iJournals: International Journal of Software & Hardware Research in Engineering (IJSHRE)
ISSN-2347-4890
Volume 9 Issue 3 March 2021

Nanoparticles Percentage Influence on Mechanical and Thermal Conductivity Properties of Epoxy Resin

Najah Rustum Mohsin

Southern Technical University (STU), Iraq

najahr2000@stu.edu.iq

ABSTRCT

In the current paper, effect of TiO_2NPs (titanium dioxide nanoparticles) and Al_2O_3NPs (aluminum oxide nanoparticles) percentage on mechanical properties and thermal conductivity of epoxy composite was analyzed. Nanoparticles size of (60-70)nm with (0, 0.02, 0.04, 0.06, 0.08 & 0.1) weight fractions were applied to implement the specimens. The empirical results showed that addition of 0.04 %wt. of TiO2NPs or 0.06% wt. of Al2O3NPs to epoxy composites achieved to the largest thermal conductivity value. Moreover, the highest value of elastic modulus was obtained by adding 0.06 wt% of Al_2O_3NPs and 0.08 wt% of TiO_2NPs. With regard to the bending stress, adding 0.04%wt of TiO_2NPs and 0.04%wt of Al_2O_3NPs to the epoxy was lead to better results. Over the above, it was cleared that the wear resistance can be improved by adding either 0.08%wt of Al_2O_3NPs or TiO_2NPs to the composite. Experimentally, adding nanoparticles to the epoxy decreased the lost weight that occurs as a result of wear from 0.43 gm/cm at pure composite of epoxy to (0.15 and 0.13)gm/cm by adding TiO_2NPs and Al_2O_3NPs, respectively.Reinforcement of epoxy composite by 0.08%wt. of Al2O3NPs Increased fatigue resistance by 14 times, while reinforcement of the same epoxy with 0.06%wt. of TiO2NPs increased fatigue resistance by 17 with compared to unreinforcement epoxy.

Keyword: **Composite, TiO_2NPs, Al_2O_3NPs, elastic modulus, wear, fatigue**

1. INTRODUCTION

The polymer is a Latin word consisting of (poly) meaning multipleand (mer) meaning unit, so the polymer means multi-units. Polymers consist of chains with large molecules formed by joining a number of small molecules known as monomers through a chemical process called polymerization. Polymeric materials have special properties such as lightweight, ease of production, cheapness, low density, high durability, wear resistance, low conductivity in thermal and electricity, coefficient of thermal expansion is much less than that of metals, their resistance to most acids and alkalizes, and their resistance to internal and external stresses. Depending on their properties and uses, polymers can be classified into two main types:

A) Thermoplastic Resins: they are polymers with long or slightly branched linear molecular chains, such as polyethylene, polystyrene, polypropylene and nylon.

B) Thermosetting Resins: they are polymers with cross-linked molecules, such as epoxy resins, unsaturated polyester resins, phenol-formaldehyde [1, 2, 3].

Polymer composite materials developed as a result of the urgent need for materials with specifications not found in traditional materials. It made by mixing specific weight ratios (or volume fractions) of one or more materials known as reinforcement materials (discontinuous Phase) with polymer matrix (Continuous Phase) to obtain a homogeneous substance without chemical reaction occurs where each material retains its properties while the resulting composite material will have different mechanical property from the properties of its constituent materials.

The properties of the composite materials are a function of the properties of their components, their quantities and also depend on the reinforcement shape, size, distribution and direction. It is worth noting that the matrix material and the reinforcement material do not perform its essential function if there is no strong bond between them [4, 5].

