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Physical Properties of Hybrid Epoxy Composites Reinforced with Carbon Fiber and Ceramic Particles

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ABSTRACT

Recently, studying and enhancing the thermal conductivity of hybrid polymer composites attract many researchers because of the multifunction of electronic devices. Scattering of particles inside fiber reinforced epoxy has a vital character in enhancing the physical and mechanical properties of their structures for serious applications such as electronic devices. Ceramic particles are considered a high-quality type for owing comparatively elevated electrical resistivity with thermal conductivity and acceptable cost. Therefore, in this study, the effect of adding ceramic particles on the thermal conductivity and density along with hardness of the hybrid epoxy composites was investigated. The reinforced plain weave carbon fibers/epoxy composites with different weight percentages of micro particles of silicon carbide and alumina were prepared by hand lay-up. The results showed an increase in the thermal conductivity by increasing the proportion of silicon carbide and alumina without affecting the density of the epoxy compound. Also, the adding of ceramic particles content has significant influence on reinforcing the carbon fiber/epoxy composites. This high improvement in thermal conductivity with low density in these hybrid epoxy composites have been driven them as possible nominations for electronic devices. The optimum content of hybrid epoxy composite for electronic applications is at SiC 10% and Al_2O_3 5% with 15 carbon fiber and 70 epoxies. Thus, a new polymer-based composite with improved thermal conductivity for electronic applications was produced.

1. Introduction

Hybrid epoxy composites are used in a variety of industrial applications, including automobiles, ships, aircraft, and electrical systems; The idea of optoelectronic and electronic devices protects electrical components from short circuits, dust, and moisture [1,2]. Epoxy is one of the most common thermosetting polymer matrixes because of its exceptional chemical resistance, and its qualities may be increased by reinforcing with fibres and particles [3]. Polymer/ceramic composite materials have recently gained popularity due to their mechanical and thermal qualities, as well as their low cost and simplicity of fabrication [4]. The strength of a polymer matrix composite is primarily determined by the capacity of the base matrix resin to transmit the given load to the reinforcing phase. The addition of filler material aids in strengthening the interfacial strength between matrix and reinforcement, which aids in the efficiency of the base matrix to transmit load, hence boosting composite performance [5]. Also, fibres have a larger load-sharing capacity than particles and they are vital additions when striving for high-performance polymer composites for different purposes [6,7]. The use of polymeric hybrid composites in electronic applications has

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increased due to their high performance, especially those that have been hybridized with particles and fibres [8]. The adding of metallic particles into polymer typically deteriorates the properties of dielectric and electric insulation of composites which leads to decrease in the dielectric strength and considerable surge in electrical conductivity. Thus, restrict their application in electronic devices. Therefore, recently ceramic particles are broadly studied because of their comparatively high electrical resistivity and high thermal conductivity as mentions in previous recent studies [9-11]. Many studies have used different hybrid fiber-particles reinforcements to study the development of the physical properties of epoxy polymer composites. It was observed that the addition of Al_2O_3 and SiC particles enhanced the mechanical and thermal characteristics of PA6 hybrid composites [12]. one of the researches involved that the thermal conductivity increased by increasing the addition of silicon carbide particles to the hybrid polymer composites reinforced with glass fibres [13]. In another study, it was found that a hybrid filler containing hexagonal boron nitride (hBN) and copper particles improves the heat conductivity of carbon fibre reinforced epoxy resin [14]. In addition, the thermal stability of the epoxy composite was improved by hybridizing it with glass and bamboo fibres, as well as coconut shell powder nanoparticles [15]. The influence of hexagonal boron nitride (hBN) and short sisal fibres based on an epoxy matrix on the physical characteristics was investigated, and the findings revealed that the density rose as the (hBN) particle content grew, while it reduced as the sisal fiber content increased [16]. Moreover, the titanium carbide particles improved the physical attributes of the combined synthetic and bio-reinforced epoxy composite with coconut fiber, resulting in a low-density composite with a high strength-to-weight ratio [17]. It was obtained by [18] that the thermal conductivity of hybrid Polydimethylsiloxane/ Aluminium nitride particles/ carbon nanotubes composite was significantly greater than Polydimethylsiloxane/ Aluminium nitride particles composite. This result referred to the ability of improve and control the temperature of electronic devices. The study by [6] revealed that adding SiC particles and E-glass fiber to the epoxy resin gave improving thermal stability and nominated to use of this hybrid composite in electronic gadget

To expand the knowledge about the effect of different types and weight percentage of ceramic particles on the polymer composites that used in electronic devices, this research investigates the effect of adding micro ceramic particles i.e., silicon carbide and alumina at different weight to the polymer composite (carbon fiber reinforced epoxy) on the physical properties in terms of thermal conductivity and density along with hardness property.

