**Benha Journal of Applied Sciences (BJAS)** **print : ISSN 2356–9751**
**Vol.(2) Issue(1) Oct.(2017), 131-135** **online : ISSN 2356–976x**
**http:// bjas.bu.edu.eg**

# Tribological Characteristics of Epoxy/Mwcnts and Epoxy/$Al_2o_3$ Nanocomposites under Dry Sliding Conditions

***E.Y.El-Kady, T.S.Mahmoud, S.S.Mohammed,T.A.Khalil, S.M.Mohammed***
Mechanical Engineering Dept., Faculty of Engineering Shoubra, Benha Univ., Egypt.
E-Mail: tamer.abdelmagid@feng.bu.edu.eg

**Abstract**

In the present investigation, the tribological performance of epoxy-based nanocomposites filled with multi-wall carbon nano-tubes (MWCNTs) and aluminum oxide ($Al_2O_3$) nanoparticles in different weight percentages was investigated. The coefficient of friction (COF) and wear rate of the Epoxy/MWCNTs and Epoxy/$Al_2O_3$ nanocomposites were evaluated using a pin-on-ring apparatus in a dry sliding conditions under different contact pressures and sliding speeds. The results demonstrated that the hardness, COF and wear rate were significantly improved by the dispersion of MWCNTs and $Al_2O_3$ nanoparticles into the epoxy resin. Increasing the MWCNTs and $Al_2O_3$ nanoparticles weight percent increases the hardness and reduces the COF and wear rate of the nanocomposites. The epoxy/MWCNTs nanocomposites showed lower COF, but higher wear rate when compared with epoxy/$Al_2O_3$ nanocomposites.

**Keywords:** Nanocomposites, Tribological behavior, Epoxy, Mwcnts, Aluminum oxide.

## 1. Introduction

Several types of nano-fillers are dispersed in epoxy resin to improve its resistance to tribological loads. One of the most common material that is used as ceramics nano-filler is alumina (Al2O3) nanoparticles. Dispersion of small amount of alumina nano-particles is known to enhance the tribological properties of epoxy-based nanocomposites [3-5]. For example, Kumar et al [3] studied the sliding wear performance of Epoxy composites filled with nano-sized Al2O3 particles. They reported that filling of nano-Al2O3 particles in epoxy changed the microstructure of epoxy and prevented the destruction of epoxy banded structure during the friction process.

Multi-wall carbon nano-tubes (MWCNTs) are one of the new nano-fillers used to improve the mechanical and tribological characteristics of epoxy-based nanocomposites due to their excellent thermo-mechanical properties [6-9]. The tribological performance of both Epoxy/MWCNTs nanocomposites were studied by many investigators [3-9]. For example, Campo et al. [7] studied the wear behavior of epoxy matrix composites with several types and weight percentages (wt.-%) of MWCNTs. The tribological properties of Epoxy/MWCNTs were investigated using pin-on-disc wear tester under different conditions. They reported that, compared with neat epoxy, the composites with MWCNTs showed a lower mass loss, friction coefficient and wear rate, and these parameters decreased with the increase of MWCNTs percentage. The results showed that the epoxy nanocomposites with 0.5 wt.-% have the best tribological performance.

Surprisingly, the available literature does not contain a comparative study between the tribological performance of Epoxy/MWCNTs and Epoxy/Al2O3 nanocomposites. Therefore, the present work is focused on the tribological performance of these nanocomposites under dry sliding conditions. The effect of the MWCNTs and Al2O3 nano-fillers weight percent on the coefficient of friction and wear rate of the epoxy resin were extensively studied.

