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ORIGINAL STUDY

Measurement of Thermal Conductivity of Epoxy Resin Reinforced With Different Weight Ratios of Glass and Carbon Powders

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Abstract

The effect of thermal conductivity was studied on the composites prepared before and after reinforcement with different weight fractions (10, 20, 30, 40, 50, 60 wt %), using a Disc Lee's device, and the dispersion of the filler was studied by morphological analysis of the complexes using scanning electron microscopy (SEM). The (SEM) of glass composite powders, showed a smooth surface with a chance of forming very few voids, clusters and blisters on the surface of the sample, which increased with the increase of the weight fractions of the filled powder. While the composites filled with carbon powders show smooth and free from micro-cracks with the chance of formation of some flakes on the surface, whereby, as the weight concentrations of powders rise, transform to rough surface with micro-cracks and voids which revealing that the surface was porous. The results also showed that adding these powders to the epoxy resin has an effect on the thermal conductivity of the prepared composites, implying that there is a direct relationship between the thermal conductivity as a function of the weight ratios of the reinforcing materials, as the thermal conductivity values increase with the increase in the weight ratios for all samples, but differ from one reinforcement to another, with the highest value being at a weight ratio of (60 wt %), which raised the conductivity by (34.511% ± 0.031) and (26.488% ± 0.045) for glass and carbon composites, respectively, in comparison to pure epoxy resin. The results also revealed that the thermal conductivity of epoxy glass composites is greater than that of carbon composites at all reinforcing material weight fractions.

Keywords: Thermal conductivity, Epoxy resin, Polymer composite, Glass powders, Carbon powder, Lee's disk

1. Introduction

Polymers have replaced metals in many applications because they are chemically stable and corrosion resistant, and because most polymers are now made as lightweight hard and soft materials, they are used as insulating materials due to their low thermal and electrical conductivity because they do not contain the most free electrons [1]. Contemporary science and technology have resulted in certain organizational changes as well as the advent of a new generation of polymers that combine the electrical capabilities of conductive and semiconductor materials with mechanical and chemical properties [2].

Polymeric composites based on polymer- and particle-supporting polymers have piqued the interest of researchers due to a wide range of features such as thermal, mechanical, and electrical properties [3]. This is accomplished by combining polymers as a base material with a variety of fillers. The thermal conductivity of the composite material, which is depicted as a multiphase material, is one of these properties, and the thermal conductivity is affected by the weight fractions of the reinforcing components as well as the phase distribution [4,5].

Epoxy resin is a thermosetting resin that may react with a variety of backing materials to create a solid, cohesive polymeric structure. Its most notable properties are its exceptional adhesion to metallic and non-metallic surfaces, strong thermal conductivity, and low coefficient of thermal expansion to disperse heat [6]. Furthermore, the reinforced epoxy resin has good thermal and electrical conductivity as well as good mechanical properties and is used to improve some properties by adding many different

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types of particles from the fillers [6], making studying the thermal and mechanical properties of such materials and possibly future materials very important. Several sophisticated materials have been developed for this purpose in order to achieve the desired properties [7].

The major goal of this research is to investigate the effect of adding different weight fractions of glass and carbon powders to epoxy resin on its thermal characteristics in order to produce a composite material with thermal applications.

- Thermal conductivity:

Thermal conductivity (K) is a measure of a material's capacity to conduct heat, and it happens when thermal energy is transported from high-temperature areas to low-temperature parts. Thermal conductivity is determined as the quantity of heat transported in 1 s divided by the temperature gradient, as shown in the following equation [8,9]:

$$k=\frac{Q/t}{dT/d} \tag{1}$$

Where (K) is the coefficient of thermal conductivity and its unit is (W/m.K).

(Q) The amount of heat.

(t) The transfer time of thermal energy.

It is a mechanism whereby heat is transferred in solid materials through conduction, and both free electrons and lattice vibration waves (phonons) contribute to the thermal conduction process [10,11]. As a result, the sum of the two contributions equals the total thermal conductivity [12].

$$\mathrm{K}=\mathrm{K}_1+\mathrm{K}_e \tag{2}$$

Where K_e and K_1 represent the thermal conductivity and lattice vibration of electrons respectively, and the value of (K) increases with increasing temperature.

