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# The Effects of Copper Additives on the Thermal Conductivity of Epoxy Resin

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**Abstract:** ***A hand lay-up method was used to prepare Epoxy/ Copper composites. Epoxy was used as a matrix with Copper powder was fillers with average diameter (240.91 nm). The preparation method involves preparing carousel mold with different weight percentage of fillers (0, 5, 15, 25, 35, and 45%). Standard specimens (in 30 mm diameter) for thermal conductivity assessments were prepared to test thermal conductivity. The result for thermal conductivity for Epoxy/Copper composites illustration that thermal conductivity increase with increasing weight percentage, For Epoxy/Copper composites, then it have maximum values of (1.502775 W/m .K), Which increased by 123.73% compared with epoxy.***

**Keywords:** Copper, thermal conductivity, Epoxy, Epoxy/ metal composites.

## 1. Introduction

A composite material is a material consisting from two or more than two materials, insoluble in one another, which are combined to form a useful engineering material possessing certain properties not possessed by the constituents” [1].

Polymer composite materials, based on a polymer matrix and Reinforcement particle, have dragged great attention among researchers, due to improvements in different properties including mechanical, thermal, and electrical properties [2].

The properties of the Polymer composite materials depend on the matrix, the reinforcement, and the interphase. Consequently, there are many variables to consider when designing a Polymer composite material. These include not only the types of matrix and reinforcement but also their relative proportions, the geometry of the reinforcement, and the nature of the interphase. Each of these variables must be carefully controlled to produce a structural material optimized for the conditions for which it is to be used [3].

Epoxy resins can be reacted with curing agent to design a cross-linked polymeric construct. Their most outstanding property is their excellent cohesion to both metallic and non-metallic surface. Cured epoxy resins are characterized by their good thermal, electrical conductivity and good mechanical properties. Epoxy resins are type thermosetting resins, used to improve the some properties by addition many particle types of fillers.

In order to obtain material with desired thermal, mechanical, electrical, and physical properties ,polymers mixed with different kinds of fillers are used as matrix materials .The thermal conductivity of composite substance, which are represented as multiphase material, dependent in thermal conductivity, proportion, and the distribution of the phase [4]. The distribution of the phase includes its size, shape, volume reaction, weight percentage, orientation, and conductivity relative to the heat flow direction [5] - [7]. In 2010, Shawky, Asmaa, Harith and Ekram, studied The Effect of metals as Additives on Thermal conductivity of Epoxy Resin. They obtained results show increase thermal conductivity with increasing weight percentage for Ep/Al and Ep/Cu composites. While thermal conductivity for Ep/Fe composite show slight increase [8]

In 2014, Yuan-Xiang Fu, Zhuo-Xian He, Dong-Chuan Mo and Shu-Shen Lu, have studied the $K_{th}$ enhancement with different fillers for epoxy resin adhesives, the $K_{th}$ of all the spacemen's were measured by Hot Disk (TPS-2500) thermal constants analyzer, the highest $K_{th}$ up to (1.68 (W $m^{-1}$ $K^{-1}$)) at (44.3) wt% of the eight thermal adhesives [9].

## 2. Thermal Conductivity

"*Thermal conductivity is the ability of a material to conduct heat. This quantity represents the rate of heat flow per unit time in a homogenous material under steady conditions, per unit area, per unit temperature gradient in toward perpendicular to area.*" [10].

"*Polymers are often utilized as thermal insulators because of their low thermal conductivities. For these materials, energy transfer is accomplished by the vibration and rotation of the chain molecules*."[11].

The mean free bath and the temperature gradient (in equation.1) are due to the random nature of the thermal conductivity processes into the expression for the thermal flux [12]. The heat transfer process depends upon several factors, such as type of material, state of the thermal substance and temperature. Generally there are two mechanisms for heat transfer through a solid material [7].

- In solid conductors the free electrons and lattice vibration are the dominant mechanism of heat transfer.
- The phonons are the exceptional mechanism in solid insulator material. According to the first clear statement proposed by Fourier, heat flow through a substance is proportional to the temperature gradient, as the following relation [13].

$$q = -k\, dT/dX \qquad (1)$$

Where $q$: the flux of thermal energy transmitted across a unit area per unit time, K is the thermal conductivity coefficient, and $dT/dX$ is the temperature gradient. The units of q and k are $W/m^2$ and W/m. k, respectively [14].

Thermal conduction is most conveniently described in terms of the scattering of phonons, by other phonons, or by electrons [15].

