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Studying the effects of different additives on thermal conductivity and mechanical characteristics of epoxy-based composite materials

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Abstract: The current research deals with the study of the effects of different types of fillers on thermal and mechanical characteristics of an epoxy compound. The fillers used during the study are: Charcoal, Pyrex, Aluminum, and Titanium Carbide, both of which are different in nature and have not been thoroughly examined or even compared fairly in terms of their effect on the polymer matrix. Moreover, it can be considered as a cheap filler, charcoal can be obtained from the simple pyrolysis of plants charcoal and Pyrex waste can be easily collected. Both species are added to the specified matrix with a size ratio ranging from 10 to 60 in increments of 10. To ensure a fair comparison, the particle size is constant (about 1.7 μm). The results showed that the thermal conductivity of epoxy was enhanced by about two degrees of amounts over the studied grouting range, and the best conductivity was for aluminum at 60% compared with the rest of the grouting. In terms of mechanical properties, charcoal and Pyrex improve the tensile strength by about 84% at 60% of the fracture size, while the effect of Pyrex is about 40% at the same level of the filler, while aluminum gave the best tensile strength when compared with the rest of the filler, titanium gave at 10% Good tensile strength and the increased fill rate has decreased significantly. In contrast, stress resistance results do not show a significant improvement overall. It decreases by approximately 12% at 60% of the fraction volume of charcoal and at 30% of titanium while increasing by approximately the same percentage with Pyrex and aluminum at the same fill level.

Keywords: *Epoxy Resin; Titanium carbide;* Aluminum*; charcoal; Pyrex; Polymer based composite; Composite Thermal conductivity; Mechanical Behavior.*

1.Introduction

Epoxies, particularly thermosetting epoxies, are widely employed in a variety of applications. Thermosetting epoxy resins have unique properties, such as a compact structure and the creation of nonvolatile compounds during curing. The degree of crosslinking and the curing temperature may both be readily regulated. Its brittle character and tendency to shatter is also due to its innately fragile nature in addition to their weak resistance to fracture propagation and low impact strength, they have a low toughness. These characteristics are regarded as their primary drawbacks [1]. The friction coefficient, as well as stress-strain curves and related data (ultimate tensile strength, Young modulus, durability, tensile toughness, and friction coefficient) were reported. My Young modulus increases at very low wt percent of the filter, but at higher wt percent (2 wt percent and beyond), the resin's brittle behavior is turned into a ductile one, as measured as a result of elongation at the break The filler has an influence on tensile toughness, with the best sample rising 11 times over pure resin [2]. Developed carbon composite that has been prepared from the carbon coir fibres which are reinforced by the epoxy resins. Carbon coir fibres have been obtained from 3 coir fibre types, which are CKCF, CRCF and CYCF. Samples have been prepared with the use of the epoxy resin that has been reinforced by the difference of the percentage of weight of 3 carbon coir fibre types, beginning with 0, 2 wt%, 4wt%, 6 wt%, 8wt% and 10 wt%. The CKCF carbon composites exhibit higher level of the mechanical strength in comparison with the CRCF and CYCF carbon composites. From the results that have been obtained, impact strength of samples, particularly the CKCF carbon composite is increased with the addition of the activated carbon [3]. Studied impacts of the utilization of the micrometer and nanometer aluminum particles in the glass fiber reinforced epoxy composite materials in the improvement of the mechanical characteristics. The glass fiber volume ratio has been maintained constant at 35%, whereas aluminum particles contents have been raised from 0.20 to 4% by weight. Developed compounds have shown improved flexural, tensile, wear, hardness, and impact behaviour in comparison with the fiberglass reinforcement epoxy. A 27% increase in the level of the tensile strength was achieved using a glass fiber reinforced epoxy that has been filled by 2wt% Al-NPs; none-the-less, the addition of 4% by weight of nm-sized particles of the Al had shown enhancement of 114%, 116%, 21%, 52.20%, 21.40%, 76.60% of improving mechanical properties when compared with elegant glass fibre reinforced epoxy. The increase of the nm-sized Al particles in glass fiber reinforced epoxy composites to 4% by weight reversed the enhancement in the level of the tensile strength, wear and toughness. None-the-less, the increase the micrometer size particles of Al to 4% by weight showed reasonable improvement in all aluminum loads used [4]. Epoxy matrix composite materials that have been reinforced by different ratios of titanium carbide (TiC) were manufactured. A different percentage of (TiC) powder was used (0wt%, 5wt%, 10 wt%, 1wt%, 20 wt%, 25 wt%) used as reinforcements in epoxy matrix. the hardness value, impact strength, tensile strength and wear rate are improved by adding appropriate proportion of titanium carbide powder. The hardness and tensile strength values show an increase with the addition of 15% by weight of Titanium carbide powder. It was found that the impact resistance increases by increasing the ratio to 20% by weight of titanium carbide[5]. studied, thermal conductivity of TiC reinforced wear and corrosion resistant MMC that are analyzed. In particular, impact of the chemical inter diffusion between the TiC and the metal matrix on resultant thermal conductivity is analyzed. It has been exhibited that the variations in chemical composition result in different reduction in the TiC thermal conductivity that must be taken under consideration in the case where the thermal conductivities of the MMC must be studied [6]. Pyrex powder filler has been added to an epoxy matrix of different weight Ratios (0, 15, 30, 45% by weight) for the study of electrical properties and hardness testing. The electrical properties were studied using a 50Hz to 1MHz frequency range at the temperature of the room. The electrical conductivity decreased with increasing to hesitate. While the hardness value decreases with the increase of Pyrex waste powder [7].