## 2. Experimental procedures

Acommercially epoxy resin matrix (Kemapoxy 150) was provided by Chemicals Company for Modern Buildings (CMB), Egypt. It consists of the resin components cured by an amine curing agent. Two Different nano-fillers were introduced into the epoxy matrix, typically, multi-wall carbon nanotubes (MWCNTs) and aluminum oxide (Al2O3) in the form of nanoparticles. The MWCNTs have average inner and outer diameters of 20 and 30 nm, respectively, and the Al2O3 nanoparticles have an average diameter of 10 nm. Several nanocomposites containing 0.25, 0.5, 0.75 and 1 wt.-% of the nano-fillers were prepared.

The nanocomposites were prepared by applying conventional mechanical mixing method using the available laboratory mixing devices. The nanocomposites were prepared by adding the nanofiller to the epoxy resin and then they mixed together at 1000 rev/min for 20 minutes. Vacuum was applied during the mixing process to eliminate entrapped air. The hardener was added to the epoxy/nanofillers mixture, with a ratio 1:2 by weight, followed by further mixing for 10 minutes. The epoxy/nanofillers nanocomposite mixture was poured into a plastic mould. The mould has 12 mm diameter and 200 mm length. The nanocomposites were cured for 168 hours at ambient temperature.

The hardness of the nanocomposites was measured using microhardness tester by applying an indentation load of 200 g using a Vickers indenter. For each material, six readings were taken for each sample and the average value was determined. Surfaces of nanocomposite specimens were ground on P1200 emery paper before microhardness measurements. Unlubricated (dry) sliding wear tests were carried out using a pin-on-ring apparatus shown schematically in Fig (1) The wear tests were carried out at several sliding velocities of 1, 2 and 3 m/s, and several applied loads of 30, 60 and 90 N. The sliding distance varies up to 1500 m. The nanocomposites wear specimens have a cylindrical shape with 10 mm diameter and 20 mm length. The counterface disc is made of 316 stainless steel, with nominal composition 0.08% C, 1% Si, 12% Ni, 17% Cr, 2.5% Mo and balance Fe (by wt.-%), with a hardness of 184 VHN. The counterface has a diameter of 200 mm (ring radius). The counterface disc was polished on 1200 emery papers before each wear test. The duration of the test was controlled by a stopwatch. Wear loss was obtained by calculating the weight loss of the specimens before and after tests using an electronic balance with sensitivity 1 mg. Friction coefficient measurements were conducted using a transducer measurement system (load cell) mounted on a pin on ring machine to measure the frictional force developed on the pin holder and caused by the ring rotation. The coefficient of friction was computed by dividing the frictional force by the normal load. Morphologies of the nanocomposites worn surfaces were observed using scanning electron microscopy (SEM). To increase the resolution for the SEM observation, the tested nanocomposite specimens were plated with gold coating.

