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A Comparative Study to the Wear Behavior of Epoxy Reinforced by Tio_2 and Al_2O_3 Nanoparticles

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Abstract: The wear behavior in dry condition for epoxy reinforced by Al_2O_3 and TiO_2 nanopowders with a constant sliding time of 10 min has been investigated experimentally in the present research and nanoparticles average diameters of both powders have been determined using AFM technique and it was found (78.52 nm) for Al_2O_3 and (52.56 nm) for TiO_2. Pin on disc wear test machine with 950 rpm speed and (5-20N) sliding loading has been used to determine the wear rate of the prepared samples. nanocomposite materials made of epoxy with different weight fractions of Al_2O_3 and TiO_2 powders were prepared by hand layout. The effects of adding nanoparticles with four different weight fractions (0.5, 1, 1.5 and 2%) have been discussed. The obtained results demonstrated that the Alumina (Al_2O_3) nanopowder has a greater effect in decreasing the wear rate of such nanocomposite material than Titanium dioxide (TiO_2). A maximum percentage decrease in wear rate of (9.7%) has been recorded for the epoxy reinforced with 0.5% Al_2O_3 nanopowder in comparison with that reinforced with TiO_2 when the applied load was (20 N). Also the wear rate decreases by (47.6 and 43.6%) for the epoxy reinforced with 2% weight fraction of Al_2O_3 and TiO_2 nanopowders, respectively, in comparison with that of pure epoxy when the applied load was (20 N).

Key words: Epoxy, composite, wear rate, nanopowder, demonstrated, alumina

INTRODUCTION

Polymer composites have a wide range of applications especially in the aviation and automotive fields. Polymeric nano-composites can be considered as a widespread method to treat the drawback of fiber composite from the strength and tribological behavior points of view. It is the material which composed of one or more types of nanoparticles with size (1-100 nm) dispersed in a polymer matrix (Kim and Palomino, 2011). Good tribological properties can be obtained for polymers filled with nano-scale fillers compared to that filled with micro-scale particles. The friction and wear resistance of these composites were found to increase with increasing the filler concentration (Aly *et al*., 2012).

Wetzel *et al*. (2003) systematically introduces various amounts of micro and nano-scale particles of Calcium Silicate $CaSiO_3$ (4-15 μm) and Alumina Al_2O_3 (13 nm) into an epoxy polymer matrix for reinforcement purposes and to enhance its tribological properties. It was found that the synergistic effects increase the wear resistance and stiffness. Effective improvement of the epoxy resin at a nanoparticle content of already 1-2 vol. % Al_2O_3 has been obtained when the nanoparticles were incorporated only. Zhang *et al*. (2004) using different fillers such as short carbon fiber, graphite, nano-TiO_2 and PTFE to enhance the wear resistance of epoxy. An enhancement of about 100% in wear resistance has been obtained in comparison with the epoxy alone. Shi *et al*. (2004) studied the sliding wear performance of epoxy composites filled with nano-sized Al_2O_3. It was found that the incorporation of nano-Al_2O_3 decreases the wear rate and the coefficient of friction even if it was added with low concentrations. Xian *et al*. (2006) and Srivastava and Tiwari (2012) studied the influence of incorporating 300 nm TiO_2 nanoparticles on the tribological performance of epoxy resin under various sliding loadings and speeds. It was shown that incorporating TiO_2 nanoparticles by 4 vol. % significantly improves the wear resistance of the epoxy resin under mild sliding conditions.

Karal (2007) prepared epoxy nanocomposites and fiber reinforced polymer composites by the addition of tungsten based nanostructured particles and investigate its effects on the tribological, mechanical and thermal

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properties. It was found that the addition of 3% by weight of nanoparticles significantly improves the wear resistance of such materials. Larsen *et al.* (2008a, b) produces an epoxy-matrix composites and test them tribologically for dry-sliding conditions. Epoxy resins (EP), glass fiber weave, Carbon/Aramid hybrid weave (CA), PTFE particles and nano-scale CuO particles have been used in the production of composite material. Friction, wear and interfacial temperatures are measured on a custom-built pin-on-disk apparatus using a steel disk as counterface. It was found that the coefficient of friction decreases and the wear rate increases when the epoxy reinforced by nano-CuO particles. Larsen *et al.* (2008a, b) prepared and tested nanocomposite material by incorporating different amounts of CuO nanoparticles into both a neat epoxy resin and into an epoxy resin containing PTFE microparticles. Different particle concentrations of CuO (0-10%) by volume have been used while the PTFE content is fixed at 7.5% by volume. Friction and wear data obtained by using a custom-made of the pin-on-disk type. Measurements were performed under dry-sliding conditions against smooth steel counter faces. It has been found that without PTFE, the coefficient of friction is roughly independent of the nano-CuO content. When PTFE is added, an average reduction in coefficient of friction of (35%) was found in the CuO range of 0-0.4 vol. %. At higher CuO concentrations the friction lowering effect of PTFE deteriorates. Oleiwi (2010) studied the wear rate behavior of polyester reinforced by micro size particles of Sio_2. Pin on disc machine with variable speed has been used to conduct the experimental work. The results show that the wear rate of such material decreases when using higher weight fraction and smaller particle size. Srivastava and Tiwari (2012) and Xian *et al.* (2006) used functionalized nano-TiO_2 with different particle concentrations by weight to enhance the wear rate, thermal and mechanical properties of epoxy. It has been revealed that the epoxy with 5% of TiO_2 shows the least specific wear rate. Also, the toughness increased by 12.15% and the impact strength by 20%. Thermal stability of the nano-composite became higher than that unfilled epoxy matrix.

