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A Review of Thermal Conductivity of Epoxy Composites Filled With Cuo AND Al_2O_3

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Abstract: The thermal properties of the epoxy resins enhances upto measurable standard by adding some micro- or nano- particles to the epoxy resin. The present paper reviews actual work in the field of epoxy materials enriched with copper oxide (CuO)[1] and aluminium oxide(Al_2O_3)[2] and compares the effective thermal conductivity obtained by both researchers.

Keywords: Composites, Density, CuO, Epoxy, Effective Thermal Conductivity, Filler

I. INTRODUCTION

A composite material is made of two or more constituent materials with different physical or chemical properties. If we mix two or more materials together then a new material is formed which have different properties. The mixture of epoxy resin with some inorganic particles like aluminum dioxide, silicone dioxide, magnesium oxide, zinc oxide or copper oxide will create a particle reinforced composite. These composites have worse mechanical properties than fiber composites. But the inorganic particles have good thermal conductivity and also sufficient dielectric strength, so the resulting thermal conductivity of the composite will rise.

The aim of scientist in this field is to develop a composite with high thermal conductivity, low coefficient of thermal expansion, low dielectric constant, high electrical resistivity, high breakdown strength, high electrical treeing resistance and most importantly - low cost [3]. Several investigations are available which pertains the improvements in the thermal characteristics with the use of inorganic fillers like (ZnO, Al_2O_3, SiO_2, and BeO) [4]-[9]. Similar other fillers such as silicon carbide SiC, nitride (AlN and BN) [4]-[6],[10]-[14].

II. EXPERIMENTAL PROCEDURE

Micro-sized copper oxide (CuO)[1] and aluminium oxide(Al_2O_3)[2] are taken as the filler material in the epoxy Bisphenol-A-Diglycidyl-Ether (commonly abbreviated to DGEBA or BADGE). Hand Lay-Up technique has been employed for the preparation of composite samples. Uncured epoxy (LY556) and its corresponding hardener (HY 951) were mixed in a ratio of 10:1 by weight. Nano-sized CuO and Al_2O powder were mixed with the epoxy in different proportions(5% to 25%). The uniformly mixed dough (epoxy filled with CuO) was then slowly decanted into the glass molds so as to get disc type specimens (diameter 65 mm and thickness 7 mm) , coated beforehand with wax and a uniform thin film of silicone-releasing agent. The castings has been placed at room temperature for about 24 hours and then the glass molds were broken and the samples were released. From this slab circular shaped specimens (diameter 65 mm, thickness 7mm) were cut for different characterization tests.[1]

Similarly, specimens with Al_2O_3 as filler are obtained with diameter 50 mm, thickness 3mm.[2]

Table: 1: Properties of CuO and Al_2O_3

CHARECTERISTICS	**CuO**	**Al_2O_3**
Thermal Conductivity	33 W/m- K	35 W/m- K
Density	6.2 gm/cc	3.89 gm/cc

III. CHARACTERIZATION

Macroscopic homogeneity of the composites, locally homogeneous and isotropic characteristics of both the matrix and filler and negligible thermal contact resistance between the filler and the matrix have been assumed for the characterization.

3.1. Density and Volume Fraction of Voids

The theoretical density (ρ_{ct}) of composite materials can be evaluated by using the following formula,

$$\rho_{ct} = \frac{1}{\frac{\omega_f}{\rho_f} + \frac{\omega_m}{\rho_m}} \qquad (1)$$

Here, ω and ρ represent the weight fraction and density respectively.

The actual density (ρ_{ce}) of the composite can be determined experimentally by using the water displacement technique i.e, Archimedes principle. The volume fraction of voids (v_v) in the composites can be evaluated by using the following formula,

$$\upsilon_v = \frac{\rho_{ct}-\rho_{ce}}{\rho_{ct}} \qquad (2)$$

3.2. Thermal Characterization

Thermal conductivity tester is used to the room temperature effective thermal conductivity of the composite specimens. Disc type specimens are used for this purpose. This test is conducted in accordance with ASTM E-1530standards[1] and Unitherm Model 2022[2].

IV. THEORETICAL CALCULATIONS BASED ON VARIOUS MODELS

4.1. Maxwell Model

Maxwell deduced the analytical expressions for effective conductivity of heterogenic medium in his famous work on electricity and magnetism [15]. He considered the problem of dilute dispersion of spherical particles of conductivity k_1 embedded in a continuous matrix of conductivity k_m, by ignoring thermal interactions between filler particles.
Maxwell's expression is written as follows:

$$\frac{k_{eff}}{k_m} = 1\,\frac{3\Phi}{\frac{(k_1+2k_m)}{k_1-k_m}-\Phi} \qquad (3)$$

Here Φ is the volume fraction of the filler. Maxwell's formula can be used and valid only for low Φ (under about 25%).

4.2 The Lewis-Nielsen Model

The effective thermal conductivity of a composite according to the Lewis-Nielsen model is given as:

$$k_{eff} = \frac{1+AB\Phi}{1-B\Phi\Psi} \qquad (4)$$

Here,

$$B = \left(\frac{\frac{k_1}{k_m}-1}{\frac{k_1}{k_m}+A}\right) \qquad (5)$$

$$\Psi = 1+\left(\frac{1-\Phi_m}{\Phi_m^2}\right)\Phi \qquad (6)$$

Here, k_m is the thermal conductivity of the matrix, k_1 the thermal conductivity of the filler, Φ is filler volume fraction, Φm is maximum filler volume fraction and A is shape coefficient for the filler particles.