Through the fig. 1, the substance S was contained between two copper discs B and C, and the heater between B and a third copper disc A. The temperatures of all the copper discs were measured with a thermometer. When the discs had were assembled they were varnished to give them the same emissivity, and the whole apparatus was suspended in an enclosure of constant temperature. In the theory given below, the following symbols are used [16]:

IV: rate of supply of energy to the heater, after the steady state has been reached.
e: heat loss per second per sq.cm for each 1˚ increase of discs temperature, over that of enclosure.
T: excess of temperature over that of the enclosure.
d: thickness of disc, r: radius of disc.

The heat received per second by disc A and given up to air is:

$$(\pi r^2 + 2\pi\, r\, dA)\, e\, TA \qquad (2)$$

The heat received per second by S and given up to air from its exposed surface or passed on to A is

$$e\, TA(\pi\, r2 + 2\pi\, r\, dA)+2\pi\, r\, ds\, (1/2)(TA+TB) \qquad (3)$$

in terms of IV can be obtained, since the total heat supplied must be equal to that given up by the various surfaces:

$$H=I.V = \pi\, r^2 e\, (TA+TB) +2\pi re\, [(1/2)\, dS\, (TA+TB) + dATA+dBTB +dCTC\, ] \qquad (4)$$

So, thermal conductivity becomes:

$$KT\, ((TB - TA)/dS) = e\, [TA+ (2/r)(dA+ (1/4)\, dS)\, TA+ (1/2r)dSTB] \qquad (5)$$

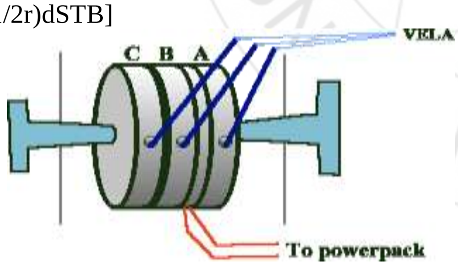


**Figure 1:** Schematic diagram of Lee's disc

## 3. Experimental work

### 3.1 Matrix Material

The matrix material that was utilized is epoxy resin (EP Euxit50). It has a trademark (EP Euxit 50) production of SwissChem is a liquid of low viscosity resin, and it is converted to solid state by adding hardener (Euxit 50 KII) at ratio of (5:2), which were supplied by Egyptian Swiss chemical industries company .The properties of epoxy resin used in this work show in Table 1 according to the properties of Product Company ASTM D-543 and ASTM C-881-87. The chemical structure of epoxy resin is shown in figure 2.

**Table 1:** Show the properties of epoxy material.

| | |
|---|---|
| *Density at 20o C (gm/cm3)* | 1.05 |
| *Viscosity at 20o C* | 300 |
| *Colour* | Colorless |
| *Glass temperature o C* | 57 |

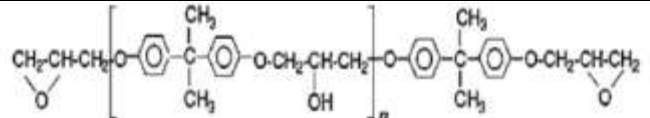

**Figure 2:** Epoxy structure [17].

### 3.2 Copper powder

In this research, Copper powder (Density 8.9 $g/cm^3$ [18] and purity 99.5), was produced by the Company Central Drug House (P) Ltd, Vardaan House, New Delhi-10002, INDIA. The powder was adding to epoxy with weight percentage (0%, 15%, 25%, 35%, and 45%). Atomic force microscope (AFM) was use to determine the average diameter of particals which was (240.91 nm) as shown in Table 2 and figure.3.

**Table 2:** Granularity Distribution for Copper powder and average diameter

| Avg. Diameter:240.91 nm | | | | | | <=10% Diameter:160.00 nm | | |
|---|---|---|---|---|---|---|---|---|
| <=50% Diameter:220.00 nm | | | | | | <=90% Diameter:320.00 nm | | |
| Diameter (nm)< | Volume (%) | Cumulation (%) | Diameter (nm)< | Volume (%) | Cumulation (%) | Diameter (nm)< | Volume (%) | Cumulation (%) |
| 160.00 | 4.35 | 4.35 | 260.00 | 6.52 | 65.22 | 360.00 | 3.62 | 94.93 |
| 180.00 | 9.42 | 13.77 | 280.00 | 12.32 | 77.54 | 380.00 | 2.17 | 97.10 |
| 200.00 | 14.49 | 28.26 | 300.00 | 6.52 | 84.06 | 400.00 | 1.45 | 98.55 |
| 220.00 | 17.39 | 45.65 | 320.00 | 3.62 | 87.68 | 420.00 | 0.72 | 99.28 |
| 240.00 | 13.04 | 58.70 | 340.00 | 3.62 | 91.30 | 480.00 | 0.72 | 100.00 |