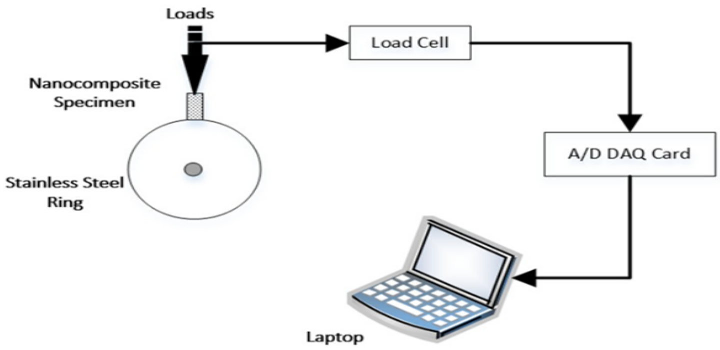


**Fig (1)** Aschematic illustration of the pin-on-ring wear tester

## 3. Results and discussion

### 3.1 Hardness of the nanocomposites

Generally, the epoxy/MWCNTs and epoxy/$Al_2O_3$ nanocomposites exhibited higher hardness than the neat epoxy matrix. However, the epoxy/$Al_2O_3$ nanocomposites demonstrated higher hardness when compared with the epoxy/MWCNTs nanocomposites. The neat epoxy matrix exhibited an average hardness of 16 VHN. The results demonstrated also that increasing the weight percent of $Al_2O_3$ nanoparticles increases slightly the microhardness of the epoxy/$Al_2O_3$ nanocomposites. However, increasing the weight percent of MWCNTs up to 0.5 wt.-% increases the microhardness of the nanocomposites. Further increase in the MWCNTs up to 1 wt.-% reduces the microhardness of the epoxy/MWCNTs nanocomposites. Among all investigated nanocomposites, the epoxy/0.5wt.-% of MWCNTs nanocomposites exhibited the maximum hardness of about 17.8 VHN. The reduction of average micro-hardness values of epoxy/MWCNTs containing 0.75 and 1 wt.-% of MWCNTs may attribute to the possibility of void formation and the weak bonding strength between epoxy resin and MWCNTs at high concentrations.

### 3.2 Tribological behavior of nanocomposites

The results revealed that epoxy/MWCNTs and epoxy/Al2O3 nanocomposites exhibited lower average coefficient of fiction (COF) when compared with the neat epoxy. The neat epoxy exhibited average COF about 0.7. Furthermore, increasing the MWCNTs weight percent reduces significantly the COF of the epoxy/MWCNTs nanocomposites. It seems that the mechanical reinforcing and self- lubricating properties of MWCNTs helped in improving the tribological properties of the epoxy/MWCNTs nanocomposites. Moreover, increasing the amount of MWCNTs assisted in reducing the direct contact between the epoxy matrix and the metallic surface of the counterface.

Increasing the amount of the Al2O3 nanoparticles reduces slightly the COF of the nanocomposites. The epoxy/MWCNTs nanocomposites exhibited lower COF when compared with epoxy/Al2O3 nanocomposites. Fig (2) shows a typical variation of the COF with MWCNTs and Al2O3

Nanoparticles weight percent at constant sliding velocity of 3 m/s and different loads. Increasing the applied load increases the COF of the epoxy/MWCNTs and epoxy/Al2O3 nanocomposites. It has been observed also that increasing the sliding velocity, at constant applied load, increases the COF of the epoxy/MWCNTs and epoxy/Al2O3 nanocomposites.

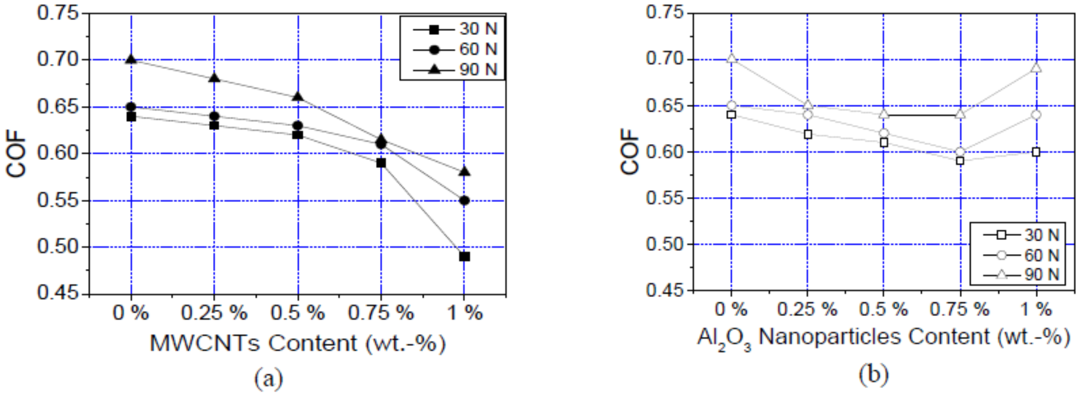


**Fig (2)** Variation of the cof with weight percent of mwcnts (a) and $al_2o_3$ nanoparticles (b) at constant sliding velocity of 3 m/s and different loads.