Heat is transferred in insulating materials such as polymers as a result of the oscillation of molecules that transfer this vibration to neighboring molecules as a result of bonds linking them together, and thus the oscillation in the material is transferred from the hot side to the cold side through quantized elastic waves known as phonons [13]. Phonons are defined as quantum patterns of vibration that occur in a solid crystal lattice and are the basic mechanisms of heat transfer in most polymers, as the free movement of electrons is not possible [14].

Many factors can significantly affect polymer thermal conductivity, including polymer density, chemical components, molecular bonding strength, polymeric chain orientation, crystal structure, degree of crystallization, structure type, molecular weight of side groups, molecular density distribution, type, and strength structural defects, processing conditions, temperature, and pressure [15].

The weight fraction of the filler and the thermal conductivity (K) of polymeric materials are mainly connected to the enhancement of thermal conductivity (K) [9]. The properties of the powders of the particles have large impact on the thermal conductivity of the composite, as the thermal conductivity systems that contain a high weight fraction of the particles (fillings) are "connected" systems in which the particles interact with each other and affect the position of the particles in the compound [10].

Based on the quantity of heat travelling through the sample of the substance under test, the value of thermal conductivity is obtained using the following equation [16]:

$$K=\frac{e.d_s}{2\pi r^2(T_B-T_A)}\left[a_s\frac{(T_A+T_B)}{2}+2a_AT_A\right] \tag{3}$$

e: indicates the amount of heat energy traveling across a unit of disk space per second (W/m^2.K), which may be computed using the following relationship [17]:

$$e=\frac{V.I}{\left[a_AT_A+a_S\frac{(T_A+T_B)}{2}+a_BT_B+a_CT_C\right]} \tag{4}$$

$$a_A=a_C=\pi r^2+2\pi rL_d \tag{5}$$

$$a_B=2\pi rL_d \tag{6}$$

$$a_S=2\pi L_S \tag{7}$$

Where T_A, T_B, and T_C are the disk temperatures (A, B, and C) above ambient (the thermal equilibrium temperature of the disk minus the ambient temperature) in units (C^o), and L_d, L_s are the disk and sample thickness in units (cm), respectively. a_D, a_C, a_B, a_A: the exposed surface areas of the discs (A, B, C) and the sample in centimeters squared (cm^2). r: the disc's radius in units (cm). V: Voltage supplied by the module (Volt). I: amperes of current going through the heater.

2. Experimental part

- Materials and testing procedure

The material used to prepare the test samples were epoxy resin (22 240 Innopure Floor Epoxy), which was manufactured by the Turkish company (Innova Polimer Sanayi ve Ticaret), with the hardener which also manufactured by the same company. The ratio of epoxy resin to hardener is (3:2) for curing at a specific temperature [18].

Table (1) shows some of the properties of the base material utilized in accordance with the specifications of the manufacturing company.

Two type of materials, glass and carbon powders), of purity (99.5%) used as fillers in this work. A weight amount of these fillers (W_p) was mixed in (10 wt %, 20 wt %, 30 wt %, 40 wt % and 50 wt %, 60 wt %) percentages with epoxy, which were estimated according to the equation [20]:

$$W_p = \frac{w_p}{w_c} \times 100\% = \frac{w_p}{w_p + w_m} \times 100\% \quad (8)$$

Where; w_c, w_P, w_m: Weight of the composites, reinforcement materials (powders) and the base material (matrix).

The hand-lay-up molding process was used to create of both glass and carbon composites samples. A mold made of glass was prepared in the form of circular shape with dimensions (41.16 * 5 mm), as cleared in Fig. (1). The two types of filler powders were made by weighing them in identical weight proportions with an electronic balance with a sensitivity of up to (0.0001), then mixing for more than (6) hours to provide the best homogeneity between powders. This powder is progressively added to the resin with continuous stirring using the magnetic mixer for a set amount of time, until the powder particles are dispersed homogeneously in the resin. The hardener is added to the mixture while continuously stirring for (15) minutes at room temperature.

The mixture is then poured continuously and regularly from one side of the mold to the other side until is completely filled, after which the castings are left in the molds for (24) An hour to dry and harden, as well as to complete the bonding between the composite molecules. The samples are carefully removed from the mold and heated in a (55 C^o) electric oven for 60 min. Before beginning the testing, the samples are removed from the oven and allowed for (10) days to determine their ultimate hardness. The samples are next polished using smoothing paper with a roughness of (600 #) to eliminate any sharp edges that develop during casting processes.