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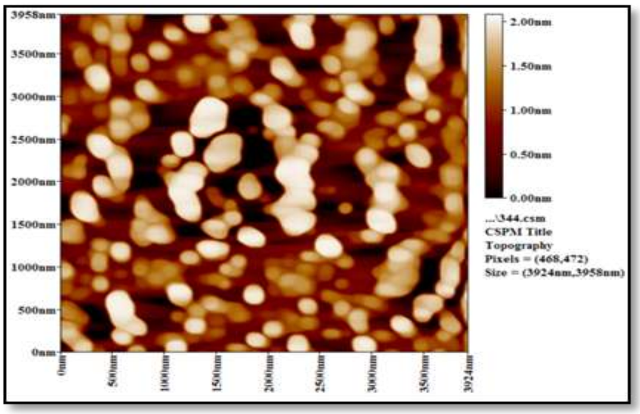
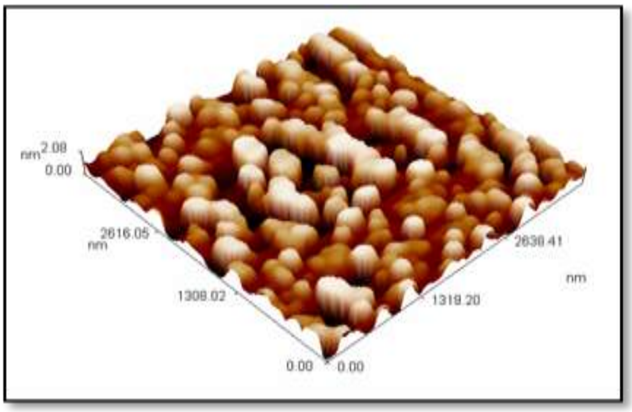
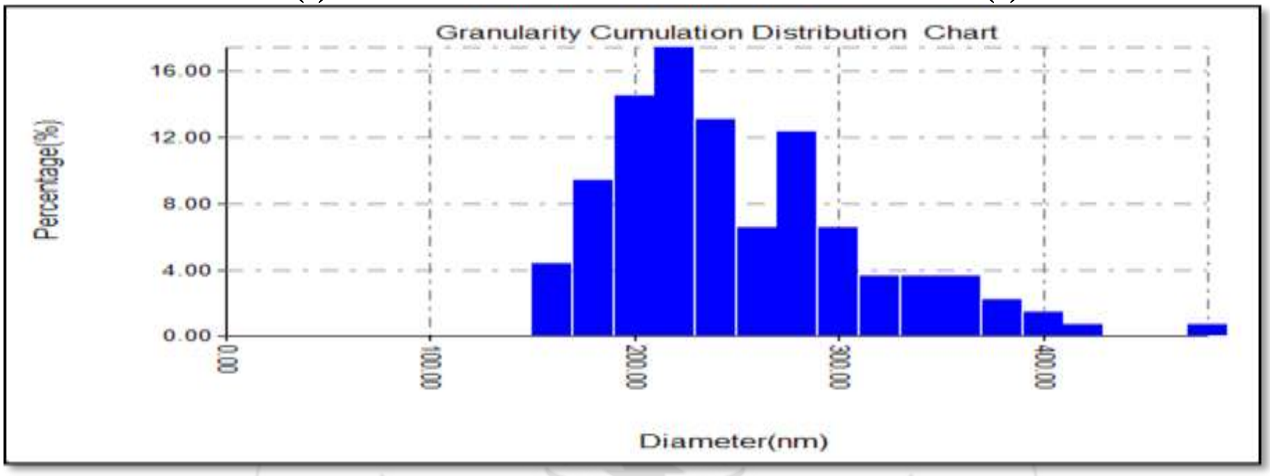



(a)



(b)




(c)

**Figure 3:** AFM image of Cu powder and represents (a) 2D view of AFM image, (b) 3D view of AFM image, (c) Granularity cumulation chart for Cu.