Polymeric composite materials are the most common types of composite materials, due to their high physical and mechanical properties. Some studies have shown clear improvement in some mechanical properties when adding nanoparticles such as SiO_2, ZnO_2, Al_2O_3 as reinforcement to the polymer composite materials, especially at lower concentrations. Within nanoscience, the researchers expected that nanomaterials would present dissimilar pathways in modern applications. Different types of nanoparticles that can be added to a polymer matrix in order to provide and produce polymeric nanocomposites with excellent properties [6]. Nanofillers can be categorized into three types: i) Fibers with a diameter shorter than 100nm and aspect ratio from 100 to 106 such as carbon nanotubes, graphite nanofibers, and boron/nitrogen nanotubes [7]. ii) 3D nanofillers with a size of smaller than 100nm such as Al_2O_3, CeO_2, SiO_2, ZnO and TiO_2 nanoparticles. iii) sheet-like nanofillers, which are layered with 1nm thickness and an aspect ratio of at smallest 25 in two dimensions [8]. P. Carballeira et.al. [9] and S. Srivastava et.al.[10] they added TiO_2NPs to epoxy resins at different volume concentrations and studied its effect on mechanical properties. L. X. Ying et al. [11] used nano-nitrile butadiene (NBR) and nano-acrylate rubber with epoxy resins to prepare two types of nanocomposite materials. They found that epoxy nanocomposites had a higher tensile strength at contented 3 %wt. of nano-acrylate and 4 %wt. of nano-NBR.While I. Mahmoud [12] studied the mechanical properties of epoxy resin reinforced with alumina particles in size (106-150)µm and silica particles in size (53-63)µm for different weight fractions 20%, 30% and 40%. Harishanand et al. [13] prepared epoxy composite reinforced with ZnO, CeO_2, ZrO_2 nanoparticles for different weight ratios and they obtained the best mechanical properties when adding 1 %wt. nanomaterials.E.V.Prasadet. al. [14] found that adding 0.1 wt. % of nanoaluminum oxide to the epoxy resin improved the fatigue life of about 46%, 45% and 94% at a stress level of 50%, 60%, and 70% of the ultimate tensile strength,respectively.In this paper, TiO_2NPs and Al_2O_3NPs were added to epoxy resin to prepare polymer nanoparticle composites. Furthermore, the influence of weight fractions of nanoparticles on the thermal conductivity, modulus of elasticity, bending stress, wear resistance and fatigue life were investigated.

2. EXPERIMENTAL PROCEDURE

2.1. Materials

2.1.1.Matrix Material

The epoxy polymer (Conbextra EP-10) with properties (that got from sheet supplied) is explained in Table 1 was used to provide the samples. It is characterized by low viscosity, low creep, good adhesion and liquid form. It mixed with hardener (Meta Phenylene Diamine) with a weight ratio of 1:3 to get the matrix material.

Table 1: Epoxy properties

Young modulus (in compression) GPa	Density g/cm^3	Thermal conductivity W/m.K	Tensile strength MPa	Specific heat J/kg.K
16	1.04	0.66	26	1050

2.1.2. Reinforcement Materials

Two types of nanoceramic particles were used in this research, Al_2O_3NPs and TiO_2NPs with (60 -70) nm size and purity of 99.8%. Each powder was mixed with the epoxy resin separately in weight fractions of (0, 0.02, 0.04, 0.06, 0.08 and 0.1). These two powders are made from Shanghai Xinglu Company. Tables 2 and 3 explain some mechanical properties of Al_2O_3NPs and TiO_2NPs, respectively.

Table 2: Mechanical properties of Al_2O_3NPs [14]

Ultimate Tensile Stress(UTM) Mpa	Young Modulus Gpa	Density Kg/m^3
146.52	58.03	2742.85

Table 3: Mechanical properties of TiO_2NPs[15]

Density Kg/m3	Hardness Kg/mm^2	Tensile strength Mpa	Tensile modulus Gpa	Compressive strength Mpa
4230	980	350	200 - 300	800 - 1000

2.2 Sample Preparation

Hand lay-up procedure was used and the samples preparation process takes place in several steps, as follows:

1) A special glass mold for the molding process with dimensions (200 * 200 * 6) mm was prepared. To prevent the sticking of the resin on the glass plate and ease of removing the manufactured pieces, wax was used.

2) A quantity of epoxy material according to the size of the mold was weighed.

3) Quantity of the reinforcing materials (aluminum oxide and titanium dioxide nanoparticles) according to the required weight fractions was weighed.

