Effect of nanoparticles on thermal conductivity of epoxy resin system

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Abstract. In this paper the effect of mixing TiO2 nanoparticles with epoxy resin is studied. The TiO2 nanoparticles would be synthesis and characterized by scanning electron microscopy (SEM), XRD FTIR, for two particle sizes of 50 and 25 nm. The thermal conductivity is measured with and without composite epoxy resin; the results showed that the thermal conductivity was increased as nanoparticle concentration increased too. The thermal conductivity was increased as particle size decreased.

1. Introduction
Epoxy resin is a chemical material which good resistance to corrosion. For these properties this nanocomposite which is used in many applications in coating, paints and sealants [1,2,3,4].

In the last decades, materials that makes composite with other inorganic material will be considered. Many additions of nanofillers given favorable enhancement in the performance of polymer nanocomposite, because of high surface area to volume ratio of nanofillers [5]. Length in small scales existing in nano system scale would be effect the energy of bind structure which can produce the change in atomic construction, this is called quantum. There are two types of descriptions for the effects of size in nanoscales they are changes in the energy of the total system and change the structure of system [6]. Nanofillers is dispersed in polymer matrix called polymer nanocomposite (PNC). These additions occurs in different shapes; plates, fibers, spherical particles. This matrix must be required a control compound stabilized. It is interesting to produce nanomaterials to form nanocomposites cable to many important properties wanted for given application. Titanium oxide TiO2 is a kind of nanoparticles that greatly used in paint, cosmetics and dyes. The TiO2 produced naturally in different type like, anatine, rutile and brookite [7].

These nanoparticles added to improve the thermal conductivity of these composite materials. The thermal conductivity is increased with composite compared to the pure epoxy material. Using TiO2 nanoparticles which have high thermal properties increased as nanoparticles decrease too. Adding inorganic filler to the epoxy can be enhanced the properties of epoxy resin. The nanoparticles filler will fill out the weak region to raise the influence force between epoxy and filler interface [8]. There is an operator function in the properties of nanocomposite are nanoparticle matrix interaction and particle–particle interaction. The attraction between nanoparticles is due to the van der Waals forces. Affected the force between particles and then break down the composites interpretation. This attraction and repulsion forces between nanoparticles controlled by many factors the volume fraction, surface modifier and the size of particles. The good results of thermal and mechanical properties depended on
the interface between the nanoparticles and the polymer. Increasing the volume or weight fraction increased the thermal and mechanical property [9]. The properties of epoxy can be improved when the interfacial area increased between epoxy and fillers which are depend on many factors such as particle size, fraction and stability of nanoparticles in the epoxy structure. Tjong et al. 2004 study the comparison between two matrixes Al-B_2O_3-TiO_2 and Al-B-TiO_2 of metals [10]. Park et al. 2008 study the effect of Al_2O_3 on the increase in volume fraction. They found that it decreased the fracture toughness of polymer MMC [11]. Amit Ch., 2008 study the mechanical properties with TiO_2 filler to epoxy composite [12]. Mirmohseni A., 2010 investigated the impact and tensile strength by TiO_2/epoxy [13]. Zhou et al, 2010 studied two types of particle sizes macro and nano particles of TiO_2 the results showed that the mechanical properties is reduced because of the agglomeration of nanoparticles [14]. Vijay R., et al, 2014 measured the mechanical properties of glass fiber with polyester composite; this addition enhanced the shear strength [16-17]. Bahjat B., et al, 2017 were used new properties of nanocomposite polymer PMMA for thermal application used with TiO_2 and ZnO nanoparticles were used, they found that the thermal diffusivity increased as the volume fraction increased [18]. Mu L., 2017 study the mechanical and thermal properties of epoxy resin with Al_2O_3 and SiO_2 of 1% wt concentration [19].

In this research two sizes of nanoparticles are added to the epoxy resin, these are 50 and 25 nm of TiO_2 with different volume fractions 0, 2, 4, 6, 8, 10 & 12 % and room temperatures of (20, 25, 30, and 35 °C). The thermal conductivity is measured to the samples by Lee-disc instrument.

