The Effect of metals as Additives on Thermal conductivity of Epoxy Resin

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Abstract

A hand lay-up method was used to prepare Epoxy/ metal composites. Epoxy resin (EP) was used as a matrix with metal particles (Al, Cu, and Fe) as fillers.

The preparation method includes preparing square panels of composites with different weight percentage of fillers (10, 20, 30, 40, and 50%). Standard specimens (88mm in diameter) for thermal conductivity tests were prepared to measure thermal conductivity k_{exp}.The result of experimental thermal conductivity k_{exp}, for EP/metal composites show that, k_{exp} increase with increasing weight percentage, For EP/ Al and EP/Cu composites, and it have have maximum values of 0.33 and 0.35 W/m.K, respectively. While k_{exp} for EP/ Fe composite show slight increase with maximum value of 0.186 W/m.K. The results show that the best values for thermal conductivity is for EP/Cu composite which has the maximum value of k_{exp} 0.35 W/m.K.

Keywords
EP, composite
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تأثير المضافات المعدنية على التوصيلية الحرارية لراتنج الايبوكسي

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الخلاصة

تضمن البحث تحضير متراكبات الايبوكسي /معدن باستخدام طريقة الخلط اليدوي .لغرض تحضير العينات تم اعداد الواح متراكبة ذات اشكال مربعة وبنسب ملئ مختلفة (10% , 20 , 30 , 40 , 50) من ثم تقطيعها الى عينات قياسية لغرض استخدامها في الفحوصات الحرارية حيث تم قياس التوصيلية الحرارية .بينت النتائج العملية للفحوصات الحرارية للمتراكبات ذات المضافات المعدنية أن. التوصيلية الحرارية تزداد بزيادة النسبة الوزنية لكل من المتراكبات (EP/Al, EP/Cu) ولأعلى قيمـــة (0.35W/m.K ، 0.33W/m.K) على التوالي بينما بينت متراكبات (EP/Fe) تزايد طفيف في التوصيلية الحرارية بزيادة نسبة المضافات ولأعلى قيمة 0.186 W/m.K . النتائج المستخلصة اظهرت ان المتراكبات ذات المضافات المعدنية للنحاس أعطت أفضل نتائج من حيث زيادة التوصيلية الحرارية .

Introduction

Epoxy resins are basically thermosetting resins, which can be reacted with curing agent to form a cross-linked polymeric structures .Their most outstanding property is their excellent adhesion to both metallic and non-metallic surface

Cured epoxy resins are characterized by their good mechanical properties, thermal and electrical insulation properties. Many particle types of fillers are used to improve the other properties of matrix materials such as mechanical, thermal and electrical conductivity

Thermal conductivity:

Thermal conductivity under steady conditions means, the quantity of heat flow in unit time through a unit area of a substance caused by a unit thermal gradient [1].The mean free bath and the temperature gradient (in equ.1) are due to the random nature of the thermal conductivity processes into the expression for the thermal flux [2].

The heat transfer process depends upon several factors, such as type of material, state of the thermal substance and temperature. Mainly there are two mechanisms for heat transfer through a solid substance [3].

1- In solid conductors the free electrons and lattice vibration are the dominant mechanism of heat transfer.
2- The phonons are the unique mechanism in solid insulator substances.

According to the first clear statement proposed by Fourier, heat flow through a substance is proportional to the temperature gradient, as the following relation [1]

$$J=-kdT/dx \qquad (1)$$

Where J: 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.

Thermal conduction is most conveniently described in terms of the scattering of phonons, by other phonons, or by electrons [4].