Table 1. Properties of epoxy resin (22 240 Innopure Floor Epoxy) [19].

Finish	Transparent
Color	Colorless
Density (20 °C)	1,00 ± 0,05 kg/l (A + B)
Mixing Ratio	10:6 (A:B – by weight)
Solids by volume	%100 (A + B)
Pot Life (+10 °C)	90 min
(+30 °C)	30 min
Wait Time Between Coats (20 °C)	12 h
Light Traffic (20 °C)	24 h
Fully Cured	(20 °C) 7 h

- Thermal conductivity test

Thermal conductivity (K) is a measurement of a material's ability to transmit heat and occurs when thermal energy is transferred from high-temperature sections to low-temperature parts. The Lee disk method was used, which is a standard method for evaluating the thermal conductivity of low thermal conductivity materials, such as plastic and ceramic materials. Fig. (2) shows the device used in the thermal conductivity test, which consists of three discs (A, B, C), the discs are made of brass, each with a diameter of (4.11 cm), and an electric heater is connected to an electrical circuit containing an ammeter, voltmeter, and resistance a variable.

The samples were tested by placing the sample between the two discs (A, B), and the electric heater is placed between the two discs (B, C) that prepare the heat and is connected to a power supply that is installed on an estimated voltage (6 V) and a current of (0.48 A), and the device is placed In a tightly closed place, in order to stabilize the ambient temperature. When the electric power supply is turned on, the disks heat up and the heat transfer begins from the heater to the next disk until it reaches the last disk and after a period of time and when the thermal equilibrium is reached, the reading of the thermometers in each disk is recorded (T_A, T_B, T_C) [21]. Using equations (3) and (4), thermal conductivity (K) was calculated.

3. Results and discussion

The scanning electron microscope (SEM) examination was used to obtain an accurate and clear picture of the shape and nature of the distribution and the shape of the powder granules within the matrix, due to its high analytical capacity of (100 000) times and magnification power

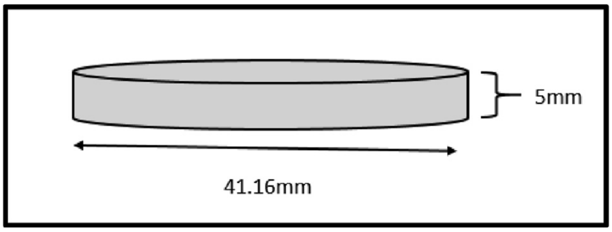
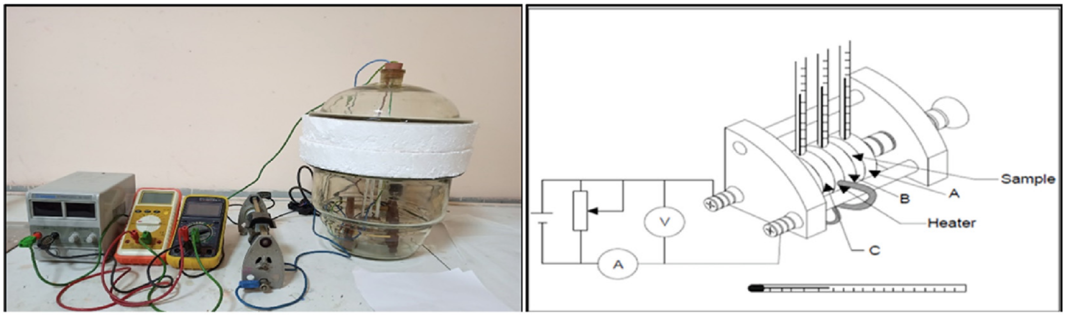


Fig. 1. Schematic diagram of the test samples.



(a) **(b)**

Fig. 2. (a) Thermal conductivity meter. (b) The schematic diagram of the Lee disk device [15].

of up to (2 million) times compared to the optical microscope. Microscopy examinations are performed using a scanning electron microscope (ZEISS SIGMA VP).

It is apparent from the Fig. (3) that the surface structure appears semi-homogeneous with many of grains that appear on the surface. By magnification of the images, we see that the surface looks semi rough and consists of some void and micro cracks, this may be the result of the interaction between epoxy resin and hardener.