Pinto *et al.* (2015) highlighted some findings and trends for the development of polymer nano-composites reinforced with TiO_2 nanoparticles. It is shown that the addition of TiO_2 nanoparticles into epoxy resin can improve important mechanical properties, abrasion and pull-off strength even at low filler contents. Mahesha *et al.* (2017) evaluate the effect of incorporation nano Titanium dioxide (TiO_2) alone and in combination with nano-clay on the mechanical and tribological wear behavior of basalt fabric-epoxy composites. The effect of different loads (10-30 N) and sliding distances from 2000-8000 m on the performance of the wear resistance of the composites was measured. The wear loss of the composites decreased with the addition of fillers and increased with increasing sliding distance. The present research focuses on comparing the wear behavior of different nanocomposite materials made of epoxy matrix reinforced by nanoparticles of TiO_2 and Al_2O_3.

MATERIALS AND METHODS

Experimental details: A commercial epoxy resin supplied by Egyptian Swiss Chemical Industries Company was used as a matrix material during the present research. Al_2O_3 nanopowder (ev-w3 20131220) with purity of 99.9% and TiO_2 nanopowder supplied by a commercial source was used as filler materials. The powders were heated to100°C for 6 h before use and then mixed with epoxy at room temperature. The average particle size of the nanopowders is measured using the AFM technique. The results for AFM analysis showed that the average diameter for (Al_2O_3) and (TiO_2) nanoparticles are (78.52 nm) and (52.56 nm), respectively. The results of particle size distribution for these nanopowders are shown in Fig. 1a, b, respectively. The nanocomposite materials were prepared by using commercially laboratory mixer. The fillers were well mixed to disperse the nanoparticles homogenously in the epoxy resin matrix. Finally, the epoxy was hardened by adding the suitable hardener with further string for few mints. The mixture was filled into 10 mm diameter and 20 mm height molds, according to Anonymous (2004).

Experimental tests: Dry wear tests were conducted using the commercial pin on disc machine shown in Fig. 2 to evaluate the wear rate of the nanocomposite materials. A hardened and polished carbon steel disc with track diameter of 6 cm was used against the nanocomposite pin. Nine pins are shown in Fig. 3 one of unreinforced epoxy; four of epoxy reinforced with different fraction weights of Al_2O_3 and the other four of epoxy reinforced with different fraction weights of TiO_2 were prepared and used in wear tests of the present experimental work. The disc was slide against the composite pin for (10 min) under ambient conditions. A rotational speed of (950 rpm) and different applied loads (5, 10, 15 and 20 N) have been used in conducting the experimental tests of the present research.