2. Materials

Epoxy resin type in a liquid state (Quick mast 105 made in Jordan for Focsroc Company) is used as a basic material in the preparation of composite polymers. The epoxy becomes into solid state by adding the hardener which has low viscosity and density properties. The hardener added to the epoxy by ratio 3:1 with continuous mixing.

2.1. Reinforcement materials

Titanium oxide TiO_2 (Eprui Nanoparticles & Microphares Co. Ltd ) is used to add to the matrix with different fraction of (0, 2, 4, 6, 8, 10, 12) %.

3. Experimental work

The nanoparticles are weighted according to the equations below and added to the epoxy resin firstly, this step was happened to the hood to reduce the interaction between TiO_2 nanoparticles and air to reduce the pollution with environment this is because of this interaction increase the particle agglomeration and decrease the matrix chain of nanoparticles with epoxy polymer [20].

Shear mixer was used to mix the TiO_2 nanoparticles and epoxy resin at 850 rpm for 20 minutes for a good distribution. Second step the using of ultrasonic homogenizer type (MTI Corporation made in USA) was used for 10 minutes for good dispersion.

Adding the hardener with TiO_2 / epoxy resin for 5 minutes by using ultrasonic homogenizer to reduce the effect of viscosity of composite. After that the vacuum is used to remove any bubbles can be appeared to the surface of composite epoxy.

TiO_2 / epoxy would be molding in a circular shape with diameter of 45 mm with thickness of 5mm the final product shape was showing in figure 1.
The volume fraction can be expressed by using equations where $V_m$ and $V_p$ the volume of matrix and nanoparticles respectively.

$$V_m + V_p = 1$$  \hspace{1cm} (1)

$$V_m = \frac{\Omega_m}{(\Omega_m + \Omega_p)}$$  \hspace{1cm} (2)

$$V_p = \frac{\Omega_p}{(\Omega_m + \Omega_p)}$$  \hspace{1cm} (3)

$$V_p = \frac{m_p}{\rho_p}, \quad V_m = \frac{m_m}{\rho_m}$$  \hspace{1cm} (4)

Where $m$ and $\rho$ are the mass and density of composite epoxy and nanoparticles.

4. Characterization

The TiO$_2$ nanoparticles were synthesized by scanning electronic microscopy (SEM) TESCAN Vega III as shown in figure 2. That showed in agglomerate form. This test was done in Materials Research Department/ Ministry of Science and Technology.

The TiO$_2$ XRD was done by using, Simadzu X-Ray Diffractometer XRD 6000, Cu Ka1 X- ray of wavelegth ($\lambda$) 1.5405Å and data was taken for the range of two theta (2$\theta$) from (10 – 80 ) $^\circ$ with aspeed of 0.02$^\circ$, the results proved the nano size of TiO$_2$ particles.

Figure 3 shows the peaks of TiO$_2$ which is matched with a standard of Antase phase TiO$_2$ type of three strong peaks at 25.3$^\circ$, 48.02$^\circ$ & 37.8$^\circ$. 
To know the particle group of titanium oxide TiO$_2$ nanoparticles the FTIR was used. Figure 4 shows the FTIR spectrum of TiO$_2$ nanoparticle at peaks of 10635 cm$^{-1}$ and 340 cm$^{-1}$ which represent to –OH group content, and peaks from 450 cm$^{-1}$ - 700 cm$^{-1}$ which represent the Ti-OTi. This test was agreed with Adawiya J. Haider [21]. The test was measured at chemistry department / University of Baghdad.

Figure 3. XRD of titanium oxide nanoparticles.

Figure 4. FTIR of Titanium oxide nanoparticles.
5. Procedure

Lee's disc apparatus (made in England) to measure the thermal conductivity of materials consists of three steel discs with a hole in the upper edge. This apparatus existing in chemical industries Department, Institute of Technology and The thermometers were settled in these holes. The room temperature was taken into account for four different (20, 25, 30, 35 °C). The current was turned out by the power apply of 10 volt and 3 amper. When the power is on the heater will rise the temperature of the first disc and the heat is transferred to the second disc the temperatures are measured every 2 minutes, then the disc of the sample TiO₂/epoxy nanocomposites was putted in the third disc. In the end of apparatus the final steel disc will putted with a thermometer in an upper hole. The temperature was taken after the three thermometers are reached to steady state. Lee's disc apparatus is shown in figure 5 below.