4.3. Rules of Mixture-Series and Parallel Model

Rules of Mixtures (ROM) is the basis of following two models[17]:
From the parallel conduction model:

$$k_c = (1-\Phi)\, k_m + \Phi\, k_f \qquad (7)$$

Here k_c, k_m, k_f are the thermal conductivities of the composite, the matrix and the filler respectively and ϕ is the volume fraction of filler.

From the series conduction model:

$$\frac{1}{k_c} = \frac{(1-\Phi)}{k_m} + \frac{\Phi}{k_f} \qquad (8)$$

V. CALCULATIONS AND RESULTS

Following parameters have been assumed for numerical analysis:

- Macroscopic homogeneity of the composites.
- Locally homogeneous and isotropic characteristics of both the matrix and filler.
- Negligible thermal contact resistance between the filler and the matrix.
- The composite lamina is free of voids.
- The problem is based on 3D physical model.
- The filler are arranged in a square periodic array/uniformly distributed in matrix.

Based on the above models, the following results are obtained:

Table:2: Calculations of Density and Voids

Filler (vol%)	**CuO**		
	Actual Density	**Theoretical**	**Void Fraction%**
5	1.100	1.147	4.113
10	1.142	1.199	4.759
15	1.195	1.255	4.793
20	1.250	1.317	5.059
25	1.311	1.385	5.319

Filler (vol%)	**Al_2O_3**		
	Actual Density	**Theoretical**	**Void Fraction%**
5	1.239	1.20	3.15
10	1.379	1.33	3.55
15	1.158	1.46	3.82
20	1.658	1.57	5.30
25	1.797	1.68	6.51

Table 3: Comparison of Experimental Values of Effective Thermal Conductivity[1,2]

S.NO.	**COMPOSITES**	**EXPERIMENTAL WITH CuO AS FILLER**		**EXPERIMENTAL WITH CuO AS FILLER**	
		k_{eff}	**%**	**k_{eff}**	**%**
1	EPOXY +HARDNER	0.363	100	0.363	100.00
2	EPOXY +5% filler	0.492	135.45	0.575	158.40
3	EPOXY +10% filler	0.622	171.27	0.712	196.14
4	EPOXY +15% filler	0.759	208.99	0.896	246.83
5	EPOXY +20% filler	1.014	279.24	1.872	515.70
6	EPOXY +25% filler	1.291	355.66	2.114	582.37

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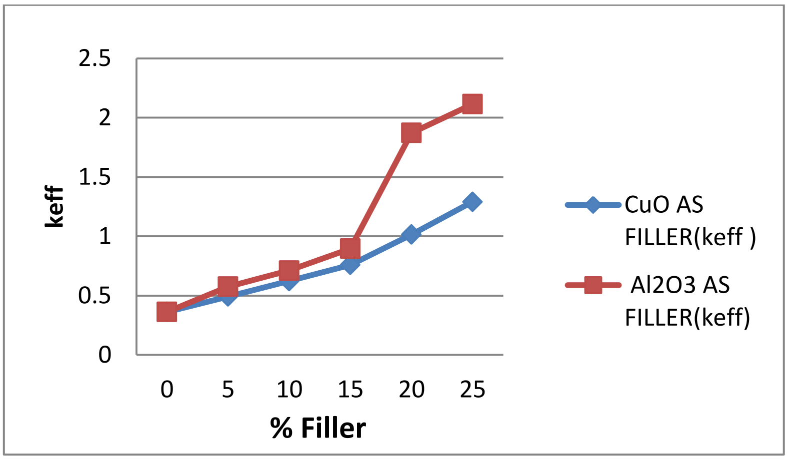

Figure: 1: Comparison of Experimental Values of Effective Thermal Conductivities by [1] and [2]

VI. CONCLUSIONS

It has been concluded that successful fabrication of particulate filled epoxy- composites with filler by hand layup technique is possible. Table 2 presents the theoretical and measured densities for the epoxy – CuO/Al_2O_3 composites and also the corresponding volume fraction of voids in the epoxy-CuO/ Al_2O_3 composites.. It may be noted that the composite density values calculated theoretically from weight fractions are not equal to the experimentally measured values. This difference is a measure of voids and pores present in the composites.

From Table 3 it has been concluded that the value of k_{eff} keeps on increasing on increasing filler content in composite. It is deduced that the results obtained from the various models are in good agreement with experimental results up to a filler concentration of about 15 vol % for epoxy . The CuO and Al_2O_3particles hence show percolation behaviour at these volume fractions (15% for) at which a sudden jump in the thermal conductivity has been noticed. This is the critical concentration, called the percolation threshold, at which CuO / Al_2O_3 particles start contacting with each other within the respective polymer resin.

It is deduced that by incorporating micro-sized CuO particulates into epoxy, the expected effects are achieved in the form of modified physical and thermal properties. Due to the presence of CuO micro-fillers, changes in their heat conduction behavior are seen. When CuO is added to in epoxy, the effective thermal conductivity of the composites is increased due to conductive nature of CuO. It has been found that there is a sudden increase in the composite thermal conductivity at this point of filler concentration.

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