2. Materials and Methods

2.1. Materials

The matrix material that has been utilized in this research has been the epoxy (Nit Fill E P L V) with a 1.1g/cm3 density and resin-to-solid ratio of 3.3. Aluminum, titanium carbide, charcoal and Pyrex were used. The size of the aluminum and titanium carbide particles is less than 2 micrometers or greater than 2 micrometers, Pyrex and charcoal particle size of less than or equal to 2 µm.

2.1.1 Sample Preparation

The epoxy and hardener were mixed in a beaker placed in water bath at constant temperature of 40 ºC and speed (300 rpm) for 10 minutes. The silicone rubber mold is pre-coated with oil to prevent the composite materials from sticking to the mold when it is time to take it out, (charcoal, Pyrex, aluminum and titanium carbide) were weighed based on the proportions of (10, 20, 30, 40, 50 and 60%) Volume fractions, after which the proportions were mixed with the epoxy; Finally, the mix is poured to a mold and left to set at the temperature of the room for 24hrs.

2.2 Methods

2.2.1 Tensile Testing

The composites were tensile tested at a temperature of 25ºC with 1mm/min testing speed and 20KN load cell with the use of INSTRON 4481 universal test machine based on the ASTM D2099.

2.2.2 Compression Test

Two testing spaces are available on the floor style unit, with a maximum test capacity of 20 KN. It can perform compression, bending, and other types of tests due to its high rigidity structure. It also includes all types of metric units, real-time graphs, and full measurement test data that can be used to perform a number of content analyses.

2.2.3 Thermal Conductivity

The Griffin and George Company produced Lee's disk. The heat is transferred through the sample from the heater to the first two disks, then to the third disk. The temperature of the three discs (TA, TB, and TC) is determined by thermometers mounted within each of them. The temperatures were taken after they had reached thermal equilibrium.

3. Results and discussion

3.1. Tensile Test

Figure 1 illustrates tensile strength value of every one of the samples. It is evident (except for the TiC compound) that tensile strength is increased with the increase of filler contents for all the samples examined. for the aluminum matrix composite, the increase in tensile strength is about five higher than that of the pure matrix without any additive, so the homogeneity is due at these ratios between (Al) and epoxy, which increases the tensile strength of composite materials. Srivastava et al [8]. Their results indicated, in contrast to ours, that tensile strength is continuously decreased with increasing the weight percentage of the padding. This could be due to the difference in preparation methods between our samples and theirs.