2. Experimental Work

2.1.Materials used

In this work, high-strength epoxy resin (composite A) (Sikadur®-52 LP (US)) with a coefficient of thermal expansion (89 x 10^{-6} per ˚C) was mixed with a hardener composite (B) (Sikadur®-52 LP (US)) and used as matrix material. The weight ratio of composite A: B was equal to 2:1 according to the recommendation of their manufacturer (Sika Egypt for Construction Chemicals Company). In addition, Plain weave carbon fibres with high thermal conductivity were used by (MB fiberglass Company). The obtained silicon carbide particles (SiC) with 37µm particle size and alumina particles (Al_2O_3) with 25µm size (Renfert GmbH Company) were used. Thermal conductivity (TC) of constituent materials at room temperature are given in Table 1.

Table 1: Thermal conductivity (TC) and density of constituent materials at room temperature [10,11,19-23]

Constituent material	TC (W/m K)	Density (g/cm^3)
Epoxy resin	0.18	1.1
CF	300–1000	1.75–2.00
SiC	120	3.215
Al_2O_3	30	3.8

2.2. Method for preparing hybrid polymer composites

A six samples of hybrid epoxy composites were prepared. Each sample includes six-layers of carbon fibre mats at a fixed weight percentage of 15% as reinforcement in epoxy resin matrix. ceramic particles (silicon carbide and alumina particles) were used as another reinforcement for the fiber/epoxy composite. Different types and weights of ceramic particles were selected as shown in Table 2. A different sensitive weight scale of particles was stirred in epoxy resin and after mixing, the mixture was placed in an ultrasonic device for 20 minutes to remove any air bubbles that might cause defects in the sample. Then curing agent i.e., the hardener was added to the mixtures and the stirring was performed again.

Table 2: The specimens with different weights of particles

Type of composite	weight percentage of CF (%)	weight percentage of particles (%)	weight percentage of epoxy (%)	Sample name
Composite (Carbon fiber +epoxy)	15	0	85	D1
Carbon/Epoxy composite filled with SiC particles + Al_2O_3(Hybrid composite)	15	10 SiC	75	D2
	15	10 Al_2O_3	75	D3
	15	15 (5 Al_2O_3+10 SiC)	70	D4
	15	15 (10 Al_2O_3+5 SiC)	70	D5
	15	20 (10 Al_2O_3+10 SiC)	65	D6

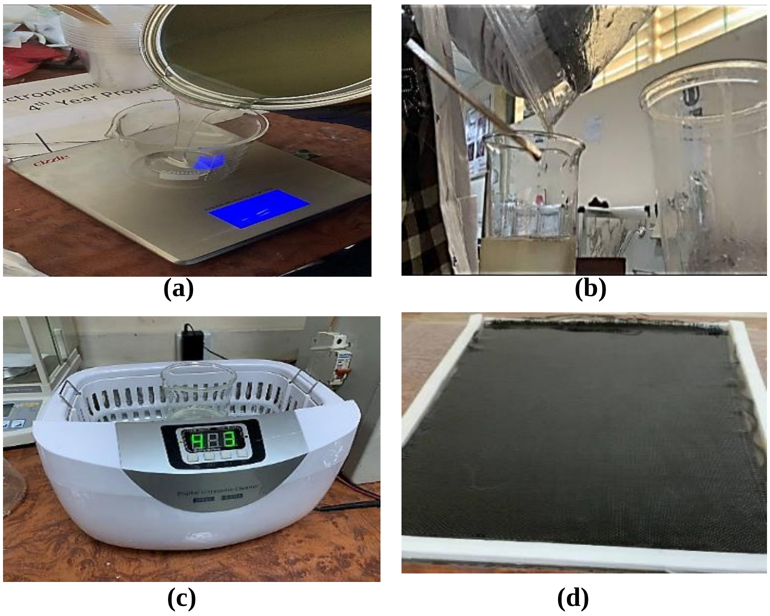

Figure 1. Hand lay-up process. (a) Sensitive scale. (b) Mixing. (c) Ultrasound devise. (d) Final product