Fig. (4), presents the surface morphology of the glass and carbon composites with magnification of (100kX).

As seen in Fig. (4a), the surface microstructure of these composites was smooth with a chance of forming very few glass clusters and blisters were discovered in various locations on the sample's surface, which could have been caused by the bursting of air bubbles during the preparation process. When the weight ratios of the reinforcing powders were increased, as it noticed in Fig. (4b), the surface of the composite materials became more wavy and rough in appearance when compared to another samples with increasing of glass clusters on the surface, this indicates the brittleness of the composite used in the study. It was also noted that the surface was porous as a result of the formation of gaps on the surface [22].

Speaking of the composite of carbon powder, shown in Fig. (4c), we find that the composite containing (10 wt %) of carbon powder was smooth and free from microscopic defects such as cracks with the chance of formation of some flakes on the surface, which could be caused by the random three dimension growth of the polymer [23]. As the weight fractions of the reinforcement powder increased up to (60 wt %), a change in the microscopic structure of the sample surface was observed, as shown in Fig. (4d), with the appearance of ripples with microscopic defects such as cracks and large voids revealing that the surface was porous as a result of the formation of these gaps.

The thermal conductivity of the epoxy resin was studied before and after reinforcement with the aforementioned filler powders, where conductivity is one of the important physical phenomena that can be used to study how the material is affected and

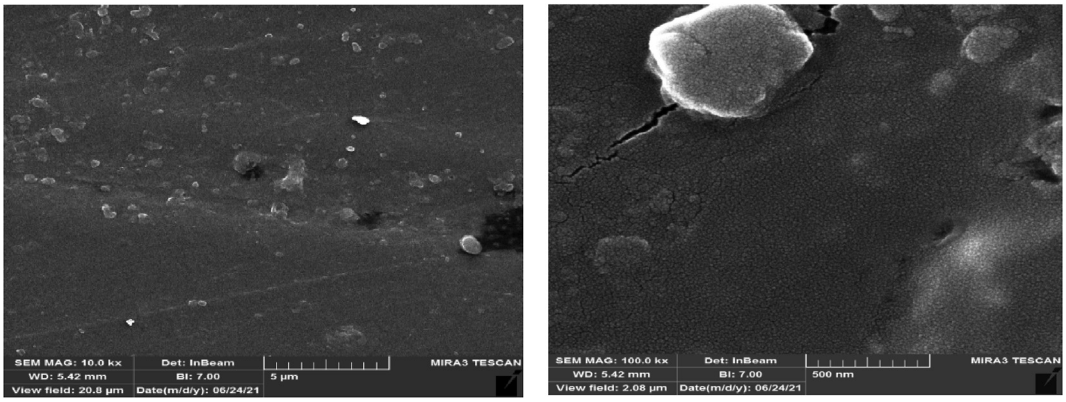
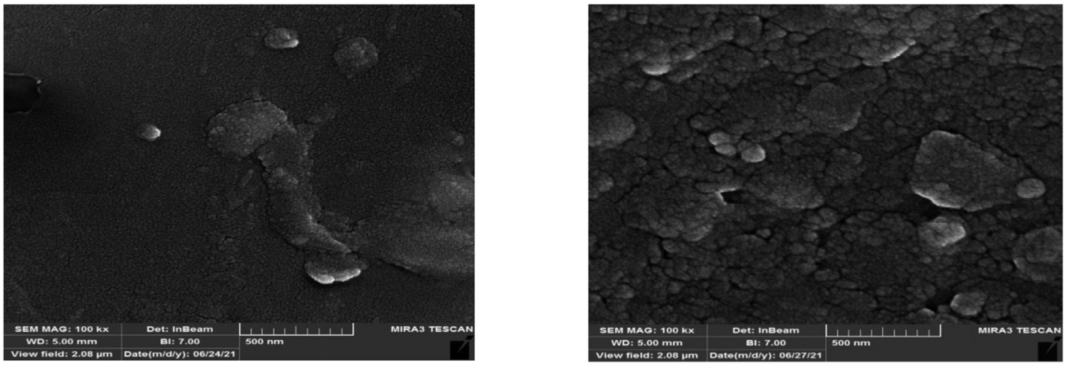
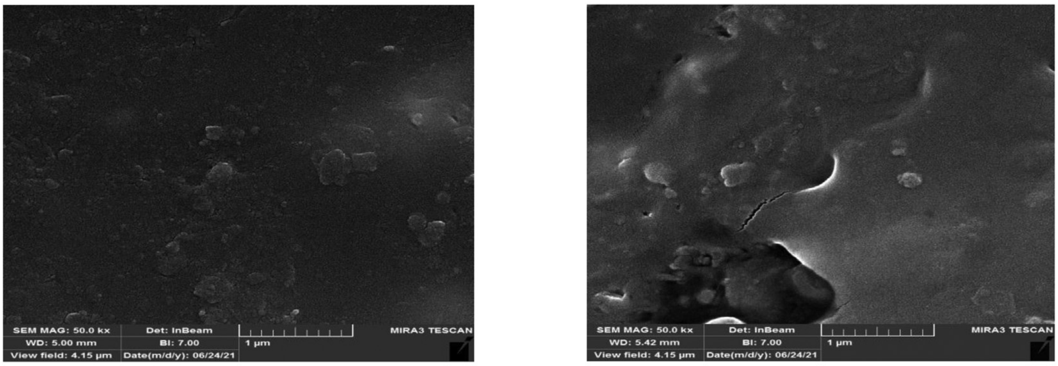