4) After that, the process of mixing the reinforcement materials with matrix material begins at room temperature. The compound was mixed for one hour by using of an ultrasound mixer, type (Pundit lab Proceq) to disperse the nanoparticles and make the mixture homogeneous, then the hardener was added with a ratio of (1: 3) and mixed for (2-3) minutes.

5) Pour the liquid mixture in the mold continuously and regularly until the mold was filled to the required level and avoid the occurrence of air bubbles in the casting.

6) The mold was put on an electric vibrator for 1-2 minutes to get rid of the existing air bubbles because it causes failure in the sample.

6) The casting is Left in the mold for 24 hours to solidify permanently, then after that it is extracted from the mold and leave 10 days to complete the polymerization process.

7) Samples were cut according to the recommended specifications for each test in accordance with American specifications (ASTM-D 790-1984).

The volume fractionswere calculated using the following equations:

$$V_m + V_r = 1 \qquad (1)$$

$$V_m = \Phi_m / (\Phi m + \Phi_r) \qquad (2)$$

$$V_r = \Phi_r / (\Phi m + \Phi_r) \qquad (3)$$

Where V, Φrepresents volume fraction and volume, respectively, and the subscripts m, r, represents the matrix and the reinforcement components.

3. RESULT AND DISCUSSION

The reinforcing effects of epoxy with different ratios of titanium dioxide and alumina nanoparticles on thermal conductivity, modulus of elasticity, bending stress, wear resistance and fatigue life has been studied and discussed. Support weight fraction ratios were tested (0.00, 0.02, 0.04, 0.06, 0.08, 0.1) % wt.

3.1 Effect of Nano Reinforcement on Thermal Conductivity

Lee's disk method for calculating the thermal conductivity was used, using the device manufactured by Griffen and George. Figure 1 shows the effect of the reinforcement of epoxy with nanoparticles on the thermal conductivity values with (0.00, 0.02, 0.04, 0.06, 0.08 and 0.1) %wt..

The experimental results explained that adding TiO_2NPsby 0.04% To the epoxy composite leads to get to the highest thermal conductivity while it was achieved with a weight ratio of (0.06%) when reinforced with Al_2O_3NPs. The polymeric materials have a random crystal structure and the chains are linked with each other in a tangential and irregular manner, which reduces the probability of scattering photons, while the ceramic materials such as TiO_2NPsand Al_2O_3NPs have a crystalline structure and their atoms are arranged in the form of a three-dimensional crystal structure, which led to an increase in the thermal conductivity of the composite material.

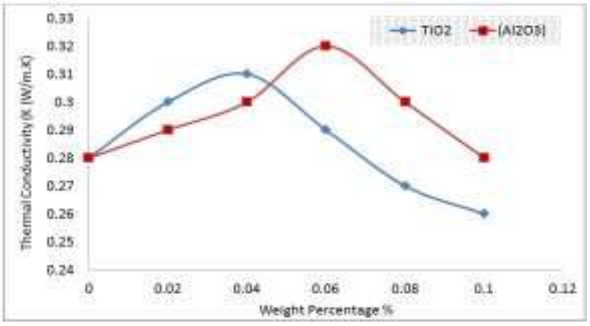

Figure 1:Effect of nano reinforcement on thermal conductivity

3.2Effect of Nano Reinforcement on Modulus of Elasticity

A tensile tester type JIANQIAO TESTING EQUIPMENT was used to calculate the modulus of elasticity. This device was equipped with a digital screen.The stress-strain curves that were used to find the modulus of elasticity were obtained on samples prepared from an epoxy material before and after reinforcing with TiO_2NPsand Al_2O_3NPs.Figure 2 shows a gradual increasing in the modulus of elasticity with an increase in the added of nanoparticles weight percentage then followed by a drop. The modulus of elasticity increased by 50% when adding 0.06 %wt of Al_2O_3NPs and 0.08 %wt of TiO_2NPs, and then decreased after that.Titanium and alumina nanoparticles are characterized by their high stiffness, so when adding low weight ratios from it to the composite, this will increase its hardness and thus increase the value of the elastic modulus, but an increase in the adding ratio more than 0.08%wt. was lead to adverse results.

