



Electrical and Thermal Conductivity Performance of epoxy/SiC Composite Prepared by a Modified Apparatus

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Abstract

In this study, epoxy composites are prepared by the centrifugal mixing method. The effects of Silicon Carbide (SiC) as a reinforcement material due to its weight percentage (wt. %), SiC particle sizes and mixing speed on electrical and thermal conductivity are investigated both experimentally and theoretically. The perfect dispersion of ceramic particles on the surrounding of the sample edge is found to be improved significantly and increases both electrical and thermal Conductivity. Additionally, both are increased with the decrease in the particle size, SiC wt. % and the mixing speed. It can be attributed to the particle to particle adjoining that is created between ceramic particles and epoxy and the electron transporting. Therefore, as the manufacturing of the polymer composite on large scale is more promising ascribable its acceptable cost, low weight and could prepare ease, it can be considered for the industrial heat transfer. Compared to carbonic particles, metallic and ceramic particles are more effective at enhancing the thermal conductivities of polymer nanocomposites.

Introduction

Polymer materials have been utilized as matrices to incorporate a variety of fillers for decades. Polymers have a low density, shape-accessible residence, and various advantages from their physicochemical features of macromolecular connections. Filling polymer matrices with fillers has long been regarded to be a better approach to combine the significant differences of each and, as a result, provide an advanced cucumber for specific applications in nanotechnology through PNCs. The selection of fillers must be carefully considered when relying on the ultimate or favored features of PNCs. Indeed, high thermal conductivity polymer composites have piqued interest in heat dissipation applications to control large amounts of heat generated by integrated circuits [1-17]. In the electronic and nanotechnology industries, electrically conductive polymer composites offer a wide range of applications. They offer unique features that enable them to be used as a smart material for sensors, printable electronics, optoelectronics, and various other uses [18-22]. However, in balancing the composites' complete bundle of homes, obtaining hybrid conductivities is a challenging aim. However, using one or more fillers while maintaining the mechanical residences of the polymer matrix -

with the growth of a variety of fillers grow - becomes more difficult. Since the beginning of polymer composites, various fillers have been used to incorporate into the polymer matrix. [23] Particles are divided into two sizes: microparticles and nanoparticles (NPS). Organic and inorganic NPs, for example, has lately been researched and can be divided into distinct categories based on their physical or chemical properties. [24]. PNCs have particles with at least one dimension of less than 100 nm, unlike conventional micro-composites, which have particles with typical dimensions on the micrometer scale. When NPS are used as fillers in polymer matrices, this phenomenon can provide an advantage, allowing for the creation of PNCs with improved performance.

SiC was employed to increase the wear resistance of epoxy in previous studies [25], and the current study intends to investigate the electric characteristics of epoxy/SiC composites generated using a new mixing technique. This study aimed to reduce the electric resistance of epoxy by introducing SiC particles of various sizes and weight percentages. In addition, the impact of mixing speed was investigated. Researchers must first understand heat transfer since it is the transfer of thermal energy from a hot to a cold body to understand thermal conductivity in materials. It can occur in a variety of circumstances:

1. When an object's temperature differs from that of its environment;

2. When an object has a temperature that is different from everything else around it, it has a temperature gradient.

The second law of thermodynamics indicates that the entropy of an isolated system that is not in thermal equilibrium tends to increase over a year, reaching a maximum value at equilibrium. This point implies that heat transfer from a higher to a lower temperature object is always present and will continue until thermal equilibrium is reached. Conduction, convection, and radiation are the three methods through which thermal energy is transported. Each mode has its heat transmission mechanism and pace. As a result, the rate of heat transmission in a given situation is dictated by the prevalence of a particular model.

Conduction is mainly defined as transferring thermal energy via a mixture of electron diffusion and phonon vibrations in which solids are affected by this type of heat transfer mode.

Convection transfers thermal energy from a hot gas/liquid to a colder medium in a moving medium (generally due to density differences).

The transfer of heat energy by electromagnetic waves is known as radiation. The sun has been observed to transfer energy through a (near) vacuum. [26]

Materials and Methods

Table 1 shows the full details of the materials used in the investigation. The description of mixing details and apparatus techniques were explained in the previous work [25].