Fig. 3. SEM for the base material with different magnification.



(a) Glass, 10 wt.% **(b) Glass, 60 wt.%**



(c) Carbon, 10 wt.% **(d) Carbon, 60 wt.%**

Fig. 4. The microstructure of the epoxy reinforced by glass and carbon powders with different concentrations.

how its behavior changes when the temperature is transferred from the hotter side to the lower side as a result of modifying the resin epoxy composition.

Fig. (5) depicts the thermal conductivity values of epoxy composites as a function of reinforcing material weight fractions.

It is obvious that all of the gravimetric tests of the reinforcing materials resulted in an increase in the thermal conductivity of the two kinds of epoxy composites; meanwhile, the value of thermal conductivity of epoxy composite reinforced with glass powder becomes higher than epoxy composites filled by carbon powder, where an increase in the value of the thermal conductivity of the unreinforced substrate was observed to increase from (1.8912 W/m.K) to (2.3921W/m.K, 2.5439 W/m.K) for each of carbon and glass, where the conductivity increased from (0.048% ± 4.16, 5.41% ± 0.22) at (10 wt %) to (26.48% ± 0.045, 34.51% ± 0.031) at (60 wt %), for the addition of fillers, respectively, (see Table 2). The reason for this is because all of the reinforcing elements have a higher thermal conductivity than the base material [6]. The main reason behind this difference in the thermal conductivity coefficients of both composites is due to the cross-linking of glass at the interface between the fillers and epoxy [24].

It is well known that pure epoxy resin is a chemical compound with low thermal conductivity, which may be owing to the fact that the unreinforced material is a good insulator and the voids that, if detected, assist to increase the thermal insulation of this material [25]. In general, the goal of the reinforcement was to determine the heat conductivity of the reinforced material by reinforcing it with various fillers like as glass and carbon. The inclusion of these

Table 2. The percentage increase in thermal conductivity of an epoxy composite reinforced using various powders.

Conductivity Coefficient Increasing % at 60 C°		
wt %	Carbon	Glass
0	0	0
10	0.048 ± 4.16	5.412 ± 0.22
20	2.187 ± 0.59	11.163 ± 0.33
30	6.734 ± 0.50	17.439 ± 0.22
40	13.381 ± 0.14	22.381 ± 0.084
50	19.024 ± 0.12	28.028 ± 0.099
60	26.488 ± 0.045	34.511 ± 0.031

