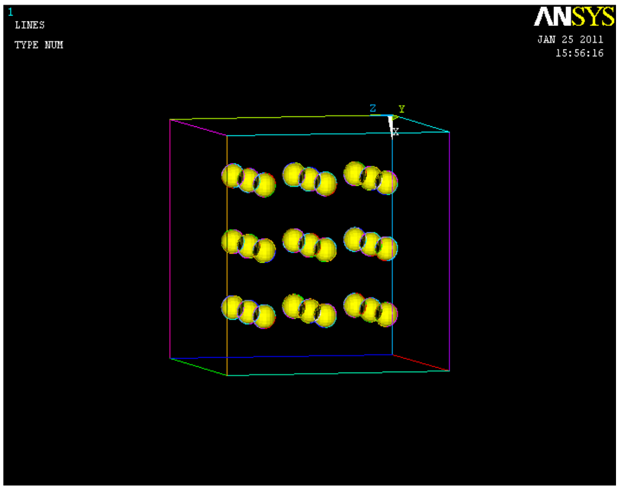

Fig. 2 A typical 3-D spheres-in-cube model with particle concentration of 1.4 vol%

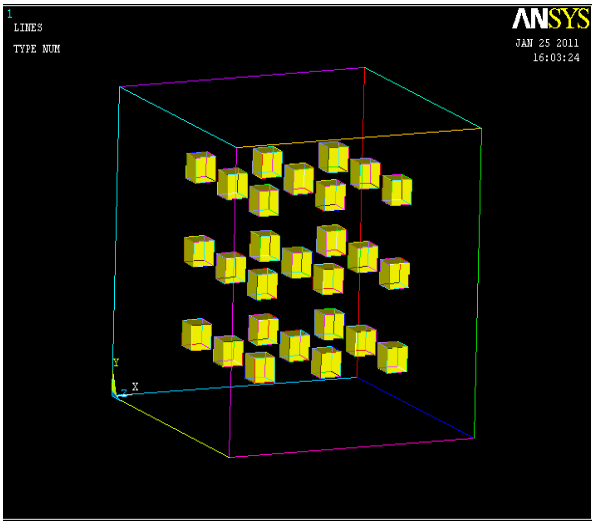

Fig. 3 A typical 3-D cubes-in-cube model with particle concentration of 1.4 vol%

Typical 3-D models showing arrangement of spherical and cubical fillers with particle concentration of 1.4 vol% within the cube shaped matrix body are illustrated in Fig. 2 and 3 respectively.

Thermal conductivities of epoxy composites filled with aluminium nitride particles up to 11.3 % by volume are numerically estimated by using the spheres-in-cube model. The temperature profiles obtained from FEM analysis for the composites (spheres-in-cube arrangement) with particulate concentrations of 1.4, 3.4, 6.5 and 11.3 vol. % are presented in Figs 4a, 4b, 4c and 4d respectively.

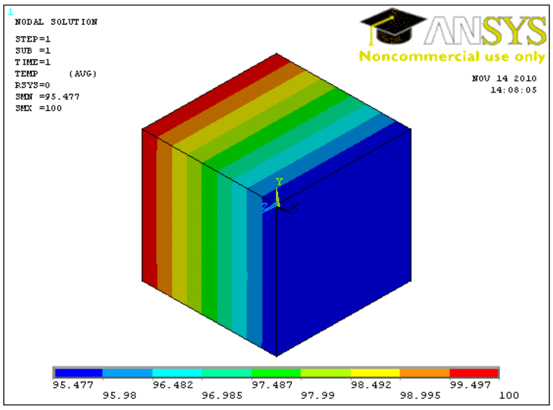

Fig. 4a Temperature profile for composite with particle concentration (spheres-in-cube) of 1.4 vol%

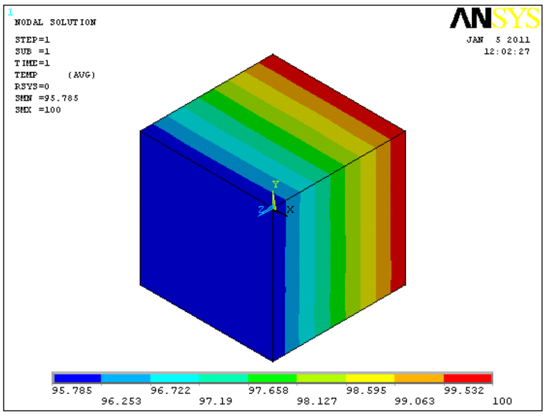

Fig. 5a Temperature profile for composite with particle concentration (cubes-in-cube) of 1.4 vol%