A glass plate serving as a mold was employed during the hand lay-up process and a piece of (PVC sheet stands for polyvinyl chloride) was put on the glass plate to prevent the epoxy resin from adhering to the surface of the glass plate. An adhesive strip was used to determine the desired dimensions of the sample and then the mold was moistened with wax to prevent the polymer from sticking to the surface of the PVC sheet, A weighted amount of the prepared mixture (epoxy/particles) was placed and distributed carefully by a small plastic plate., Finally, the layer of carbon fiber was arranged as per the requisite size and inserted into the mixture. This procedure is repeated six times for six layers of carbon fiber that are added during fabricating each sample. The hybrid composite sample was carefully removed from the mold without any damage after the curing time at room temperature for 24h. Fig.1. depicts the hand layup setup for preparing the hybrid epoxy composites. The samples were cut using a water jet machine to obtain the required shape and dimensions for thermal conductivity measurement and density as shown in Fig.٢. The samples were cut into a cylindrical shape with a diameter of (25 mm) and thickness (6.9 mm).

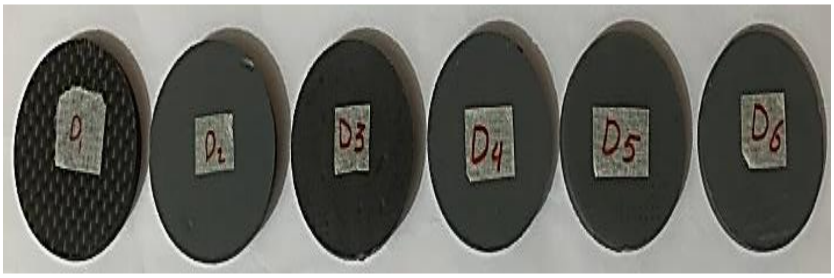

Figure 2: Prepared samples after cutting

2.3.Thermal conductivity

The thermal conductivity coefficient of the polymeric hybrid composites was calculated using Lee's Disc method. Then the thermal conductivity of the insulating materials was calculated using the device manufactured by Griffen and George Company in England as shown in Fig.3. The device consists of three discs (A, B, C) and an electric heater which is connected to an electrical circuit. The sample is placed between the two discs (A, B), and the electric heater is placed between the two disks (B, C), and when the power supply is turned on, the discs are heated by the heater, and this temperature transfer to the next disc until it reaches to the last disk. When the heating time 30min is reached, the reading of the existing thermometers records the temperature in each disk, which are (TA, TB, TC). Then, the thermal conductivity coefficient of the composite (K) is calculated using the following equation [24]:

$$k\{(TB-TA)/ds\}=e[TA+r/2(dA+ds/4)\ TA+dsTB/2r] \quad (1)$$

where e: represents the amount of thermal energy that passes through a unit area of disk material per second (W/m^2. K) and is calculated from the following equation:

$$IV = \pi r^2 e (TA+TB) + 2\pi r e [dA\ TA+ ds /2 (TA+TB) + dB\ TB + dC\ TC] \quad (2)$$

Since: TA, TB, TC: represents the temperature of the discs (A, B, C) respectively and is measured in units (°C) where the temperature degree of equilibrium was =18˚C.
d: the thickness of the disc = 0.013m.
ds: the thickness of the sample (0.0069 m).
r: the radius of the disk = 0.02m.
I: The current that passes through the heater coil =1.5 A.
V: the potential difference on both ends of the heater coil in (6 Volt).

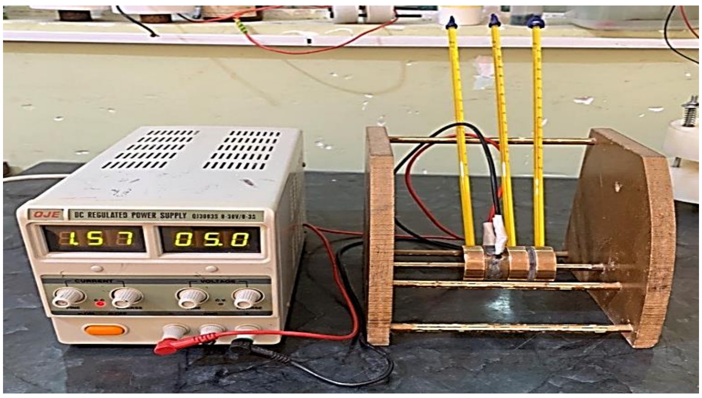

Figure 3. Thermal conductivity device

2.4. Density

Density is one of a substance's physical qualities that is measured by measuring the mass and volume of samples (Archimedes principle). Lower density is preferred, while it may degrade mechanical qualities because it makes composites lightweight and appropriate for a wide range of electronic applications. The mass was measured by electronic digital balance with four digits (KERN company) as shown in Fig.4. and the volume by the electronic digital equation used to calculate density [25]:

$$P = m/V \tag{3}$$

where:

