Iraqi Journal of Physics, 2019 *Vol.17, No.40, PP. 1-9*
DOI: 10.20723/ijp.17.40.1-9

Wear rate of epoxy resin reinforced with multi walls carbon nanotubes

Ayad Qabash Hameed and Faik Hammad Anter

Department of Physics, College of Science, University of Anbar

E-mail: ayadqabash@gmail.com

Abstract

In this study, nanocomposites have been prepared by adding multiwall carbon nanotubes (MWCNTs) with weight ratios (0, 2, 3, 4, 5) wt% to epoxy resin. The samples were prepared by hand lay-up method. Influence of an applied load before and after immersion in sodium hydroxide (NaOH) of normality (0.3N) for (15 days) at laboratory temperature on wear rate of Ep/MWCNTs nanocomposites was studied. The results showed that wear rate increases with increasing the applied load for the as prepared and immersed samples and after immersion. It was also found that epoxy resin reinforced with MWCNTs has wear rate less than neat epoxy. The sample (Ep + 5wt% of MWCNTs) has lower wear rate. The immersion effect in base solution led to increase in wear rate values for all samples compared to natural condition.

Key words
Epoxy resin, nanocomposites, multiwall carbon nanotube, wear rate, optical microscopy.

Article info.
Received: Jul. 2018
Accepted: Sep. 2018
Published: Mar. 2019

معدل البلى لراتنج الايبوكسي المدعم بأنابيب الكربون النانوية متعددة الجدران

اياد قباش حميد و فائق حماد عنتر

قسم الفيزياء، كلية العلوم، جامعة الانبار

الخلاصة

تم في هذا البحث تحضير عينات المتراكبات النانوية باستخدام تقنية القولبة اليدوية بإضافة نسب وزنية (0، 2، 3، 4، 5)% من أنابيب الكربون النانوية متعددة الجدران الى راتنج الإيبوكسي. حيث تمت دراسة تأثير الحمل المسلط قبل وبعد الغمر بمحلول هيدروكسيد الصوديوم ذو عيارية (0.3N) ولمدة (15) يوم على معدل البلى للمواد المتراكبة النانوية ومقارنتها بالحالة الطبيعية (قبل الغمر). بينت نتائج الدراسة ان معدل البلى يزداد مع زيادة الحمل العمودي المسلط ولجميع العينات. كما وُجد ان عينات الإيبوكسي المدعمة بأنابيب الكربون النانوية تمتلك معدل بلى اقل مقارنة بالإيبوكسي النقي. اقل قيمة لمعدل البلى سُجلت بالنسبة لـ(Ep + 5wt% من MWCNTs). أدى تأثير الغمر بالمحلول القاعدي الى زيادة معدل البلى بالنسبة لجميع العينات مقارنة بالحالة الطبيعية.

Introduction

The carbon nanotubes (CNTs) were discovered in 1991 by Japanese scientist Sumio Iijima. Carbon nanotubes are 1-D carbon materials which consisting of wrapped up graphite plates [1]. They are classified according to the number of their graphite layers to single walled carbon nanotubes (SWCNTs) and multi walled carbon nanotubes (MWCNTs) [2]. Structurally, MWCNTs be made up of multi-layers of graphite that are rolled-up on themselves to make a tubular structure as shown in Fig. 1

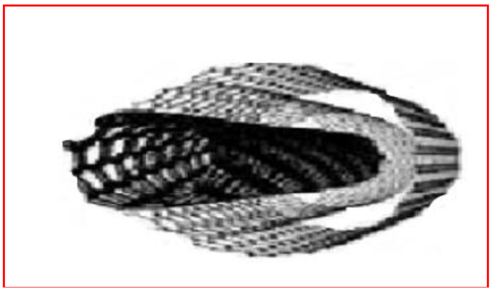

Fig. 1: Multi-walled carbon nanotube [3].

CNTs are considered to be one of the stiffest and strongest engineering materials known. They have a high tensile strength (up to 200 GPa), a high elastic modulus about (270-1400 GPa) and calculated Young's modulus (E >1.4 TPa). Plus, they possess a low density value ranging from 1.2 g/cm^3 for (SWCNTs) up to 2.1 g/cm^3 for (MWCNTs) [4].

These exceptional mechanical properties of carbon nanotubes combined with the large surface area and high aspect ratio have made them outstanding nano-fillers in fabricating polymer based nanocomposites [5, 6]. Particularly, epoxy resins have been utilized in many industrial fields like aerospace, automobile, and oil applications because these important thermosetting polymers have high adhesion, good chemical resistance, very low shrinkage after curing and low weight. Nevertheless, epoxy resin after curing process can turn into brittle and possess a relatively low flexural and tensile strength. These poor properties of epoxy resin bound many of its possible engineering applications. That's why carbon nanotubes provide a wonderful nano filler material for improving the mechanical properties of epoxy resin in particular to enhance and modify its surface [7-10]. Preparation of CNTs-reinforced epoxy resin or any other type of polymer are required a strong interfacial interaction between CNTs and the matrix, and a homogeneous dispersion in the matrix. Polymer-based nanocomposites with CNTs reinforcement have become popular in structural applications as a result of extraordinary properties of CNTs. The high bond strength between carbon–carbon atoms in (MWCNTs) are the reason behind its exceptional mechanical properties [11].