Electrical Conductivity

The amount of electric conductivity (EC) is calculated by measuring the resistance of samples at different contents and sizes of SiC and different mixing speeds. Table 2 shows the full details of each sample. Resistance values were measured according to the ASTM standard D257 by the insulation tester megger (MIT515) model (figure 1). The samples were cylinders with 13 mm diameter and 90 mm length, detailed in table 2. The test was performed according to the following steps:

Fixing the sample for 30 sec. to stabilize the pressure.

Running the electrical current for 1 min.

Taking the reading.

The reading is an average of three readings.

Resistivity values were calculated by the following equation (1):

$$\rho = (RAc)/h \quad (1)$$

where

ρ : resistivity (Ωmm),

Ac: area of the electrode (mm^2)

h : the average thickness of the samples (mm).

R: resistance(Ω).

then, the electric conductivity (S/m) is expressed as:

$$\sigma = 1/\rho \quad (2)$$

Table 1. Details of the primary materials

Polymer	Kemapoxy 150 JM CMB International, Egypt	Density at room temperature	1.15 \pm 0.02 kg/l
		Compressive strength	500 - 1000 kg/cm ²
		Tensile strength	150 - 250 kg/cm ²
Ceramic	SiC (Sigma Aldrich, Germany)	Size of microparticle (M)	>25 μm
		Size of ultrafine particles (UF)	>90 nm



Figure 1: Measuring resistance values by insulation tester megger (MIT515) model.

Table 2. Details of each sample

Sample No.	SiC particle size, (wt%)	Mixing speed (Hz)
1	UF, 10 %	10
2	UF, 10 %	20
3	UF, 10 %	30
4	UF, 20 %	10
5	UF, 20 %	20
6	UF, 20 %	30
7	UF, 30 %	10
8	UF, 30 %	20
9	UF, 30 %	30
10	UF, 5 %+ M, 5%	10
11	UF, 5 %+ M, 5%	20
12	UF, 5 %+ M, 5%	30
13	UF,10%+ M, 10%	10
14	UF,10%+ M, 10%	20
15	UF,10%+ M, 10%	30
16	UF,15%+ M, 15%	10
17	UF,15%+ M, 15%	20
18	UF,15%+ M, 15%	30
19	M,10%	10
20	M,10%	20
21	M,10%	30
22	M, 20%	10
23	M, 20%	20
24	M, 20%	30
25	M, 30%	10
26	M, 30%	20
27	M, 30%	30

Thermal conductivity

Some phonon modes are frequently used to ensure conduction and heat transfer in materials. [27,28] The conventional Debye equation is used to predict the thermal conductivity of polymers theoretically:

$$\lambda = (C_p \times v \times l) / 3 \quad (3)$$

As C_p denotes the capacity of heat, it refers to phonons average speed while l denotes the phonon mean free path, and C_p denotes specific heat capacity. Amorphous polymers have low thermal conductivity because l is often small increment with the degree of crystallinity as seen for semi-crystalline

polymers; for example, when determining PTFE (polytetrafluoroethylene). [29] Metallic fillers with competent conduction capacities can be inserted into the polymer matrix, using the mechanical properties of polymers, where proper conductivity and desired electrical conductivity are required, as in metal. [30,31]. Nevertheless, this procedure is always followed by a decrease in the polymer's mechanical characteristics and raising the composite material's density. Ceramic fillers are used when the emphasis is on thermal conductivity while preserving a reasonably high electrical resistance. Ceramics such as aluminum nitride (AlN), boron nitride (BN), and silicon carbide (SiC) have aroused interest in this respect. [32].

However, various factors, including filler packing density, particle measurement and size, surface treatment, and mixing procedure, limit the usage of this type of filler. [33-37] The volume fraction of filler is proportional to this model, given by the equation [32].

$$\lambda_c = \lambda_p \times \phi_p + \lambda_m \times \phi_m \quad (4)$$

λ_c , λ_p , and λ_m refer to the thermal conductivities of the composite, the filler, and the polymer matrix, respectively. ϕ_p and ϕ_m are the volume fractions of the filler and the polymer matrix, respectively. The parallel model increases the contribution of the conductive section in a percolating network and maintains complete contact among the conductive fillers. This model overestimates the thermal conductivity of the composite. It is appropriate in particular conditions, such as the direction of fibers in a continuous fiber composite. The series model in equation one determines the lower bound of effective thermal conductivity.

$$(1/\lambda_c) = (\phi_p / \lambda_p) + (\phi_m / \lambda_m) \quad (5)$$

The conductive phase's contribution is dependent on the polymer portions around the fillers, as there is no direct contact between particles or fillers. Typically, the experimental values of the composite's thermal conductivity lie between these two estimates from simple models, as shown in Fig. 2.