For the matrix of charcoal and Pyrex, the difference in the increase in the value of the tensile strength is very slight, as a result of the high adhesion and Homogeneity between (Pyrex, charcoal) with epoxy in this ratio this result was investigation in reference [3].

For the TiC matrix composite, the result of investigations reveals that the tensile strength enhances from (0 to 10) %v/v TiC and starts to decrease after adding 10% v/v TiC. The bonding and wettability between compounds may range from 0%. to 10% by volume fractions. TiC affects the close distribution of TiC particles in our alloy matrix. add 10% by volume fractions. to 30% by volume fractions. of TiC in the alloy matrix causes the resistance and load bearing capacity to decrease and the particle is no longer insulated with the alloy matrix causing the worst value of tensile strength. Ali [5], their results indicated that, in contrast to ours, in general, increasing the TiC content leads to an increase in the final tensile strength. In general, the aluminum matrix represents the best tensile strength among all other additives.

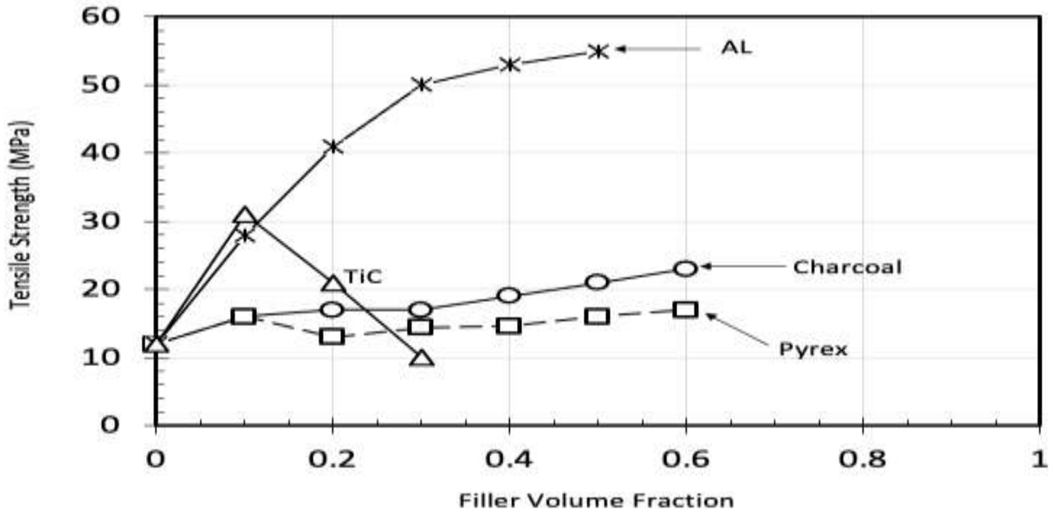

Figure 1. Effect of filler content on tensile strength

3.2 Compressive Strength

Figure 2 shows that compression strength is increased with the increase of the volume fractions Aluminum and Pyrex. However, at 40%, the compression strength of (Al) decreased due to the weak bonding between the epoxy and (Al), unlike the Pyrex compound, where the compression strength increased at 40% significantly with the increase in the Pyrex content. The compression strength (MPa) values ranged from 80 to 100 (MPa) for the filler due to the increase in crosslinking and void filling in the polymer and thus the compression strength increased this result was investigation in reference [4]. for charcoal the compression strength gradually decreases as the filler ratio is increased. Also, figure 2 describes the compression strength of TiC content. The decrease in the compression strength value is the highest for the TiC composite matrix. Because of the weak interaction between epoxy resin and particulate matter behind the low value of compression strength.