A number of researchers was studied the effect of wear on epoxy resin reinforced with carbon nanotubes. Dong et al. [12] fabricated MWCNTs/Ep nanocomposites by adding weight ratios (0 to 4%) of MWCNTs. The wear and friction behaviors were studied. The results showed that MWCNTs/Ep nanocomposites have higher wear resistance and smaller friction coefficient than neat epoxy. Adnan et al. [13] studied some the mechanical properties of epoxy-polysulfide blend reinforced with carbon nanotubes. The nanocomposite materials are prepared by adding weight ratios (0.2, 0.4, 0.6) wt% of MWCNTs into blend. The wear and tensile were evaluated. The results showed significant difference in mechanical properties after add MWCNTs. It was observed that Young's modulus increased from 245 MPa to 273 MPa while tensile strength increased from 30.5 MPa to 38.5 MPa when add 0.2%-0.6% of MWCNTs. It was also found that wear rate increase with increasing an applied load. Khalid et al. [14] studied the effect of heat treatment on wear and hardness properties of Ep/MWCNTs nanocomposites. The nanocomposites adding different weight ratios (0-2.5) wt% of MWCNTs into epoxy resin. The wear and hardness properties before and after heat treatment (at 80 ^{o}C) are studied. The experimental results before of heat treatment (natural condition) showed that the least value of wear is at the concentration of MWCNTs (2.5 %), it was also found that hardness increase with increasing concentration of MWCNTs.

The aim of this study is to study the effect of applied load on wear rate before and after immersion in sodium hydroxide solution for (15 days) of Ep/MWCNTs nanocomposites, and studying the effect of weigh percentages of MWCNTs on wear rate of Ep/MWCNTs nanocomposites.

Experimental work

1. Materials: Epoxy resin (Euxit 50 KI) is used as matrix, which has density (1.05g/cm^3). It manufactured by Egyptian Swiss chemical Inc. Epoxy resin converts into solid state adding its hard (Euxit 50 KII) at percentage of (1:3). Multi wall carbon nanotubes (CNTs) used to reinforce epoxy resin. They are manufactured by the Cheep Tube Inc. (USA). The properties of MWCNTs are explained in Table 1 according to Product Company.

Table 1: Shows properties of MWCNTs.

NO.	Properties	Quantity
1	Purity	90%
2	Inner dimension	5-10 nm
3	Outer dimension	10-30 nm
4	Length	10-30 μm
5	Specific surface area	>200 m^2/g
6	Bulk density	0.06 g/cm^3
7	True density	~2 g/cm^3

2. Immersion solution: Sodium hydroxide (NaOH) is used as immersion solution in this research. It supplied by store of the chemical material in university of Anbar. Sodium hydroxide solution is prepared at a concentration (0.3N). All samples are immersed in chemical solution for (15 days) at the laboratory temperature.

3. Preparation of nanocomposites

A hand lay-up molding was used to prepare Ep/MWCNTs nanocomposites as shown in the following steps:

1. The amount of hardener with epoxy resin are weighted according to the weight percentages in the Table 2, taking into account mixing ratio, Then CNTs powder is weighed to achieve the weight ratios (0, 2, 3, 4, 5)% showed in the Table 2.
2. The hardener was added into epoxy resin according to mixing percentage (1:3) and mixed slowly and continually using glass rod to avoid bubbles and then CNTs powder is added gradually into the mixture and stirring to get homogeneity for (10) minutes.
3. The mixture was then poured into the mold has dimensions (100x85x10) mm and left for (72) hr at laboratory temperature for completing the curing.
4. Samples are then separated from the molds and then are placed in oven for (4) hours at (50 ^{o}C).
5. All wear test samples are then cut according to (ASTM-D695) as shown in Fig.2.

Table 2: The weight percentages of epoxy and MWCNTs.

Sample No.	MWCNTs wt%	Sample Composition
1	0	Ep 100%+MWCNTs 0%
2	2	Ep 98%+MWCNTs 2%
3	3	Ep 97%+MWCNTs 3%
4	4	Ep 96%+MWCNTs 4%
5	5	Ep 95%+MWCNTs 5%

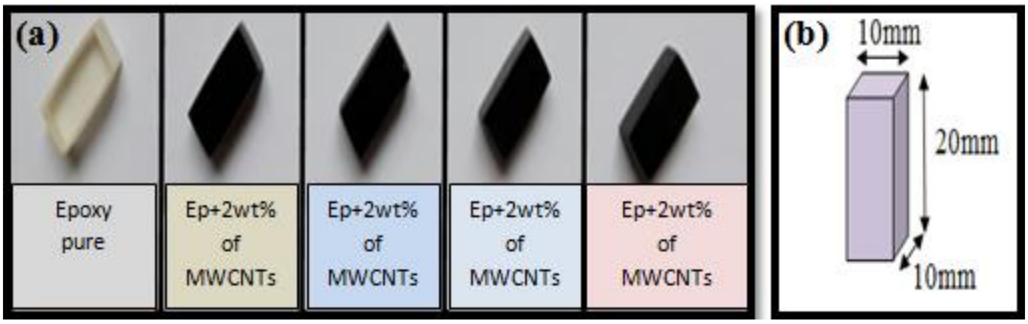

Fig. 2: (a) Photograph of wear rate samples. (b) Standard dimensions of wear rate sample.