Heat Flow Theory

The phenomenons of heat flow sometimes make the basis for the definition of temperature equality. When a steady state has been attained, the rate at which heat is conducted across the sample disc (shown in Fig.1) is equal to the rate at which it is emitted from the exposed surface of the metal slab at D3, k is the thermal conductivity of sample disk D2, A its surface area and the readings of the thermometers, in the steady state, are T1and T2, so that, dT represent the heat flowing across a section of the sample at the coordinate x, during the time interval dt between t and t + dt, the ratio (dT/ dt) represents the heat flow per unit time ,as aresult , the heat current H is equal to [4].

$$H=mcdT/dt \qquad (2)$$

Where m = is the mass of the lower disc (kgm)

c= is the specific heat for the upper and lower discs

The thermal conductivity k of the material is defined at the heat current per unit area, which is perpendicular to the flow, and per unit temperature gradient

$$k=Hb/A(T_1-T_2) \qquad (3)$$

Where A =the area of the specimen (πr^2) ($m^{2)}$, r is the radius of the specimen, and b is the specimen thickness (m).

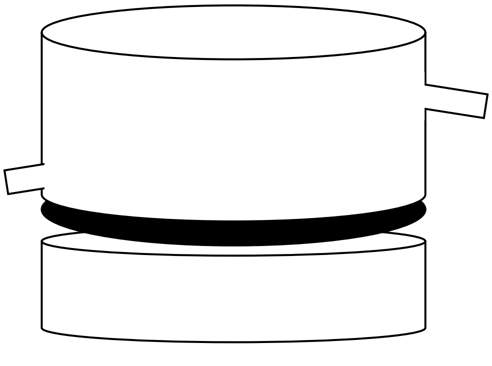

Fig. (1) Schematic diagram of Lee's disc.

Thermal Conductivity in Composites

In order to obtain material with desired thermal, mechanical ,electrical ,and physical properties ,polymers [mixed with deffrent kinds of fillers (fibers or particals)]are used as matrix materials .The thermal conductivity of compsite materials , which are represented as multiphase substance , depends upon thermal conductivity ,proportion,and the distribution of the phase [5]. The distribution of the phase includes its size, shape ,volume reaction,weightpercentage,orientation,and conductivity relativeto the heatflow direction [6,7,and8].

Agari et al. (1990), studied thermal conductivity of a polymer (PS and PS composite), filled with particles (quartz or Al_2O_3) of wide range of volume concentration. The obtained results show increase in thermal conductivity within a wide range (from low to super-high) of filler con In order to obtain materials with desired thermal, mechanical, electrical and physical properties, polymers [mixed with different kinds of fillers (fibers or particles)] are used as matrix material. The thermal conductivity of composite materials, which are represented as a multiphase substance, depends upon thermal conductivity, proportion, and the distribution of the phase [5]. The distribution of the phase includes it's size, shape, volume reaction, weight percentage, orientation, and conductivity relative to the heat flow direction [6, 7, and 8].

tent [9].Torquto and Rintoul (1995) studied the effect of interface on the properties of composite media for metallic particles in epoxy matrices for various volume friction They developed rigorous bounds on the effective thermal conductivity k_{exp} of dispersion. [10].

Tavaman (2002) studied models predicting the effective thermal conductivity of composites filled with particles .His results were compared with experimental data of micro sized Al_2O_3 particles filled with HDPE composites [11].

Aim of the work:-

The main objectives of this study is to prepare and test samples of particulate composite, which consists of epoxy resin as a matrix, with metal particles (Al, Cu, Fe) of different weight percentage (10,20,30,40,and 50 %). as fillers .The research aims to study the effect of filler weight percentage and its type on the thermal conductivity of the composite.

Experimental

Preparation of Composite Samples

For thermal tests, the procedures of preparing EP/Cu, EP/Al, and EP/Fe, composites respectively with different additive weight percentage (10-50 weight percentage) were almost similar.

Materials Used

The materials used to prepare the test samples ware epoxy resin (EP10 Conbextra) supplied by Fost Company with the hardener aliphatic amine (HY 956) as a matrix and metal particle Al, Cu, and Fe with averge partical size 10.2 ,15.01, and 21.4 μm respectly (of purity 99.5%) as fillers. Table (1) summarizes the materials and some of their properties.