ρ: symbol for density measured in (g/cm^3).

m: mass, measured in grams (g).

V: volume of cylindrical sample in cubic centimetres (cm^3) unit and calculated using equation below:

$$V=\pi\, r^2\, h \tag{4}$$

where:

r: The radius of sample and is equal to (1.25 cm).

h: The height of sample and equal to (0.69 cm).

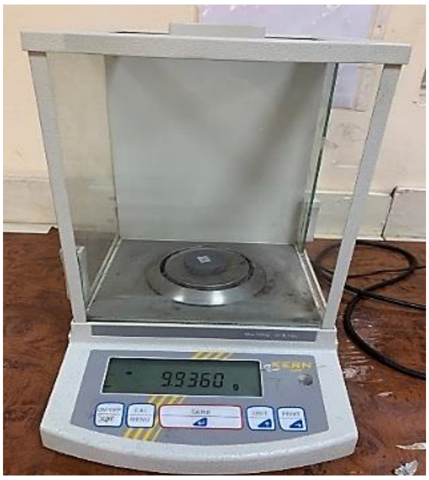

Figure 4. Electronic digital balance

2.5.Hardness

Shore hardness is the best regularly procedure for measuring the hardness of polymer composites [26]. The shore D hardness test in this article was performed to measure the surface hardness of the six prepared samples of hybrid epoxy composites as shown in Fig.5. The content of the composite i.e., carbon fibre and ceramic particles had randomly distributed therefore five points on the surface of each sample were calculated and the average of hardness for all spots was obtained.

Figure 5. D shore hardness device

3. Results and discussion

3.1. Thermal conductivity of hybrid epoxy composites

The results of the thermal conductivity of six samples of hybrid epoxy composites at different weights of reinforcements were obtained as shown in Fig.6. Commonly, for all samples, the existence of reinforcement particles (silicon carbide and alumina) in hybrid carbon fibers /epoxy composites has a significant impact on the thermal conductivity. Increasing thermal conductivity of the composite by adding hybrid conductive particles attributes to the existence of contacts between fibres and particles that generate conductive paths which results in increasing the conductivity and this path is increased with an increase in the volume fraction of particles. In addition, it was shown that the effect of SiC is much stronger as compared to the Al_2O_3 on the thermal conductivity. It was seen from previous studies that SiC particles have perfect thermal conductivity properties along with the effect of their particle size [13]. Further, the value of thermal conductivity exhibited the highest enhancement of 40% at sample D4 (10Sic +5 Al_2O_3 wt%) without requiring to increase in the volume fraction of Al_2O_3 particles because it contains the highest percentage of SiC at 10% as well as this indicating to the providing perfect particles matrix interaction. Sample D1 produced the lowest thermal conductivity of carbon-fibre-reinforced epoxy composites, reaching (0.739733315 w/m.k) because it did not contain particles of silicon carbide and alumina, and this can be clear from Fig.6. Moreover, sample s D5 and D6 shows a noticeable reduction in the thermal conductivity and this might be due to a high-volume fraction of particles or more loading of small particle size of Alumina in composite results in increased particle aggregations which lead to an important increase in interfacial thermal resistance and unacceptable thermal conductive rendering of polymer composites. as indicated in previous studies [11, 27,28].