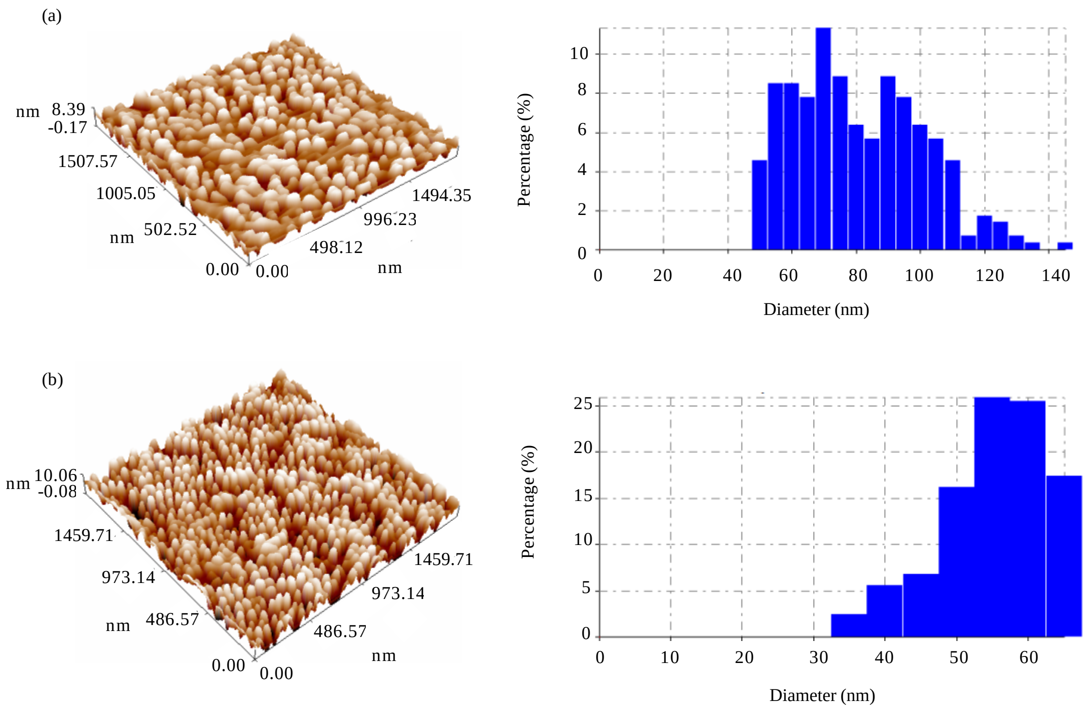

Fig. 1: Atomic force microscopy test for nanopowders: a) Sample: Al_2O_3, average diameter: 78.52 nm and b) Sample: TiO_2, average diameter: 52.56 nm; Granularity cumulation distribution chart

Fig. 2: Pin on disc machine used for wear test

The specimen mass loss (Δm) was calculated by weighting the specimen before and after wear test and the wear rate for each specimen was calculated using Eq. 1 (Pinto *et al*., 2015):

$$\dot{W} = \frac{\Delta m}{\rho L} mm^3/mm \quad (1)$$

Fig. 3: Pins used in wear tests with different particle concentrations of Al_2O_3 and TiO_2

Where:

ρ = Density of the specimen (gm/cm^3)
L = The total sliding distance = V×t
V = ω×r
ω = Rotational speed (rad/sec)
r = Disc radius (mm)
t = Time (sec)

The inverse of the wear rate is usually referred to as the wear resistance of a material. The epoxy used in the

Table 1: Density of the nanocomposite materials

Weight fraction of Al_2O_3 or TiO_2 nanopowder %	Density of epoxy reinforced by Al_2O_3 nanopowder (gm/cm^3)	Density of epoxy reinforced by TiO_2 nanopowder (gm/cm^3)
0.5	1.210	1.236
1	1.235	1.272
1.5	1.253	1.294
2	1.265	1.304

present research has a density of 1.2 gm/cm^3. The density of the nanocomposite materials has been measured and the results presented in Table 1.

RESULTS AND DISCUSSION

The calculated wear rate has been represented against the applied load for different types of pins made of epoxy reinforced with different weight fractions of Al_2O_3 and TiO_2. Figure 4 shows the wear rate against the applied load for the epoxy nanocomposite material with different weight fraction of Al_2O_3. It can be seen from this figure that the wear rates increase with increasing the applied load at different rates. Also it can be shown from this figure that the wear rate of such material decreases when the material filled with higher weight fraction of Al_2O_3 in comparison with that of pure one that due to increasing the reinforcing materials that lead to increasing the average hardness of the composite specimens. The percentage decrease was calculated and found to be (47.6%) for the epoxy reinforced with 2% weight fraction of Al_2O_3 nanopowder in comparison with that of pure epoxy when the applied load was (20 N).

The same behavior can be shown for the epoxy reinforced with TiO_2 nanopowder as can be shown in Fig. 5. The wear rate of the nanocomposite material becomes lower when the epoxy filled with a higher weight fraction of (TiO_2). The lowest value of the wear rate for the nanocomposite material for the applied load (20 N) was found to be (8.56×10^{-7} mm^3/mm) when the epoxy filled with 2% weight fraction of (TiO_2) in comparison with (15.182×10^{-7} mm^3/mm) for pure epoxy with the percentage decrease of (43.6%).

A comparison of the wear rate of the epoxy filled with 2% weight fraction of Al_2O_3 with that filled with 2% TiO_2 can be shown in Fig. 6. It is clear from Fig. 6 that the epoxy filled with Al_2O_3 nanopowder shows a lower value of wear rate than that filled with TiO_2 nanopowder.