![Lee's Disc Apparatus](image)

**Figure 5.** Lees’ Disc apparatus

In the figure 6 showed the diagram of measuring the thermal conductivity of the samples with different volume fraction of TiO₂/epoxy nanocomposites.

![Diagram of Lees' Disc](image)

**Figure 6.** Diagram of lees’ disc.
These temperatures were applied in the equations below to calculate the thermal conductivity of the TiO\textsubscript{2} / epoxy nanocomposites for different volume fraction and two types of nanoparticle sizes of 50 and 25 nm.

\[ VI = e[A_1(T_1 - T) + A_2(T_2 - T) + A_x\left(\frac{T_2 + T_3}{2} - T\right) + A_3(T_3 - T)] \]  
\[ e = \frac{VI}{A_1(T_1 - T) + A_2(T_2 - T) + A_x\left(\frac{T_2 + T_3}{2} - T\right)} \]

Where \( A_1, A_2, A_3 \), are the lees disc area of values:
\( A_1 = 4.01 \times 10^{-3} \) m\(^2\)
\( A_2 = 2.01 \times 10^{-3} \) m\(^2\)
\( A_3 = 4.01 \times 10^{-3} \) m\(^2\)

And \( A_x \) is the area of the samples used to the thermal conductivity.

\( T_1 \): Is the temperature of the first disc.
\( T_2 \): Is the temperature of the second disc.
\( T_3 \): Is the temperature of the third disc.

\( T \): is the room temperature in K.

\( V \): the voltage.
\( I \): current.
\( e \): emissivity.

\[ q = kA_x\frac{T_2 - T_3}{x} \]  
\[ kA_x\frac{T_2 - T_3}{x} = e\left[A_x\left(\frac{T_2 + T_3}{2} - T\right) + A_3(T_3 - T)\right] \]
\[ k = e\left[A_x\left(\frac{T_2 + T_3}{2} - T\right) + A_3(T_3 - T)\right]\frac{A_3}{A_x\left(\frac{T_2 + T_3}{2} - T\right)} \]

\( q \): Heat transfer rate.
\( x \): Thickness of the samples.

6. Results

The results showed that the thermal conductivity of nanocomposite TiO\textsubscript{2}/epoxy is increasing as the volume fraction increase compared to the epoxy without TiO\textsubscript{2} nanoparticles. This is agreed with Muhammad U. [22]. The thermal conductivity increased as the particle size of nanoparticle decreased for 50 and 25 nm. This is agreeing with Michael P. [23]. As shown in figures (7, 8, 9, and 10).

The temperature of the first disc will be transferred to the second disc and the temperature disc depends on the ability of transfer the heat from the second disc. The performance of samples TiO\textsubscript{2}/epoxy nanocomposites appeared when the temperature of the third disc was raised and because near the temperature of the first and second discs.
**Figure 7.** Thermal conductivity of TiO$_2$/epoxy at different particle sizes and fraction of 20 °C temperature.

**Figure 8.** Thermal conductivity of TiO$_2$/epoxy at different particle sizes and fraction of 25 °C temperature.
Figure 9. Thermal conductivity of TiO$_2$/epoxy at different particle sizes and fraction of 30 °C temperature.

Figure 10. Thermal conductivity of TiO$_2$/epoxy at different particle sizes and fraction of 35 °C temperature.

7. Conclusions
1. The thermal conductivity of (0, 2, 4, 6, 8, 10, 12) % volume fraction of TiO$_2$/epoxy nanocomposites showed increased in the value of thermal conductivity as the volume fraction increased too. This is because of the activity of TiO$_2$ of nanoparticles in the epoxy matrix.
2. The particle size of 25 nm gives high values of thermal conductivity increasing by 93% from epoxy without and additions. This is due to the high performance of nanoparticles in that size of huge surface area it is volume.
3. The room temperature are represent important factor because that the thermal conductivity of TiO$_2$/epoxy nanocomposites increased as the room temperature increased too.

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