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Experimental and Theoretical Thermal Conductivity Analysis of Copper/Aluminium Reinforced Epoxy Polymer Composites

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Abstract—*The utilization of thermal conductive polymeric composites is growing up, where the polymers filled with the thermally conductive fillers effectively dissipate heat which generated from electronic components. Therefore, the management of heat is directly related to the durability of electronic devices. For the purpose of the improvement of thermal conductivity of composites, fillers with excellent thermally conductive behaviour are commonly used. Thermally conductive particles filled polymer composites have advantages due to their easy processibility, low cost, and durability to the corrosion. In this paper, epoxy composites were fabricated by varying the copper/aluminium ratio such as 1, 2.5 and 5.5 weight (wt%). The effect of adding copper/aluminium particles on the thermal conductivity of composite material was investigated. Also, the thermal conductivity of composites was analysed by Finite element method using Ansys. The results indicated that the thermal conductivity of the epoxy composite has been improved by adding metallic filler. The experimental results were correlated with the theoretical model. Thermal conductivity obtained from the series conduction model was shown better results compared to the experimental value.*

Keywords*: Polymers, Thermal conductivity, Epoxy resin*

1. INTRODUCTION

Thermal conductivity of polymers is an important thermal property for both polymer applications and processing. Polymers typically have intrinsic thermal conductivity much lower than those for metals or ceramic materials, and therefore are good thermal insulators. Further enhancement of this thermal insulating quality can be achieved by foaming polymers[1]. In other applications which require higher thermal conductivity, such as in electronic packaging and encapsulations, satellite devices, and in areas where good heat dissipation, low thermal expansion and light weight are needed, polymers reinforced with fillers, organic or inorganic, are becoming more and more The main drawback of polymers is their low mechanical properties. PP is a form of thermoplastic used in the production of non-woven fiber and structural plastic products. The properties of PP that make the material popular include the non-toxic and non-staining nature of the plastics. Common in producing advanced polymer composites for these applications. In our daily life we are surrounded by more and more articles produced of polymers rather than traditional materials such as wood, metals or ceramics. One of the main drivers contributing to the popularization of polymers is their ease of processing into complexly shaped parts at high speeds and low costs via relatively simple processes, such as extrusion, injection and compression moulding.

Complementary advantages of polymers are their low density and large range of specific properties; due to these properties polymers are becoming attractive [2]. Polymers generally referred as insulators of both thermally and electrically because of their low thermal and electrical conductivity. Increasing the thermal and electrical conductivity of these polymers allows them to be used in various applications for replacing metals for various shielding applications in defence, electrical and electronics industries. This is mainly due to their better characteristics in terms of electrostatic discharge, shielding from electromagnetic interference (EMI), radio-frequency interference (RFI), and thermal expansion, density and chemical (corrosion and oxidation resistance) properties. The main drawback of polymers is their low mechanical properties. PP is a form of thermoplastic used in the production of non-woven fiber and structural plastic products. The properties of PP that make the material popular include the non-toxic and non-staining nature of the plastics [3-6].

2. EXPERIMENTAL WORK

Epoxy resin [Araldite 53] is used as a matrix material, copper and aluminium is used as reinforced material.

3. FABRICATION OF MATERIAL

Composites are fabricated by hand layup technique. Fig. 1 shows the dimensions of specimen according to ASTM 1530 standard. The properties of materials are given in the Table 1.

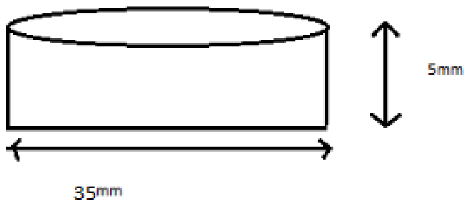

Fig. 1: Composite specimen

Table 1: Properties of materials

Sl. no	Material	Density (g/cm3)	Thermal expansion coefficient (10-6m/mk)	Thermal conductivity (w/mk)	Specific heat (J/kg^{0}c)
1	Epoxy	1.1	45-65	0.35	1000
2	Copper	8.96	16.6	400	385
3	Aluminium	2.7	22.2	150	900

The low temperature curing Epoxy resin (LY 556) and corresponding hardener (HY951) are mixedin a ratio of 10:1 by weight as per recommendation. To prepare the composites, copper and aluminium with average size 100-200μm are reinforced in epoxy resin (Density 1.1 g/cc). The glass tubes coated with wax or some other kind of releasing agent. Then the dough (Epoxy filled with Cu powder) is slowly decanted into the glass tube. Epoxy based copper/aluminium composites are prepared by adding volume fraction of fillers such as 1%, 2.5% and 5.5% respectively.

4. THERMAL CONDUCTIVITY TEST

A sample of the material is held under a uniform compressive load between two polished surfaces, each controlled at a different temperature (Fig. 2). The heat flows from the upper surface, to the lower surface, through the sample, so that an axial temperature gradient is established in the stack. A dimmer stats is provided for varying the input to the heater and measurement of input is carried out by a voltmeter, ammeter. Thermocouples are embedded between interfaces specimen to read the temperature at the surface. It is required to for the test that the both the surfaces of the sample should be in thermal equilibrium [5].