Figure 7 shows a comparison between the maximum wear rates for the epoxy reinforced Al_2O_3 and that reinforced with TiO_2 nanopowders. This figure obliviously shows that Al_2O_3 nanopowder is better than TiO_2 nanopowder as filler from the wear rate point of view. The

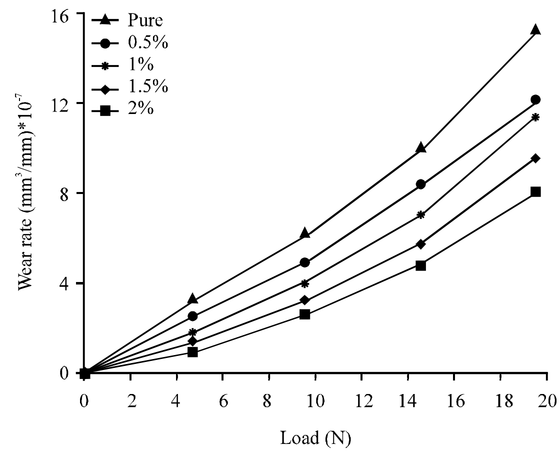

Fig. 4: Wear rate against applied load for nanocomposite material with different weight fraction of Al_2O_3

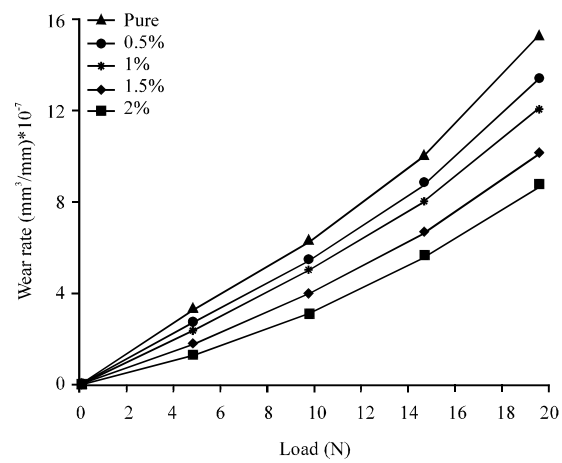

Fig. 5: Wear rate against applied load for nanocomposite material with different weight fraction of TiO_2

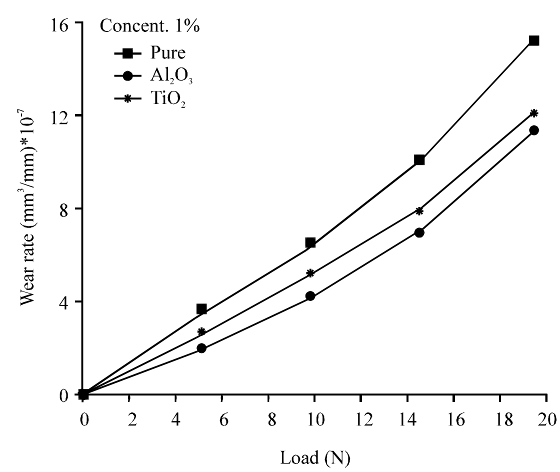

Fig. 6: Comparison for the wear rate of epoxy filled with 2% of Al_2O_3 and TiO_2

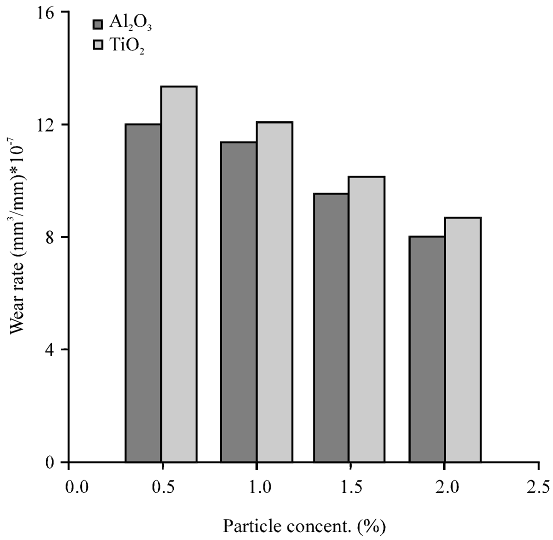

Fig. 7: Maximum wear rate for epoxy reinforced with Al_2O_3 and TiO_2 nanopowders against particle concentration

epoxy reinforced with Al_2O_3 nanopowder shows a higher percentage decrease in wear rate than that reinforced with TiO_2 by about 5.5-9.7%. The maximum percentage decrease (9.7%) has been recorded for the epoxy reinforced with 0.5% Al_2O_3 nanopowder.

CONCLUSION

From the previous discussion of results obtained in the present research the following conclusions can be drawn: the pure epoxy shows the highest wear rate with maximum value reaches (15.182×10^{-7} mm^3/mm).

The wear rate decreases by (47.6%) for the epoxy reinforced with 2% weight fraction of Al_2O_3 nanopowder in comparison with that of pure epoxy when the applied load was (20 N).

The wear rate decreases by (43.6%) for the epoxy reinforced with 2% weight fraction of TiO_2 nanopowder in comparison with that of pure epoxy when the applied load was (20 N).

A maximum percentage decrease in wear rate (9.7%) has been recorded for the epoxy reinforced with 0.5% Al_2O_3 nanopowder in comparison with that reinforced with TiO_2.

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