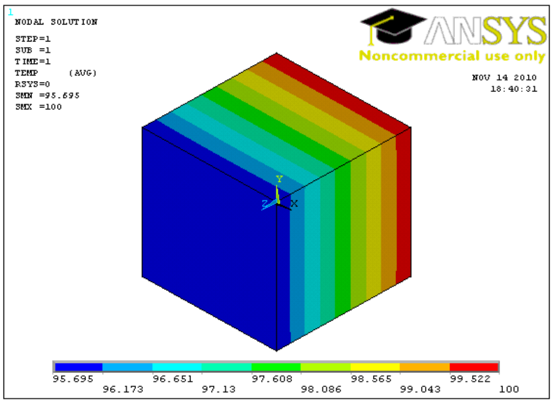

Fig. 4b Temperature profile for composite with particle concentration (spheres-in-cube) of 3.4 vol%

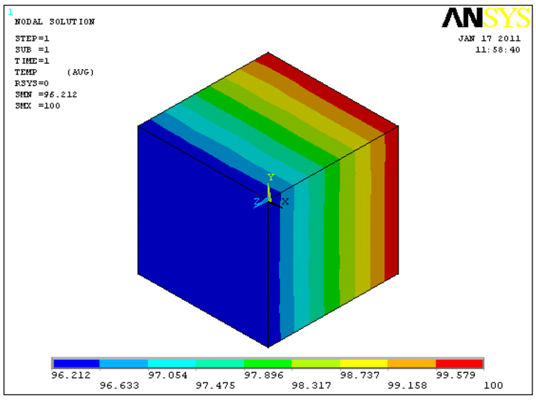

Fig. 5b Temperature profile for composite with particle concentration (cubes-in-cube) of 3.4 vol%

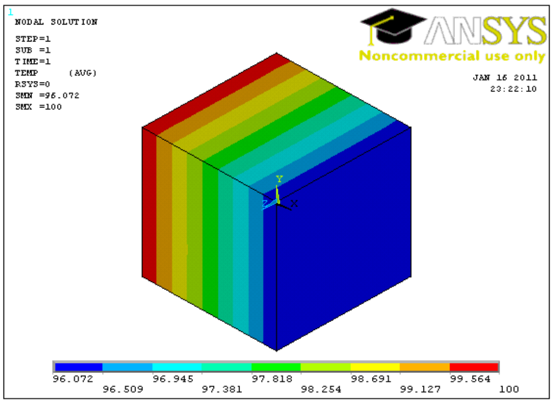

Fig. 4c Temperature profile for composite with particle concentration (spheres-in-cube) of 6.5 vol%

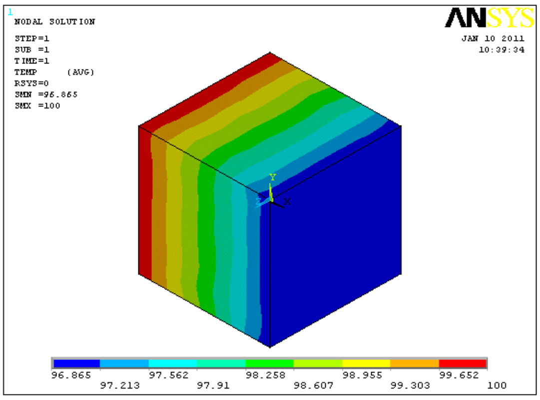

Fig. 5c Temperature profile for composite with particle concentration (cubes-in-cube) of 6.5 vol%

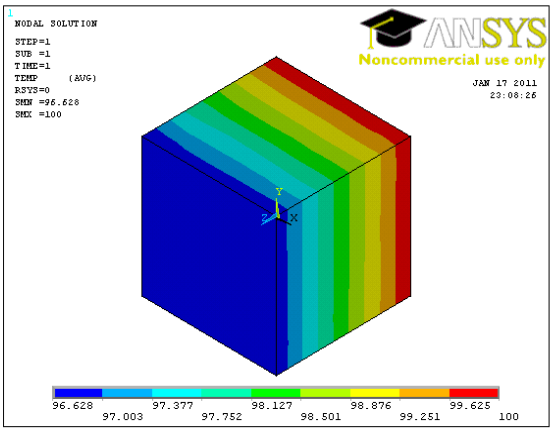

Fig. 4d Temperature profile for composite with particle concentration (spheres-in-cube) of 11.3 vol%