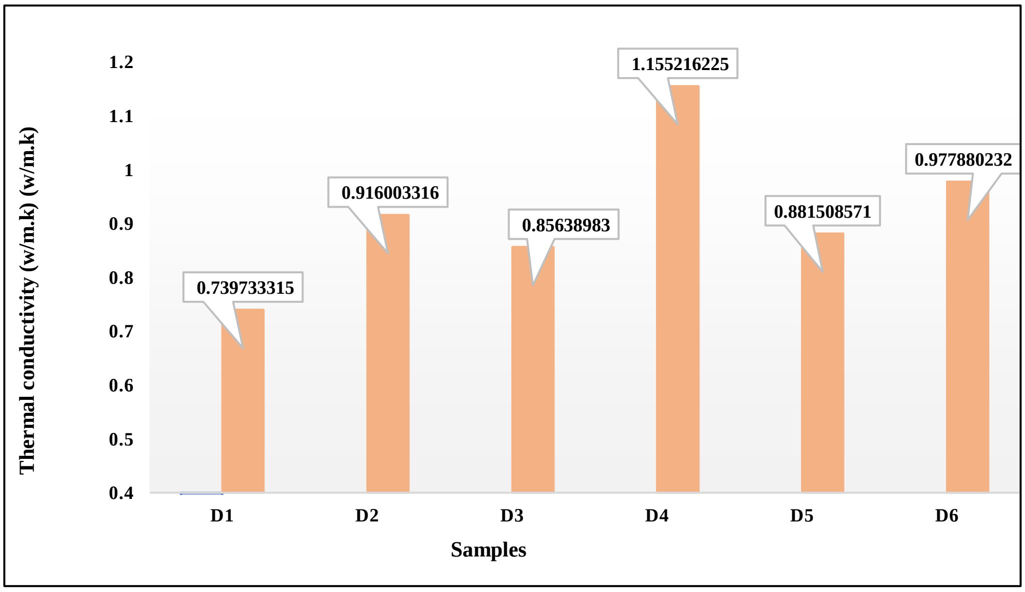

Figure 6. Thermal conductivity of hybrid epoxy composites

3.2. Density of hybrid epoxy composites

In this section, the density of hybrid epoxy composite reinforced with carbon fiber and reinforced with silicon carbide and alumina particles are measured as shown in Fig.7. The results of the experimental work showed that the amount of carbon fiber is constant and the amount of epoxy in each sample decreases with increasing reinforcement with silicon carbide particles and alumina. Generally, it has been observed that the density of hybrid composites is not affected much as compared to the density of fiber/epoxy composite (sample D1), and in turn, the reinforcement in these particles does not affect the density of the hybrid epoxy composite. The density of the sample D1 is 1.12 g/cm^3 where this sample is free of silicon carbide and alumina particles, and it gradually increases by a very small percentage till reaches 15% increasing the proportion of silicon carbide and alumina particles in the sample D4 to 1.32 g/cm^3. This slight irregular change in the density values for all samples attribute to the fabrication of composites particularly through using the hand-lay-up process. High improvement in thermal conductivity with low density in these hybrid epoxy composites have been driven them as possible nominate for electronic devices.