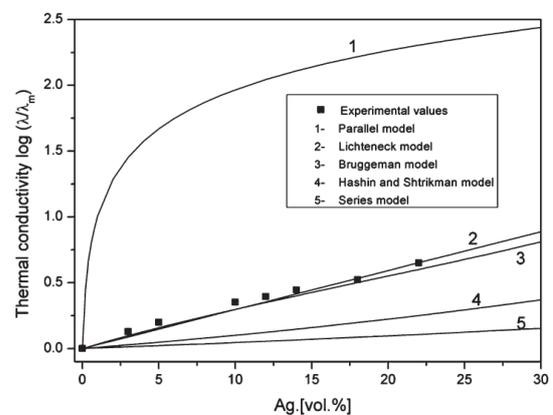


Figure 2: Experimental verifications and theoretical models [27].

Table 3 shows error % of obtained experimental results by Che et.al [28], the values show that the error % in the mathematical models did not exceed

0.06%. on the other hand, same results were obtained by Jouni et. Al[27], they also found that mathematical models can calculate the thermal conductivity with high accuracy.

Table 3. Thermal properties of polymer based on a range of fillers [28]

Wt.% content of SiC	λ_m (W/mK-1)	λ_f (W/mK-1)	λ_C (W/mK-1)	Error % in (λ_m) values	Error % in (λ_f) values	Error % in (λ_c) values
4	0.32	35-70	0.64	0.02	0.06	0.03
13	0.32	35-70	0.57	0.04	0.03	0.06
21	0.32	35-70	0.52	0.02	0.04	0.05

Results and Discussion.

Electrical conductivity

Polymer composites were prepared with different sizes, weights % of SiC (wt%), and mixing speed. To identify the changes in electric properties for each sample due to electric conductivity, values were measured. Figure (3) shows the conductivity values as a function for each sample. The figure shows that the particle size, wt%, and mixing speed significantly affect the electrical conductivity values. Electric conductivity (EC) increases with the decrease of the SiC particle size and wt%. On the other hand, it is decreased by the increase of the mixing.

It can be observed that by increasing the mixing speed from 10 to 30 HZ, (EC) values decrease by fixing the SiC particle size and wt% values.

On the other hand, it can be observed that the ultra-fine SiC particle sizes show more enhancement by increasing the EC 3 times than the micro size by fixing the wt% and mixing speed. Furthermore, it can be observed that by increasing the wt%, the EC values decreased from 0.2 to 0.5 times with fixing the SiC particle sizes and mixing speed.

It is noted that the size of the reinforcement particles has a greater impact on the electric conductivity than the size of the matrix particles or the mixing speed. Furthermore, decreasing the size of both the reinforcement and matrix particles adds an increase in the EC. The increase of EC of composites and matrix could be attributed to the electron scattering at the SiC interface,

It appears from electric conductivity results that the particle size significantly affects the electrical

conductivity values. That means the micro size samples showed lower electric conductivity than ultra-fine samples, regardless of mixing speed. This result is due to electron-transporting through SiC and the electron scattering at the SiC and epoxy interface. Also, the voids formed during the mixing process can be one of the other factors affecting the electron moving and reducing the electrical conductivity. The electron is carried through SiC, which causes grain boundaries to expand and the matrix's microstructure to alter due to SiC inclusion [38]. The collapsed voids and their dispersion affecting with the particle sizes in the current movement across the cross-section, as shown in the previous work [25]