Table (1) some of properties of the used material

Material	Sample	Density (g/cm^3)	Thermal conductivity (W/m.K)
Epoxy	EP	1.2	0.19
Aluminum	Al	2.7 (12)	247(12)
Iron	Fe	7.3 (13)	80 (13)
Copper	Cu	8.9 (14)	398 (14)

A hand lay up method was used to lubricate all the specimens in this work according to these steps:

Many testes showed that the ratio of hardener to epoxy, which will be used in this study, is approximately [3:1]. To prepare the composite sheets, which ware cut later to get the thermal specimen samples: the metal powder was added to the epoxy ,stirred for 5 minutes to be well mixed and for more diffusion the mixture was put in the oven at 50°C for 15 minute. The mixture was then left for 24 hours for curing **.**

All prepared sheets were checked by optical microscopic to see the good dispersion of the particles distribution.

Apparatus

For thermal tests, Lee's disc was used to calculate the thermal conductivity .the prepared sampels have adiameter 88mm and the thickness of these specimens were measured by screw gauge, also, the temperatures were measured by thermometers to calculate heat current Heat current (H) and thermal conductivity (K) were calculated by using eq. (2) and (3).The ratio T/t in the H eq. is obtained from the slope of Temp. vs time curve [6].The apparatus were calibrated using epoxy as a standard .The standard value which are given by the suppliers and the experimental values for epoxy are shown in Table (2), it have been seen that the experimental value have agood agreement with the standard value of epoxy given with error 5%.

Table (2) The standard and experimental values of k_{exp} for EP

Material	Published value k (W/m.K)	Experimental value k_{exp}(W/m.K)
EP	0.19 [13]	0.201

Thermal Conductivity Results

The results show that k_{exp} values for increase with increasing filler weight percentage (wt %), with maximum value 0.332 W/m.k at 50% filler weight percentage for EP/Al composite and of .351 W/m.K at 40% filler weight percentage for EP/Cu composite as shown in Table (3).

Table. (3) Thermal conductivity k_{exp} for EP/Al composite

wt%	V%	kexp (W/m.K)
0		0.201
10	0.047	0.215
20	0.100	0.242
30	0.160	0.3262
40	0.228	0.317
50	0.307	0.332

Table. (4) Thermal conductivity k_{exp} for EP/Cu composites

wt%	V%	kexp (W/m.K)
0	0.000	0.201
10	0.0147	0.214
20	0.0326	0.220
30	0.0547	0.284
40	0.0825	0.352
50	0.1349	0.3481

Table. (5) Thermal conductivity k_{exp} for EP/Fe composites

wt%	V%	kexp (W/m.K)
0	0.000	0.201
10	0.0179	0.175
20	0.0395	0.186
30	0.0706	0.166
40	0.0988	0.1788
50	0.1412	0.186

While the values for EP/Fe composite increase slightly with increasing weight percentage with a maximum value 0.186W/m.k at 50%.

Discussion

The obtained results show that the type and weight percentage affect thermal conductivity of the composite.

Thermal Conductivity Results for EP/Metal composites

Figure (2) shows the obtained results of thermal conductivity for the three composites under study state. It is clear that k_{exp} for EP/Cu composites increase with increasing wt% of filler, this can be due to the well separation of the particles, that there is no interaction between them. This behavior agrees with the results which obtained by Garrett and Roseberg [16], EP/Al composite give the same behavior at 30% but it decreases at high weight percentage .This can be explained that Al particles size are smaller than Cu particles as seen in figures 3 and, 4. At higher weight percentage the particles agglomerate and interact among themselves .This behavior agrees with that obtained result by Hasselman and Johnson [17].In spite of the high thermal conductivity of Fe,but the thermal conductivity of EP/Fe composites has increased only slightly with increasing filler weight percentage. This is because of the precipitation of filler particles, which lead to the formation of two layers with less homogeniety in particle distribution as shown in fig (5) .