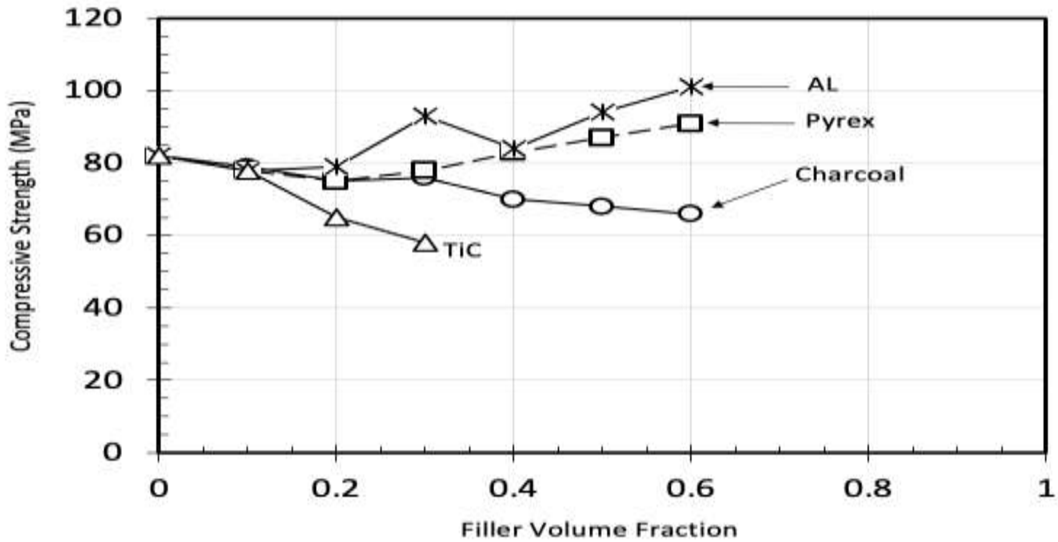

Figure 2. Effect of filler content on compression strength

3.3 **Thermal Conductivity**

Figure 3 shows The thermal conductivity of charcoal shows the K value it decreases at 10% from (0.4 W/mk) to (0.3 W/mk) due to the presence between of epoxy and charcoal voids, which leads to a decrease in thermal conductivity, with the increase in the filler ratios, the conductivity increases significantly due to the filling of the spaces between the matrix, heat is transferred easily, which leads to an increase in thermal conductivity. [9].

For Pyrex as shown in figure the situation is rather different. The composite material with pyres shows a constant thermal conductivity as volume fraction function up to percentage of 30%, then thermal conductivity is rapidly increased with volume fraction increase till a percentage of 50%, where it decreases again. which can be attributed to the density of particles that reduce the number of voids in the composite material, which leads to a decrease in thermal conductivity.

Figure 3 exhibits the thermal conductivity as a volume fraction function of added Aluminium. It is clear that the level of the thermal conductivity increases linearly with volume fraction increase, this is because (Al) have high thermal conductivity compared with epoxy and the addition of (Al) fills the voids between the matrix and therefore the heat transfers easily, which leads to an increase in thermal [10]. Therefore, the Aluminium composite compound offer better thermal conductivity than matrix do due to no reactivity of the matrix with aluminium.

Reinforced (TiC) composite provides thermal conductivity close to (Al) as shown in figure 3. Although thermal conductivity of the TiC composite is increased linearly with an increase in the volume fraction of TiC [6]. Comparing thermal conductivity of the four composite material as shown in figure 3, it is conclude that the best achievable properties can be obtained using Aluminum as an additive material.