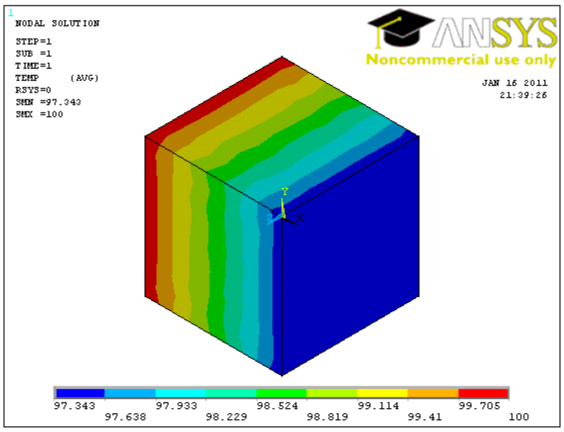

Fig. 5d Temperature profile for composite with particle concentration (cubes-in-cube) of 11.3 vol%

Similarly, thermal conductivities of AlN-epoxy composites are numerically estimated by using the cubes-in-cube model in an identical manner and all the results are presented in Table 1. The resulting temperature profiles obtained from FEM analysis for these composites with particulate concentrations of 1.4, 3.4, 6.5 and 11.3 vol % are shown in Figs 5a, 5b, 5c and 5d respectively.

AlN Content (vol %)	Effective thermal conductivity of composites K_{eff} (W/m K)		
	FEM (Spheres-in-cube Model)	FEM (Cubes-in-cube Model)	Experimental value
1.4	0.378	0.408	0.394
3.4	0.399	0.457	0.439
6.5	0.440	0.557	0.542
11.3	0.516	0.662	0.637

Table 1 *Thermal conductivity values for composites obtained from FEM and Experiment*

AlN Content (Vol %)	Percentage errors with respect to the experimental value (%)	
	FEM *Spheres- in-Cube Model*	FEM *Cubes-in-Cube Model*
1.4	4.06	3.55
3.4	9.11	4.1
6.5	18.82	2.77
11.3	19	3.92

Table 2 *Percentage errors with respect to the experimental value*

On comparing with the experimentally measured values, it is seen that, while the errors associated with cubes-in-cube model simulations lie in the range 2-5 %, the errors associated with the spheres-in-cube model simulations lie in the range as high as 4-19 % (Table 2). It is further noticed that while the FEM for spheres-in-cube model underestimates the value of thermal conductivity, FEM for cubes-in cube arrangement overestimates the value with respect to the experimental ones. It leads to a conclusion that for a particulate filled composite of this kind the FEM (Cubes-in-cube model) can very well be used for predictive purpose in determining the effective thermal conductivity for a wide range of particle concentration.

The difference between the simulated values and the measured value of conductivity may be attributed to the fact that some of the assumptions taken for the numerical analysis are not real. The shape of AlN is assumed to be cubical, while in actual practice they are irregular shaped. Moreover, although the distribution of AlN particulates in the matrix body is assumed to be in an arranged manner, it is actually dispersed in the resin almost randomly. However, it is encouraging to note that the incorporation of AlN results in enhancement of thermal conductivity of epoxy resin. With addition of 1.4 vol. % of AlN, the thermal conductivity improves by about 8.54 % and with addition of 11.3% of AlN the thermal conductivity improves by about 75.48 % when compared with neat epoxy resin.

4. CONCLUSIONS

Finite Element Method can be gainfully employed to determine effective thermal conductivity of epoxy based composites filled with different amount of micro-sized aluminum nitride particles. Incorporation of aluminum nitride results in increase of thermal conductivity of epoxy resin and there by improves its thermal energy transfer capability. With an addition of 11.3% of AlN, the thermal conductivity of neat epoxy improves by about 75.48%. With light weight and improved insulation capability aluminum nitride particle filled epoxy composites can therefore be used for applications such as electronic packages, insulation board, food container, thermo flasks, etc.

5. REFERENCES

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