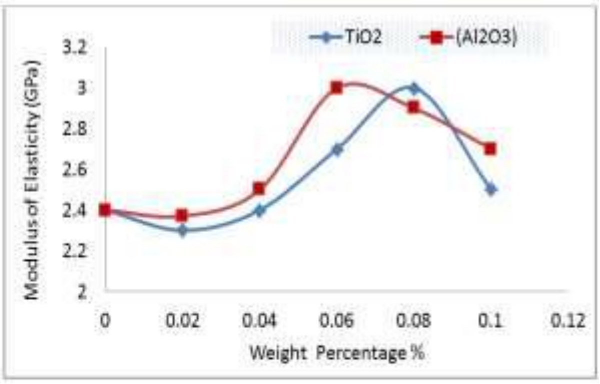

Figure 2:Effect of nano reinforcement on Modulus of Elasticity

3.3 Effect of Nano Reinforcement on Bending Stress

The Three Point Bending Test was performed using the Tinus olsen device of English origin with an operating capacity of (50 KN). This device wasprovided with a digital screen as well as an oscilloscope to record the values of the load on the sample.The test was performed on samples prepared from epoxy material before reinforcing with nanoparticles and after reinforcing. Values of bending stress were calculated by using the following equation [16]:

$$\sigma_b = 3FL / 2bh^2 \qquad (4)$$

Where:σ_b: Bending stress (N / m^2), F: force at the fracture point (N), L: lengthof theSupport span(mm), b: sample width (mm), h: sample thickness (mm).

From Figure 3, it is evident that the bending stress behavior of the composite after adding nanomaterial was very similar to the behavior of the elastic modulus with different values, as it is seen that by addingany of TiO_2NPsor Al_2O_3NPs, the bending stress values increase with the addition of 0.2 %wt. and reach to the highest value when adding 04. %wt. where up to 84Mpa and 92Mpa when adding TiO_2NPsand Al_2O_3NPs,respectively. After that, it drops gradually with the percentage of addition increases.

At a low reinforcement ratio (0.02 - 0.4) %wt, the bending stress increases due to present a large bonding force between the matrix material and the reinforcement particles. thereafter, the bending stress turns to decrease when the reinforcement percentage increases more than (0.04%wt.), this is due to the decrease in the interface bond (the contact area between the different materials in the composite) as a result of the additive and agglomeration of the reinforced nanoparticles, which leads to decrease in the ductility and fracture stress of the composite.

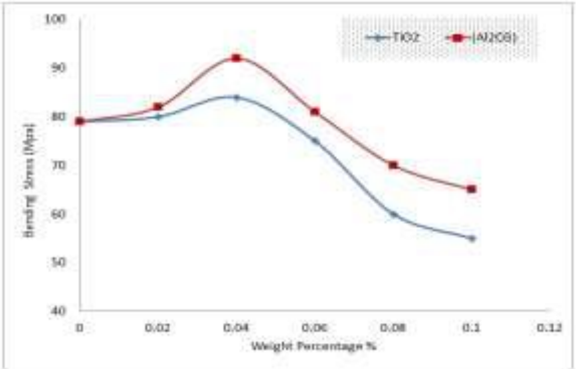

Figure 3:Effect of nano reinforcement on Bending Stress

3.4 Effect of Nano Reinforcement on Wear Resistance

Wear is defined as the loss or removal of material from one or both of the two contact surfaces in their solid or liquid state as a result of the relative movement between them. The amount of wear depends greatly on the relative sliding velocity between the two contact surfaces, friction coefficient, theaxial pressure between the two specimens, Surface roughness, Running time, Materials properties (surface hardness, crystal structure, thermal conductivity, etc.) and the presence of surface films such as paint or oil.

The wear test was performed using a dry slip wear measuring device type(Pin – on – Disc) designed according to ASTM specifications with a motor velocity of 940 r. p. m with vertical load was 20 N and a linear velocity of the sample relative to the friction surface was 1.4 m /s. The weight loss method was used to measure the wear rate using a sensor balance with accuracy 0.0001gm depending on the following equations [17]:

$$\text{Wear rat (g/cm)} = \Delta w / S \quad (5)$$
$$\Delta w = w1 - w2 \quad (6)$$
$$S = 2\,\pi\,.r\,.n\,.t (7)$$

Where: Δw : Weight loss (gm), w1 & w2: Sample weight before and after testing, respectively, S :Sliding distance (cm), r: disk radios=4.9cm, n:revolution/minute=940 rpm, t:sliping time = 1min.