### 3.2.2 Wear rate of nanocomposites

Both epoxy/MWCNTs and epoxy/$Al_2O_3$ nanocomposites exhibited better wear resistance than the neat epoxy. However, the epoxy/$Al_2O_3$ nanocomposites exhibited lower wear rates than the epoxy/MWCNTs nanocomposites. The typical variation of the wear rate with the MWCNTs and $Al_2O_3$ nanoparticles, at constant load of 90 N, and several sliding velocities is shown in Fig (3) Increasing the MWCNTs weight percent dispersed in the epoxy matrix reduces significantly the wear rate of the epoxy/MWCNTs nanocomposites. However, the epoxy/$Al_2O_3$ nanocomposites containing 0.25 wt.-% exhibited the lowest wear rate for epoxy/$Al_2O_3$ nanocomposites. Increases the $Al_2O_3$ nanoparticles weight percent up to 1% wt.-% slightly increases the wear rate of the epoxy/$Al_2O_3$ nanocomposites. Increasing the sliding velocity and/or applied load increases the wear rate of the epoxy/MWCNTs and epoxy/$Al_2O_3$ nanocomposites.

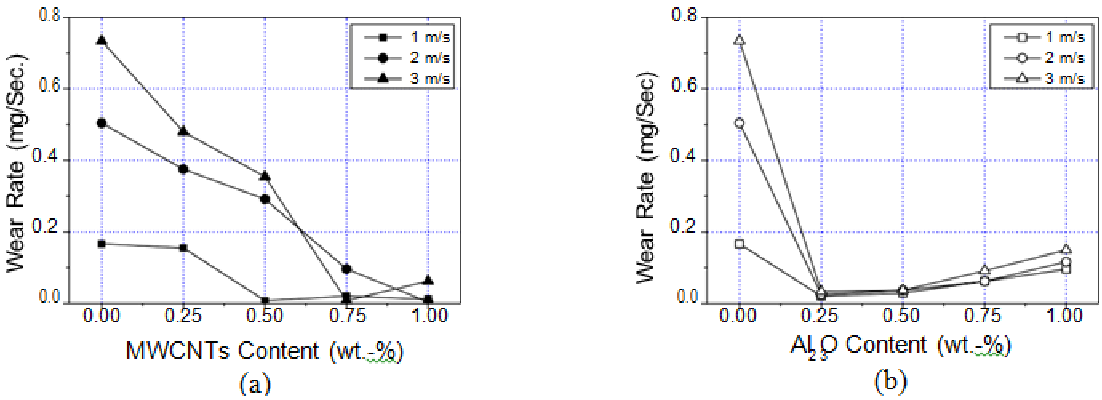


**Fig (3)** Variation of the wear rate with weight percent of MWCNTs (a) and $Al_2O_3$ nanoparticles (b) at constant load of 90 N and several sliding velocities.

### 3.3 Sem examinations of the worn surfaces

Fig (4) shows SEM micrograph of worn surface for a neat epoxy specimen after dry sliding against a stainless-steel disc under a load of 90 N and sliding velocity of 3 m/s for 900 sec. Severe damages and material break out of the surface of the neat epoxy is noted. Fatigue crack propagation is clearly seen due to the acting pressure and shear loads produced by the rotation of the steel counterpart. Fig ( 5 ,6) shows SEM micrographs of the worn surfaces for nanocomposites specimens containing different weight percent MWCNTs and Al2O3 nanoparticles after dry sliding against a stainless-steel disc under a load of 90 N and sliding velocity of 3 m/s for 900 sec. The appearances of the worn surface are completely different and become smoother. The addition of MWCNTs and/or Al2O3 nanoparticles reduced the amounts of large blocks of removal pieces of material and produced smoother worn surfaces. Increasing the amount of MWCNTs and/or Al2O3 nanoparticles increasing the flatness and smoothness of the worn surfaces. The worn surfaces of the nanocomposites containing Al2O3 nanoparticles appears to be slightly rougher than those containing MWCNTs. The worn surfaces of the epoxy/Al2O3 nanocomposites showed very fine scratches due to the Al2O3 nanoparticles. The Al2O3 nanoparticles could move into the asperities and gaps on the surfaces and may be able to roll rather than scratching or sliding movement, this rolling effect reduce the matrix damages. In this case abrasive wear is joined by fatigue cracking of the matrix appears as light lines.