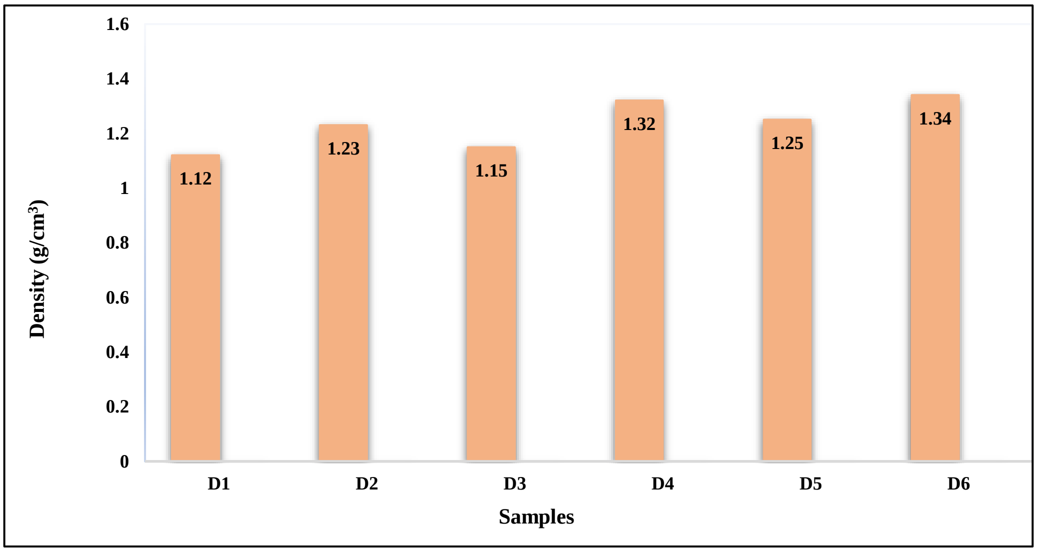

Figure 7. Density of hybrid epoxy composites

3.3.Hardness of hybrid epoxy composites

Figure 8 indicates the surface hardness values of hybrid epoxy composite. The results showed that the content of the ceramic particles has a significant effect on increasing the hardness of the epoxy composite. The results exhibited that the surface hardness of hybrid epoxy composites including ceramic particles was considerably higher than the epoxy composite without particles i.e., sample D1. The highest value of hardness about (69.6 HV) was reached in sample D4 (15% CF, 5% Al_2O_3, 10% SiC and 70% of epoxy) with the highest enhancement ~ 12%. This due to the accumulation of hard ceramic particles that increases the hardness of the matrix and as indicated in previous studies [29, 30].

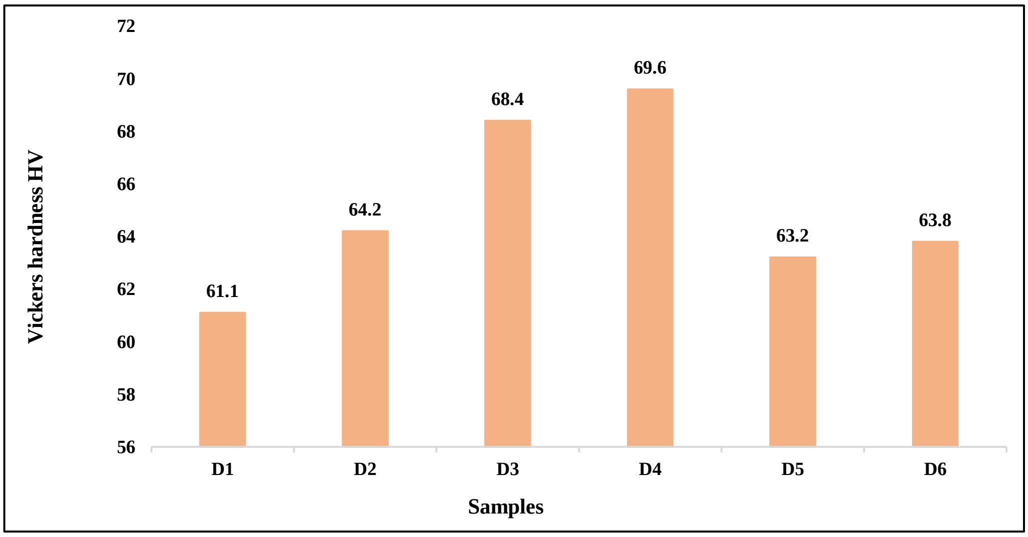

Figure 8. Hardness of hybrid epoxy composites

4. *Conclusions and further recommendation*

This experimental study on physical properties i.e., thermal conductivity and density of hybrid epoxy Composites reinforced with carbon fiber and ceramic particles has led to appointed conclusions:

- effective fabrication of hybrid fiber/epoxy composites filled with SiC and Al_2O_3 particles using the hand lay-up method is possible.
- It has been found that the thermal conductivity can be enhanced by loading both conducive micro particles types (SiC and Al_2O_3) compared to the typical type of fiber/epoxy composite.
- The hybrid composite with constituents (15%CF, 10%SiC, 5% Al_2O_3, and 70%E) showed the best thermal conductivity reaching to 1.431156757 w/m.K, with 40% enhancement of thermal conductivity. This constituent indicates to optimum content of hybrid epoxy composites that used for electronic applications.
- In examining density, the result indicated a relatively slight increase in density by increasing the percentage of particles reinforcement with silicon carbide and alumina particles. Thus, it was concluded that the reinforcement of epoxy composites with micro-particles of SiC, and Al_2O_3 increases the thermal conductivity and does not affect the density of the composites. Therefore, the direction of researchers on hybrid epoxy composites in electronic applications has become fruitful at present.
- The surface hardness test results displayed that adding of ceramic particles content had a noticeable influence on reinforcing the carbon fiber/epoxy composites. The observed enhancement was about 12%.

Despite the excessive development achieved over the ancient few years in improving the thermal conductivity in hybrid polymer composites with different types of particles, still, various challenges can be addressed if high thermal conductive of polymer matrix composites is required like the fabrication process of hybrid polymer composites besides type, size, the shape of selected particles.

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