Figure 4 illustrates the relationship between lost weight (wear rate) and the reinforcement Percentage with nanoparticles. The test was administered on reinforced epoxy by adding (0, 0.02, 0.04, 0.06, 0.08 and 0.1) %wt of Al_2O_3NPs and TiO_2NPs. Generally, it was found that the wear rate decreases with increasing the weight proportions of the nanoparticles. The best results of wear rates were obtained when adding 0.08%wt. It can be seen that, epoxy reinforced with nanoparticles was more resistant to wear than pure epoxy because those particles make it harder. Adding alumina nanoparticles produced better results compared to adding titanium nanoparticles due to the truth that alumina is harder than titanium.

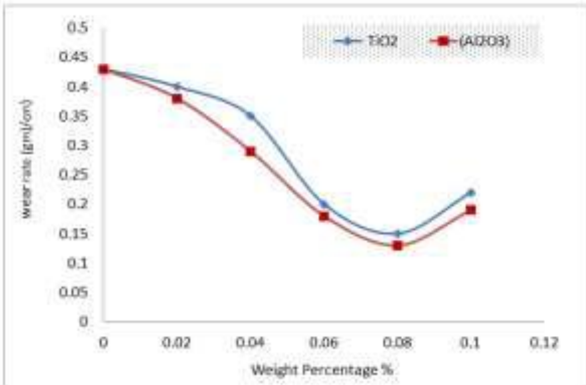

Figure 4:Effect of nano reinforcement on wear resistance

3.5 Effect of Nano Reinforcement on Fatigue

Alternating bending fatigue machine made by Hi-Tech Companywas used in this test. The device wassupplied with a digital screen to count the number of cycles.

Fatigue failure is one of the most common types of failure, and it occurs when the material is subjected periodically to repeat or variable stress, then the failure occurs in the material with less stress than the stress required for failure in the case of static. The stress at which no failure occurs even if the number of cycles continues indefinitely is called the fatigue limit.Fatigue damage in a material is cracked with three stages: Crack Initiation (micro cracks), Crack Propagation and Final Failure (fracture).

Figure 5 illustrates the effect of epoxy reinforcement with Al_2O_3NPs and TiO_2NPson the number of cycles required for fatigue failure to occur (fatigue failure resistance).The results showed that, at 0.08%wt of Al_2O_3NPs reinforced, Epoxy was the highest resistance to fatigue where the amount of increase over pure epoxy was 14 times, while the highest fatigue resistance of epoxy achieved at 0.06%wt of TiO_2NPs where the amount of increase over pure epoxy was 17 times.

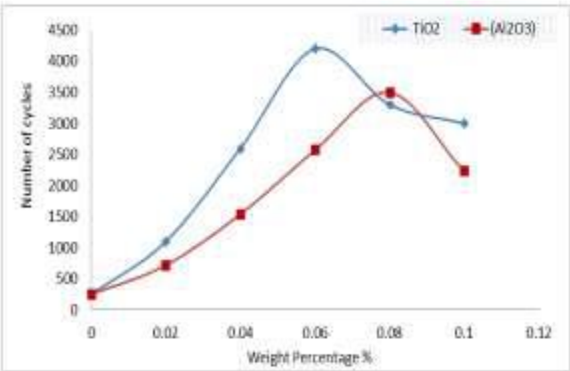

Figure 5:Effect of nano reinforcement on Fatigue

4. CONCLUTION

Based on the results, it is discovered that adding TiO_2NPs and Al_2O_3NPs in low weight percentages lead to improve the mechanical and thermal properties of the epoxy composite. The best properties were obtained when the nanoparticle's addition rate ranged between (0.04 - 0.08)% wt. Adding (0.04, 0.08 and 0.06)%wt of Al_2O_3NPs leads to better results in bending stress, wear rate, and thermal conductivity, respectively. Otherwise, adding 0.06 %wt of TiO_2NPsleads to more agreeable results in fatigue life. The largest value for the modulus of elasticity was obtained when adding 0.08%wt of TiO_2NPsor 0.06%wt of Al_2O_3NPs to epoxy composite.