Fig. 2: Thermal conductivity test

5. THEORETICAL MODELS FOR THERMAL CONDUCTIVITY

Series conduction model and parallel conduction model are used to predict the thermal conductivity of the composites [3]. Series conduction model for thermal conductivity of composites is given by following equation

$$1/kc = (1-\emptyset)\, km + \emptyset . kf$$

Parallel conduction model for thermal conductivity of composite is given by following equation

$$1/kc = (1-\emptyset)/km + \emptyset/kf$$

Where

kc, km and kf - thermal conductivities of composites, matrix material and filler respectively

$\emptyset$ are the filler volume fraction

6. FINITE ELEMENT ANALYSIS

In the numerical analysis of the heat conduction problem, a cube of 100x100mm dimension is considered and the temperatures at the nodes along the surfaces ABCD is prescribed as (T1 =100^{0}C) and the convective heat transfer coefficient of ambient is assumed to be 2.5 W/m^{2}K at ambient temperature of 27°C. The heat flow direction and the boundary conditions are shown in Fig. 3. 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 adiabatic boundaries are unknown. These temperatures are obtained with the help of finite-element program package ANSYS. Designing part of this work has been completed in CATIA and the file has been imported in ANSYS 14.5 for analysis part.

Z-PINNING model has been used to simulate the thermal conductivity of the composites. The dimensions of the pins have been calculated according to the volume fraction of the filler and then pins have been inserted in the composites randomly.

Table 2: Comparison of thermal conductivity of composites

Sample	Volume fraction	Experimental thermal conductivity of copper filled epoxy composites	Experimental thermal conductivity of Aluminium filled epoxy composites	Thermal conductivity (series conduction model)	Thermal Conductivity (parallel conduction model)	Thermal Conductivity (FEM)
1	0	0.3518	0.3518	0.3631	0.3636	0.3895
2	1	0.3721	0.3517	0.3651	0.3642	0.4268
3	2.5	0.3828	0.3715	0.3757	0.3710	0.4457
4	5.5	0.3911	0.3836	0.3782	0.3723	0.4985

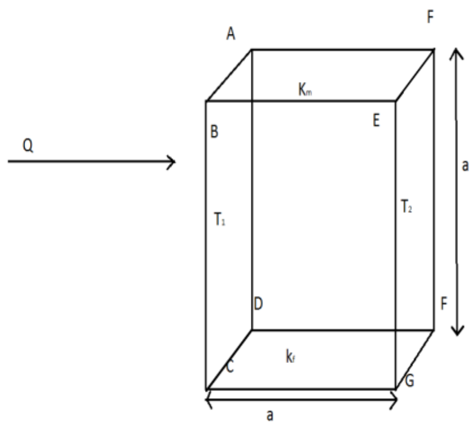

Fig. 3: Boundary conditions [3]

7. RESULTS AND DISCUSSION

7.1. Thermal Conductivity analysis

Thermal conductivity is the property describing a materials ability to transfer heat. It is well known that thermal conductivity of the composites is depend on such factors as polymer filler interaction and filler characteristic [5]. Thermal conductivity of copper and aluminium filled epoxy resin has been obtained through experiments. Table 2 shows the experimental values of thermal conductivity. Higher thermal conductivity is obtained for copper filled epoxy. Thermal conductivity of copper filled epoxy composite shows higher thermal conductivity than aluminium filled epoxy up to 8.195% and at a higher volume fraction this effect becomes stronger. This Experimental study predicts that copper filled epoxy composites have better thermal conductivity than the aluminium filled epoxy. It is clear by the experimental studies, the thermal conductivity of particulate filled epoxy is directly depend on the conductive nature of filler materials.

7.2. Finite Element Analysis

FEM analysis for thermal conductivity has been obtained as shown in Fig. 4. The thermal conductivity has been obtained using heat flux, direction heat flux etc [3].

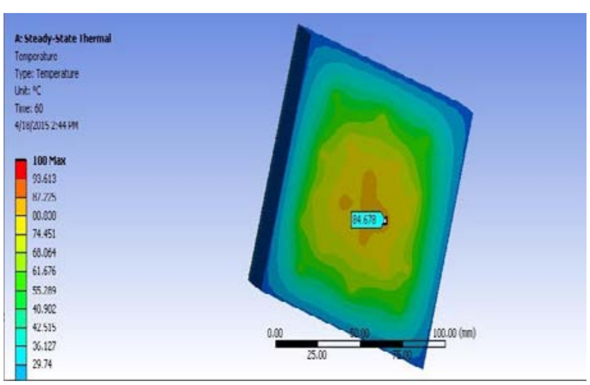

Fig. 4: FEM analysis of thermal conductivity

Fourier law of conduction are used to determine the thermal conductivity. Thermal conductivity obtained using FEM is compared with experimental results and theoretical results (Table 2) .

8. CONCLUSIONS

An experimental and theoretical work has been completed in this research. This theoretical and experimental investigation on thermal conductivity of copper and aluminium filled epoxy composites have led to the following specific conclusions:

- Successful fabrication of epoxy based composites filled with aluminium and copper by hand-lay-up technique is possible.
- Finite element method can be gainfully employed to simulate the thermal properties of these composite with different amount of filler content.
- The value of thermal conductivity obtained for various composite models are in reasonable agreement with the experimental values for a wide range of filler contents from about 1 to 5.5 vol. %.
- Theoretical and experimental values of thermal conductivity show that the enhancement in thermal conductivity of copper filled epoxy is greater than aluminium filled epoxy.
- Incorporation of copper and aluminium results in enhancement of thermal conductivity of epoxy resin. With addition of 3.34 vol. % of TiO_2, the thermal conductivity improves by about 9 % with respect to neat epoxy resin.
- These new class of copper and aluminium filled epoxy composites can be used for applications such as electronic packages, encapsulations, die (chip) attach, thermal grease, thermal interface material and electrical cable insulation.

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