The improvement mechanisms of MWCNTs and/or Al2O3 nanoparticles may attribute to the increase in hardness of the epoxy matrix. These results have clearly shown that the addition of MWCNTs and/or Al2O3 nanoparticles is potentially useful to improve the tribological performance of epoxy, even at a relatively low content.

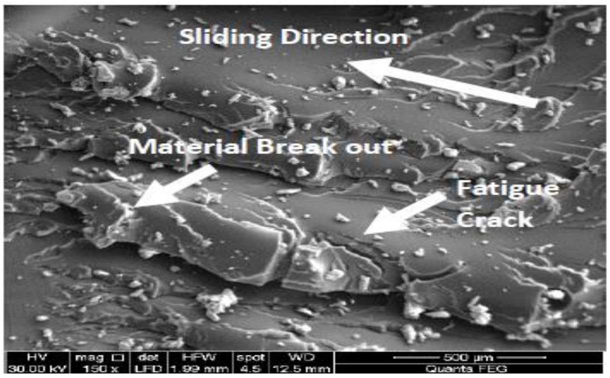


**Fig (5)** SEM micrograph of worn surface for the neat epoxy specimen after dry sliding against a stainless-steel disc under a load of 90 N and sliding velocity of 3 m/s for 900 sec.

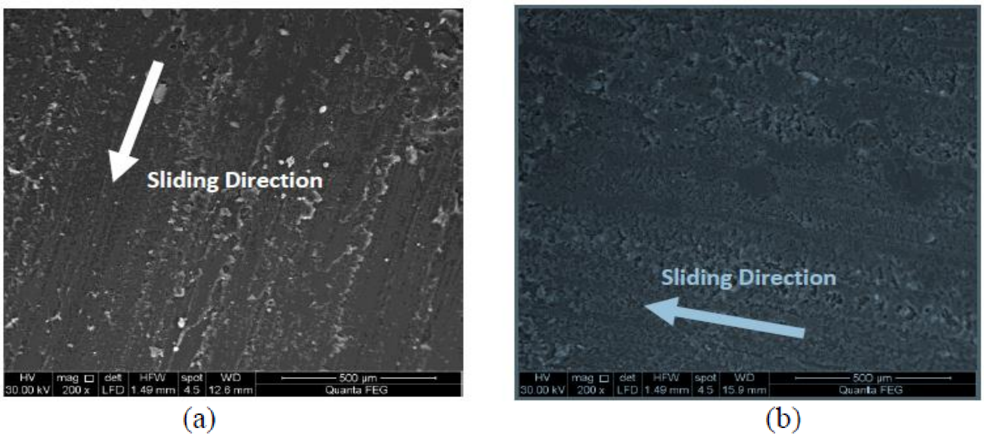


**Fig (6)** SEM micrograph of worn surface for the epoxy containing MWCNTs specimen with percentages (a) 0.5 wt % and (b) 1 wt % under a load of 90 N and sliding velocity of 3 m/s