5. ACKNOWLEDGMENTS

I would like to provide my honest gratitude to the workers in the laboratories of Southern Technical University and University of Technology for their help to me in completing this paper.

6. REFFERENCES

[1] D. B.Miracle and S.L. Donaldson, "Composites", Published by the ASM International Handbook Committee, Vol. 21,2001.

[2] V.Raphanvan,"Material Science&Engineering A frist Course",2nd edition,Prentice-Hall of India Private Limited, New Delhi, 1979.

[3] M.M.Schwarts, "Composite Materials", Handbook,Mc.Graw-Hill Co0,1984.

[4] F. Kreith, "Mechanical engineering hand book (section-12-compsites by vector A.green hunt)",CRC Press LTD,1999.

[5] M. C. Gupta and A. P. Gupta, "Polymer composites",New Age International LTD Publishers, 2005.

[6] C.Sanchez, B. Julián, P. Bellevilleand M. Popall,"Applications of hybrid organic-inorganic nanocomposites", Journal of Materials Chemistry, Vol. 15, No. 35-36, pp. 3559–3592, 2005.

[7] M. S. Dresselhaus, G. Dresselhaus and P. Avouris, "Carbon Nanotubes: Synthesis, Structure, Properties and Applications", pp. 81–109, Springer, New York, USA, 2000.

[8] P. M. Ajayan, L. S. Schadler and P. V. Braun, "Polymer-based and polymer-filled nanocomposites,", Nanocomposite Science and Technology, pp. 112, Wiley-VCH GmbH & Company KGaA, 2005.

[9] P. Carballeira and F. Haupert, "Toughening effects of titanium dioxide nanoparticles on TiO_2/epoxy resin nanocomposites", Polymer Composites , Vol. 31, No. 7, pp. 1241 – 1246, 2009.

[10] S. Srivastava and R. K. Tiwari, "Synthesis of Epoxy-TiO_2Nanocomposites: A Study on Sliding Wear Behavior", Thermal and Mechanical Properties,International Journal of Polymeric Materials, Vol. 61, No. 13, pp. 999-1010, 2012.

[11] L. X. Ying, S. Yong, J. Z. Cheng, Z. Y. Hua and D. M. Wei, "Mechanical Property of Nano-Particles Reinforced Epoxy Resin Composite Materials", Advanced Materials Research, Vol. 181, No. 3, pp. 99-102, 2011.

[12] I. A. Mahmood, “Study the Mechanical Properties of Epoxy Resin Reinforced With silica (quartz) and Alumina Particles”. The Iraqi Journal for Mechanical and Material Engineering, Vol.11, No.3, 2011.

[13] S. Devikala, P. Kamaraj and M. Arthanareeswari, "Conductivity and dielectric of PMMA composites",Chemical Science Transcations, Vol. 2, No. 129, 2013.

[14] E.V.Prasad, C. Sivateja and S.K.Sahu, “Effect of nanoalumina on fatigue characteristics of fiber metal laminates”, Polymer Testing, Vol. 85,May, 2020.

[15] A. Chatterjee and M. S. Islam, “Fabrication and characterization of TiO_2 epoxy nanocomposite”, Materials Science and Engineering: A, Vol. 487, No. 1, pp.574-585, 2008.

[16] P. R. G. Hein and L. Brancheriau, “COMPARISON BETWEEN THREE-POINT AND FOUR-POINT FLEXURAL TESTS TO DETERMINE WOOD STRENGTH OF Eucalyptus SPECIMENS”, MaderasCiencia y tecnología, Vol. 20, No. 3, pp. 333 - 342, 2018.

[17] T. Uygunoğlu, W. Brostow and I. Gunes, “Wear and friction of composites of an epoxy with boron containing wastes”, Polímeros, Vol. 25, No. 3, 2015.