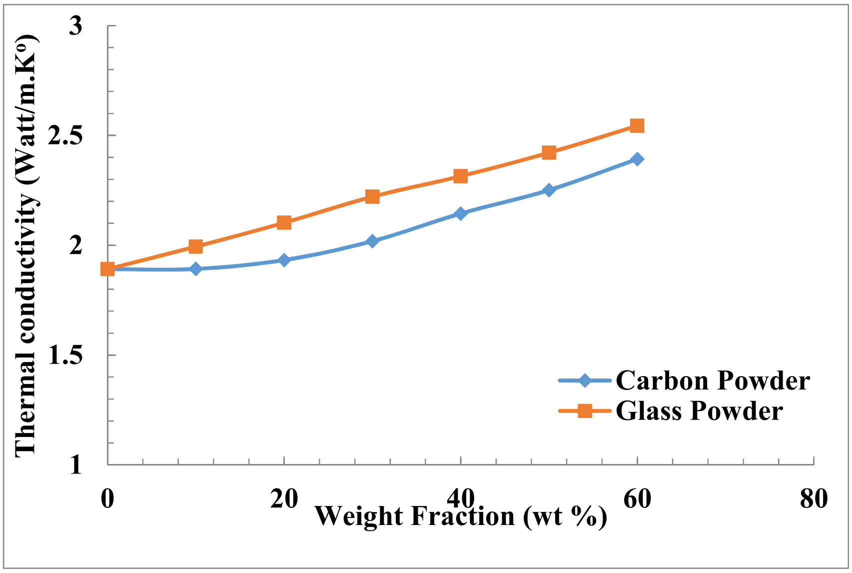


Fig. 5. Thermal conductivity of epoxy composites as a function of reinforcement powder weight fraction.

fillers resulted in an increase in thermal conductivity values by progressively increasing the weight fractions in the substrate gradually, and this finding is compatible with the general theory of composite thermal conductivity [6,8].

It was discovered that the heat conductivity of reinforced epoxy composites (glass) is greater than that of carbon epoxy composites and the unreinforced substrate. The variation in thermal conductivity values between the element's supporting powders may be explained by the functional bonding between the powder's micro particles and the chemical compound. Furthermore, the heterogeneous dispersion of glass filler demonstrated by microscopy reduces thermal resistance, and the weak crosslinking at the interface between filler and epoxy led to this discrepancy in thermal conductivity measurement, and the other thing is that heat fluxes speak not only through chains of molecules of glass particles, but also through the epoxy itself. Epoxy composites glass had a higher heat conductivity rating than the other composites [21].

The particle size and distribution of the reinforcing powder affects the thermal conductivity of the composite because varied particle sizes result in variable interfacial surface area per unit volume in the same epoxy percentage. The high particle size of the glass powder may be an efficient strategy to enhance the thermal conductivity of this composite, while increasing the particle size may be attributed to the greater stability of the thermally conductive pathways of the bigger particles [26]. Because the contact area between the particles and the epoxy decreases with particle size, there may be less epoxy layer around each particle at the same epoxy concentration as with smaller carbon particles. Consequently, more stable thermally conductive paths may be considered for particles with higher grain sizes because thicker conductive channels are less likely to be disrupted by contact with grains [27]. Another explanation for the biggest effect in raising the thermal conductivity of glass composites is the existence of glass clusters and a group of blisters in the epoxy resin, as illustrated in Fig. (5a, b), which increase with increasing the weight fraction of this powder, [28].

Moreover, heat is transmitted through polymeric materials as elastic waves, but these waves' ability to travel freely is constrained by the existence of the interface between the matrix and the additive. The transmission of thermal energy as an elastic wave is still a complicated and challenging process, which is due to the separation in the structure and the change in phase, which results in the wave losing some of its energy at the interface between the substrate and the reinforcing material [29]. Since epoxies are weak thermal conductors, adding cementing powders improved heat transport inside the composite. The contribution of fillers to thermal conductivity is determined by their composition, load, and dispersion. Thermal energy transmission is also affected by the structural properties of the material under consideration [30].

4. Conclusions

1. The surface of glass composite is smoothest with some voids and glass clusters which increase

with increase of glass weight concentration, the surface also became rough. Topography of carbon composite remains smooth and free from microscopic defects at small adding of this filler, also the surfaces appear porous as a result of increasing the concentration of this filler.

2. Pure epoxy resin has the lowest thermal conductivity value compared to other composites.
3. The addition of fillers (glass and carbon) steadily enhanced thermal conductivity by increasing the weight fractions of these materials in the matrix, with the greatest value of thermal conductivity occurring at a weight fraction (60 wt %) for all fillers.
4. At all weight fractions of reinforcing elements, the thermal conductivity of the glass composite was greater than that of the carbon composite.

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