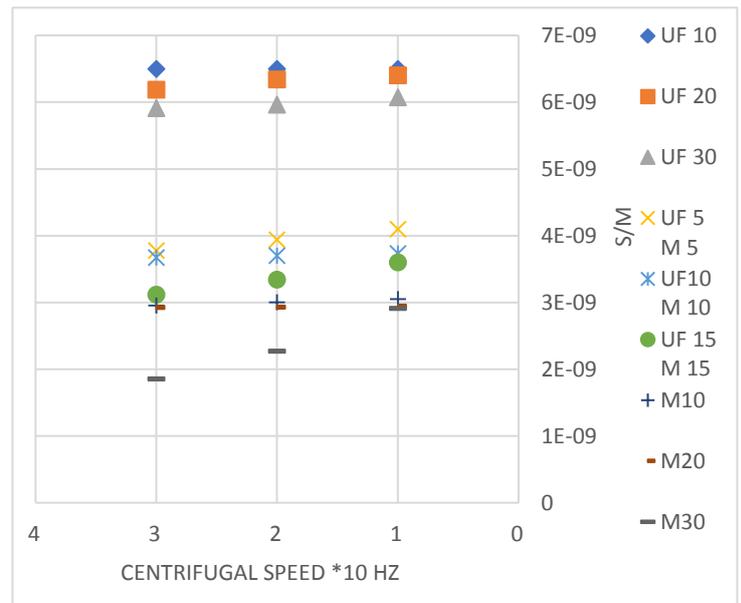


Figure 3: Conductivity values as a function for each sample.

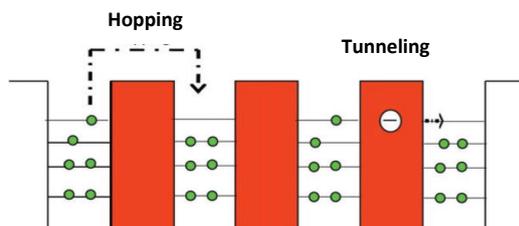
The filler concentration determines the possibility of forming a percolating network that causes change to a conducting phase from insulating. [39] This shift occurs to ensure that conductive fillers receive the necessary attention (pc). The conductive particles are scattered at low concentrations and are less likely to come into direct touch.

The possibility of making direct connections between conductive particles grows as the filler concentration rises until it reaches critical concentration pc. The electrical conductivity of the composite increases dramatically (usually by several orders of magnitude).

Mechanisms of electronic transport in CPC Electronic conduction is represented by one of two major models, based on the insulating barriers' size, in an electrically inhomogeneous medium characterized by the coexistence of strongly conducting patches separated by insulating barriers. Charge transport between arbitrarily distributed localized electronic states is defined in these two models, which follow either a versatile range hopping (VRH) or a fluctuation-induced tunneling (FIT) mechanism. [40]

Thermally active jumps between localized electronic define the charge transfer indicates that they are randomly dispersed in energy and position

(Fig. 4), as suggested by Mott and Davis[41]; the temperature dependence of electrical conductivity in the FIT model. Because they give strong fits to experimental data for electrical dc conductivity as a function of temperature, these two approaches have been widely employed. [42-44]



Thermal conductivity

Figure 4: Different electron transfer mechanisms[27]

The crystalline content material, as expected, has a role in improving thermal conductivity. Some information can be gleaned when comparing high-density polyethylene (HDPE) to low-density polyethylene (LDPE).CPCs packed with metallic or ceramic particles have thermal homes. The addition of CNT fillers was not required for the manufacture of thermally performing CPCs. To achieve good thermal characteristics, further kinds of fillers, for example, metallic or metallic oxide particles, were used. Table 5 provides some examples to go along with this research. As examples of amorphous and semi-crystalline matrices, it focuses on epoxy and polyethylene (PE). These composites have a much higher thermal conductivity increase than PNCs packed with CNTs. References [45-47] found epoxies with excellent thermal conductivities. In addition, the PE matrix elicits proper augmentation using micrometric fillers. The thermal conductivity increased as the particle measurement dropped for the same type of filler and matrix.

These effects reflect the composite's ability to switch heat amends when steel fillers are used. In contrast to big Ag particles, this is the case with epoxies loaded with Ag-NPs. In contrast to composites crammed with CNTs, this needs to be credited with the unique residences of particle-particle interactions and particle-matrix interfaces.

Conclusions

The consequence of mixing speed, wt.%, and particle size of SiC particles on the electric and thermal conductivity of polymer composites are inquired. The outcomes observed that both the electrical conductivity and thermal conductivity increase with the decrement in the particle size, SiCwt %, and the mixing speed.

Therefore, as the manufacturing of the polymer composite on a large scale is more promising ascribable its acceptable cost, low weight, and could prepare ease, it can be considered for the industrial heat transfer.

Metallic and ceramic particles outperform carbonic particles in enhancing the thermal conductivities of polymer nanocomposites. This is most likely owing to enhanced particle-particle contact and particle-matrix interaction, which increases the heat transmission capacity of the polymer composite. Furthermore, the thermal conductivity appears to change more when the particle size is reduced for the identical particle scenario.

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Conflicts of interest

There are no conflicts to declare

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