## 4. Composite Fabrication

A hand lay-up method was used to prepare all the specimens in this work .Samples composed of epoxy resin with Copper powder at different weight percentage (0%, 5%, 15%, 25%, .35%, and 45%), and the ratio of Epoxy to hardener is (5:2).To get good homogeneity between epoxy resin and Copper powder, homogenizer device at 700 rpm with 10 minutes to have good distribution for particles in epoxy resin. Vacuum system was used to remove the bubble before cast the composites in earlier prepared mold, blend was then poured into the mould, allowed to cure for 24 hours at room temperature (26 ± 2) $^{o}$C. Lee's disc was used to calculate the thermal conductivity. the prepared samples have a diameter 30 mm as shown in Figure 4 and Figure 5, the temperatures were measured by thermometers to calculate Heat current (H) and thermal conductivity (K) were calculated by using equations 4 and 5 [5]. The experimental values for epoxy (0.671688 W/m. K)

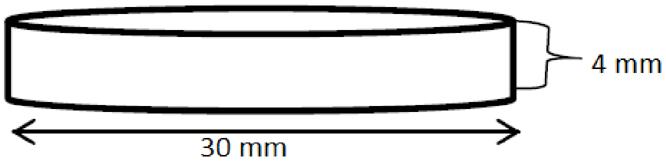



**Figure 4**: Dimension of thermal conductivity Test Specimens


**Figure5:** Photograph of Thermal conductivity Test Specimens for Epoxy and Epoxy/ Copper composites.

## 5. Results and Discussion

Atomic force microscope (AFM) was used to calculate the average diameter partical for Cu (240.91 nm). The results illustration that thermal conductivity (k) values for increase with increasing filler weight percentage, with maximum value (1.5027 W/ m. K) at (45%) Cu for EP/Cu composite, which increased by (123.73%) compared with epoxy, as shown in Table .3

**Table 3:** Thermal Conductivity for Ep/Cu composite

| wt% | V% | K exp ( W/m. K) |
|---|---|---|
| 0% | 0 | 0.671688 |
| 5% | 0.617103 | 0.79167 |
| 15% | 2.039495 | 0.876408 |
| 25% | 3.783784 | 1.248396 |
| 35% | 5.973182 | 1.317728 |
| 45% | 8.802981 | 1.502775 |

Figure 6, Shows the obtained results of thermal conductivity for EP/Cu composites under study state. It is clear that k for EP/Cu composites increase with increasing weight percentage of filler, this can be due to the well separation of the particles, that there is no interaction between them.

The results illustration that the thermal conductivity k increases for all composites .Also it is affected by the weight percentage of additive, this result is agreement with general theory of the thermal conductivity of composites. In polymeric materials, heat is transferred as elastic wave, and because of the existence of an interface (between the matrix and additives) the transfer's motion of these waves are restrained. The transfer of thermal energy as elastic wave is still complex and difficult process since there is disconnection in structure and transference from one phase to another, i.e. the wave loses part of its energy at the interface region between the matrix and the reinforcement materials [19].

The increase in thermal conductivity is due to the fact that copper is a good heat conductor and its value of thermal conductivity (398 W/m. K) [18].

Add a certain percentage of copper to epoxy led to an increase in thermal conductivity Compare with value Epoxy pure. This is due to the proliferation of copper granules randomly in Epoxy according to the manufacturing process having these particles play an important role in the process of Thermal conductivity.

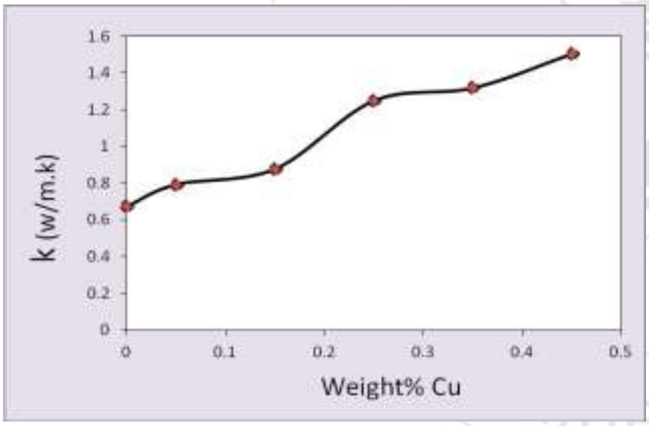



**Figure 6:** Thermal conductivity V.s Cu weight percentage for Ep/ Cu composites.

## 6. Conclusion

Composites were preparation using Epoxy as a matrix with Copper particles as fillers with different weight percentage (0%, 5%, 15%, 25%, 35%, and 45%). Thermal conductivity for EP/Cu composites were increase with increasing weight percentage from fillers, the maximum value (1.502775 W/m. K) at (45%) Cu, Which increased by (123.73%) compared with epoxy.

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