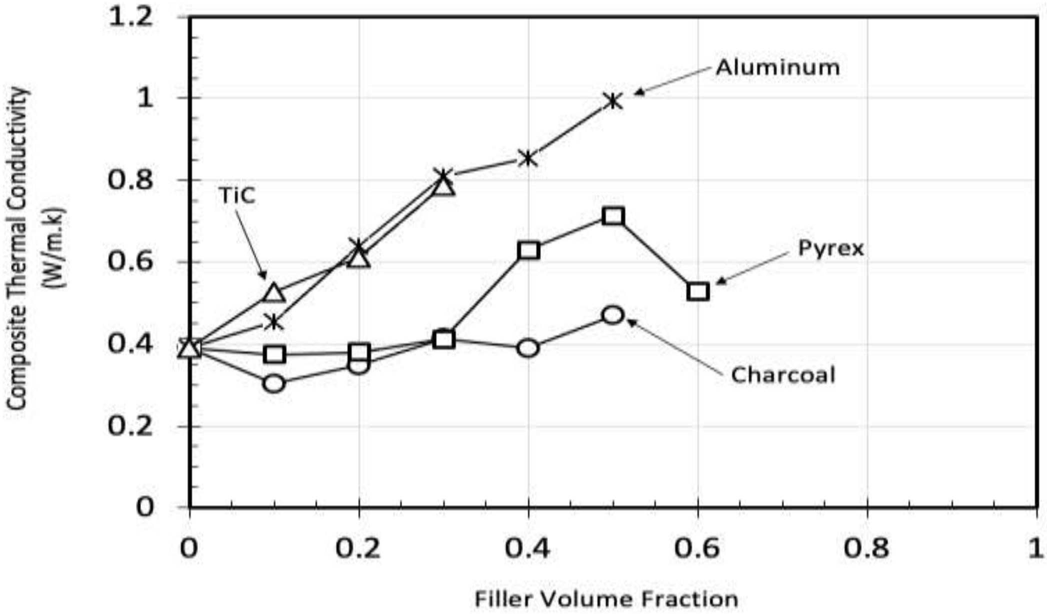

Figure 3. Effect of Filler content on the composite thermal conductivity.

Figure 4 shows a comparison between the data and the prediction of two models developed by Maxwell [11] and Bruggeman [12]. it is useful here to examine their predictions. Maxwell's model is a simplified model and is slightly different than Rayliegh's model [13], while Bruggeman's model is a fuller model and it is expected to give better results for high volume fraction comparing to Lewis-Nielsen method. The parameters used in the two models as listed in (Table 1)

Table 1 The parameters used in the two models

Parameters	Value (W/m.k)	Reference
K_{epoxy}	0.4 W/m.k	Measured in the current work
K_{Al}	250 W/m.k	Yan et al. [14]
K_{Pyrex}	1.1 W/m.k	Gaal et al. [15]
$K_{charcoal}$	0.5 W/m.k	Eltom et al. [16]
α	0.5	Here, it is assumed that the bulk property of the particles is important (i.e. <1) , following Every et al. [17].

It is obvious from Figure 4 that both models have captured the general behavior very well, although Maxwell model is more precise. Maxwell model predicts the effective thermal conductivity of epoxy/Aluminum and epoxy/TiC systems with less than 5% error. However, the prediction is not precise when one comes to epoxy/Pyrex and epoxy/charcoal systems which is obviously due to data discrepancies. In terms of Bruggeman's model, it is clear that the model fails to predict the experiments. This is, perhaps, due to the effect of α parameter. This parameter has been approximated and relies mainly on interfacial thermal resistance. Adjusting this parameter, one can find that the model prediction gets closer to the experimental data.