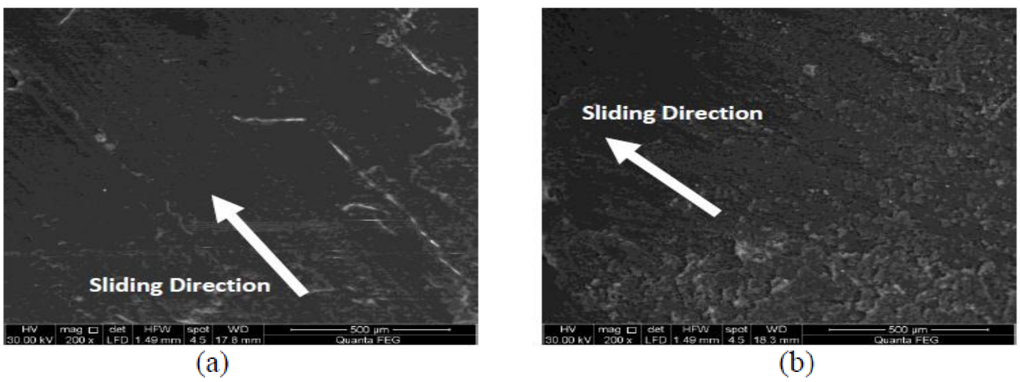


**Fig (7)** SEM micrograph of worn surface for the epoxy containing $Al_2O_3$ specimen with percentages (a) 0.5 wt % and (b) 1 wt % under a load of 90 N and sliding velocity of 3 m/s.

## 4 . Conclusions

Based the aforementioned results, the following conclusions can be concluded:

1. The addition of MWCNTs and $Al_2O_3$ nanoparticles proved to be useful in enhancing the hardness, wear resistance and reducing the friction coefficient of the epoxy.
2. Increasing the weight percent of MWCNTs and $Al_2O_3$ nanoparticles increases the hardness and reduces, the coefficient of friction and improves the dry sliding wear resistance of the nanocomposites.
3. The epoxy/MWCNTs nanocomposites exhibited lower coefficient of friction, but lower dry sliding wear resistance when compared with epoxy/$Al_2O_3$ nanocomposites.

## References


[1] D.L.Burris, B.Boesl, G.R.Bourne, W.G.Sawyer, “Polymeric Nanocomposites for Tribological Applications”, Macromol. Mater. Eng., 292, pp. 387- 402, 2007.

[2] F.L.Jin, X.Li, S.J.Park, “Synthesis and application of epoxy resins: A review”, Journal of Industrial and Engineering Chemistry, Vol.29, pp. 1–11, 2015.

[3] N.S.Kumar., K.Ve.Rao, G.Chakraverti, C.S.Chakra, “Tribological Properties of Epoxy/$Al_2O_3$ Nanocomposites”, International Journal of Engineering Trends and Technology (IJETT), Vol.4(5), pp. 2095-2098, 2013.

[4]R. V. Kurahatti, A. O. Surendranathan, A. V. R. Kumar, V.Auradid, C. S. Wadagerie and S. A. Kori, “Mechanical and Tribological Behaviour of Epoxy Reinforced with Nano-$Al_2O_3$ particles”, Applied Mechanics and Materials, Vol.592-594, pp. 1320-1324, 2014.

[5] G. Shi, M. Q. Zhang, M. Z. Rong, B. Wetzel, K. Friedrich, “Sliding wear behavior of epoxy containing nano-$Al_2O_3$ particles with different pretreatments” Wear, Vol.256, pp.1072-1081, 2004.

[6] G. Manjunatha, S. Rajesh, R. George, K. Naik, “Influence of Post Heat Treatment Temperatures on Wear Properties of MWCNTs Reinforced Epoxy Composites” American Journal of Materials Science, Vol.5(3C), pp. 183-187, 2015.

[7] M. Campo, A. Jimenez-Suarez, A. Urena, “Effect of type, percentage and dispersion method on multi-walled carbon nanotubes on tribological properties of epoxy composites”, Wear, Vol.324, pp. 100-108, 2015.

[8] L. J.Cui, et al., “Functionalization of multi-wall carbon nanotubes to reduce the coefficient of the friction and improve the wear resistance of multi-wall carbon nanotube/epoxy composites”, carbon, Vol.54, pp. 277-282, 2013.

[9] B. Dong, Z. Yang, Y. Huang, H.L.Li, “Study on tribological properties of multiwalled carbon nanotubes/epoxy resin nanocomposites”, Tribol. Lett., Vol.20(3-4), pp. 251-254, 2005.