The results show that the thermal conductivity k increase for all composites .Also it is affected by the kind and weight percentage of additive ,this result is in a good agreement with general theory of the thermal conductivity of composites ;which has been predicted that the addition of a second phase with thermal conductivity k different than that of the matrix can be major effect on the thermal conductivity k of the resulting composite [18]. 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. This behavior agrees with the results obtained by Resan [19].

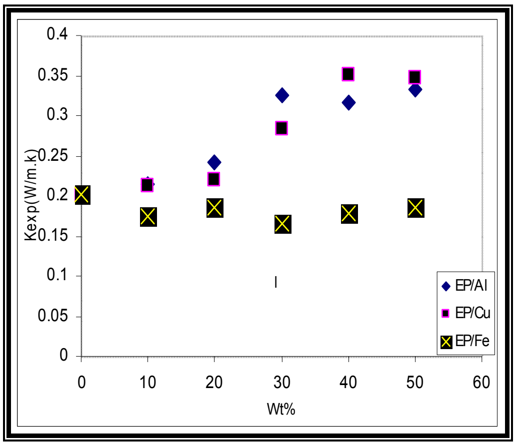

Fig. (2) K_{exp} v.s wt% of EP/ metal of composites.

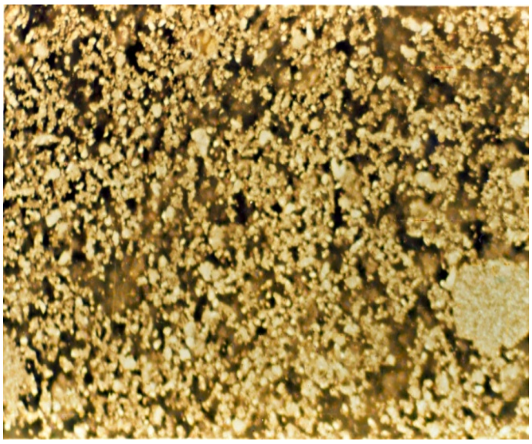

Fig. (3) The distribution of metal particle for EP/ Al composite (X 20).

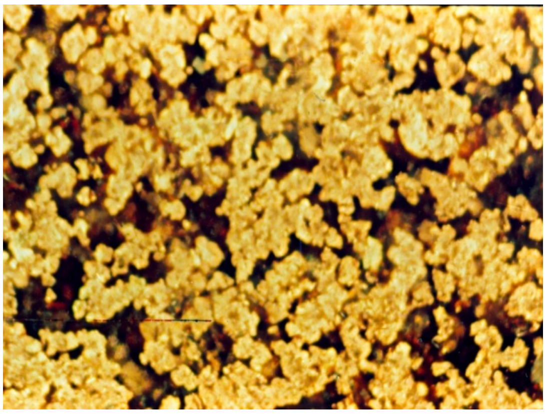

Fig. (4) The distribution of metal particles for 70%EP/ 30%Cu Composite (X 20)

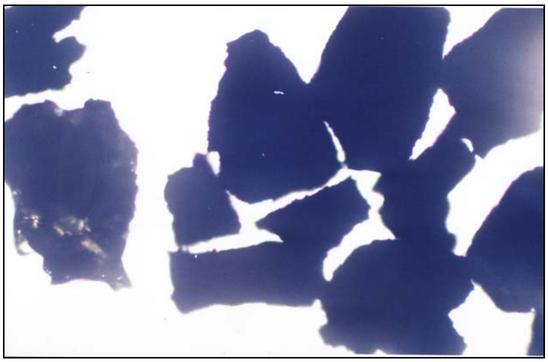

Fig. (5)The distribution of metal particles for 70%EP/ 30%Fe composite(X20)

General conclusions

The following conclusions and observations can be made concerning this study.

Thermal conductivity measurements show that k_{exp} for EP/ metal composite increase with increasing filler weight percentage for both of EP/Al ,and EP/Cu except EP/ Fe composite which show a slight increase.

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