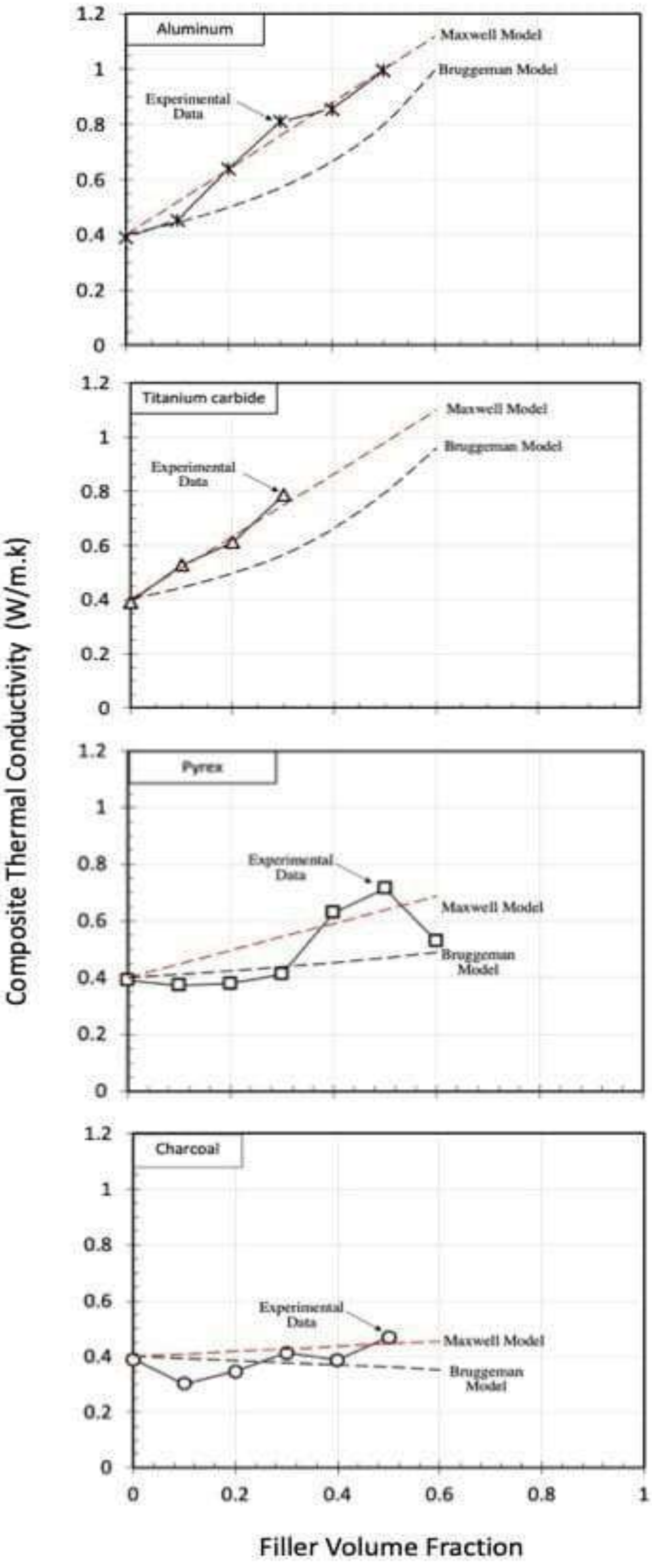

Figure 4 Compassion between the experimental data of the current work and the effective thermal conductivity predicted by Maxwell and Bruggeman models presented.

4.Conclusions

1- When the volume fraction of (charcoal, Pyrex, and Al) was raised, the tensile strength rose. The biggest increase (60%) was observed for (Al), whereas decreases (20% and 30%) were obtained for (TiC).

2- When the volume percentage was raised, the compression strength (Pyrex and Al) rose. The maximum increase obtained is 60% for (Al) with a considerable loss of 40%, gradually decreasing when (30%) for charcoal with a constant decrease for (TiC)

3- Thermal Conductivity It is possible to infer effects of additives on heat characteristics of the composite material are as follows: -

Thermal conductivity when adding (AL, TiC) to epoxy note is greater in the thermal conductivity of (60,30%), when adding (Charcoal) to the epoxy, the decrease in temperature was observed conductivity (50%), the largest decrease in thermal conductivity is observed in the (60%) when adding (Pyrex) to epoxy.

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