4. Instruments
4.1 Wear test instrument
Sliding wear test machine consists of a metallic disc has diameter (30 cm) connected to a rotating electric motor and a flat metallic arm containing holder which hold the sample during test as shown in Fig. 3. The hardness of iron disc is 269HB. We can control the rotational speed of the wear test instrument through a special button.

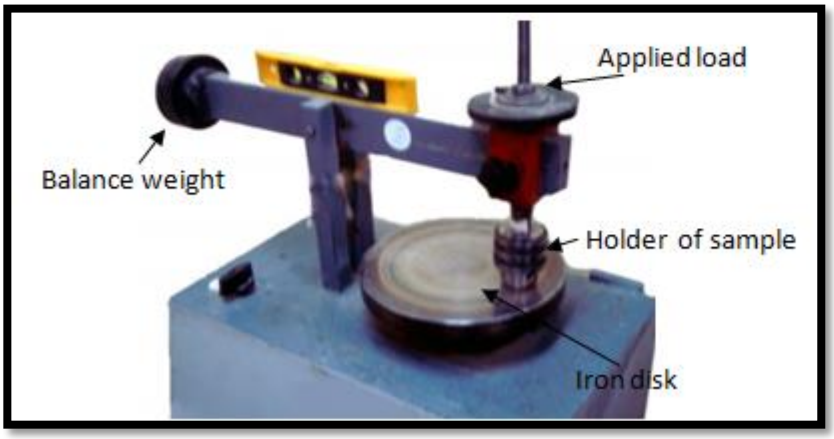

Fig. 3: Sliding wear machine.

The wear rate was calculated according to the following equation [15]:

$$Wear\ rate = \frac{\Delta w}{S_D} \quad (1)$$

where: (ΔW) is the weigh difference given by:

$$\Delta W = W_2 - W_1 \quad (2)$$

W_2: is weight of sample after wear test (gm).
W_1: is weight of sample before wear test (gm)
(S_D): is the sliding distance (cm) given by:

$$S_D = 2\pi rnt \quad (3)$$

r: is distance from the center of the disc to center of the sample (cm).
n: is number of rotations of disc (r/min).
t: is test time (min).

4.2 Optical microscopy
Optical microscopy type used in this study is **(**Eclipse E200 Trinocular) manufactured by Japanese Nikon company. It is supplied by two ocular eyepiece lenses have magnification power (10X) and four objective lenses have magnification power (4X/10X/40X/100X).

Results and discussion
1. Wear rate test
1.1 Wear rate test of Ep/MWCNTs nanocomposites in natural condition

The effect of applied load on the wear rate in normal conditions (N. C.) was studied. The applied loads are (10, 15, 20) N, while disc type (iron disc), test time (10 min), rotational radius (5 cm), sliding speed (2.61 m/sec) are constant along test period for all samples. The wear rate was calculated using the weight method by applying Eqs. (1), (2) and (3). The experimental results for wear rate are showed in Table 3.

Table 3: Variation of the wear rate values with applied load for Ep/MWCNTs nanocomposites at natural condition and after immersion.

Samples	Wear rate*10^{-8} (gm/cm)					
	Applied Load (N)					
	10		15		20	
	N. C.	A. I.	N. C.	A. I.	N. C.	A. I.
Ep (pure)	0.828	1.122	0.982	1.215	1.210	1.407
Ep+2wt% of MWCNTs	0.639	0.746	0.722	0.866	0.905	1.092
Ep+3wt% of MWCNTs	0.530	0.677	0.666	0.721	0.827	0.921
Ep+4wt% of MWCNTs	0.540	0.695	0.672	0.783	0.835	0.958
Ep+5wt% of MWCNTs	0.510	0.578	0.626	0.669	0.779	0.863

From Table 3 and Fig. 4 we noticed that wear rate increases with increasing the applied load for all samples. This due to increasing friction force (F) which is directly proportional to the applied load (N) according to the following relationship:

$$\boldsymbol{F \propto N}$$
$$\boldsymbol{F = \mu N}$$

where μ is friction coefficient.

The relationship above means that by increasing the applied load, the friction force increases and thus the plastic deformation for sample surface increases. As well as, increasing of temperature between the sample surface and the disc surface due to friction has an effect on wear rate; because when the local temperature exceeds the glass transition temperature (Tg) of epoxy, the epoxy resin surface begins to degrade and emerges plastic deformation, so the ability of material to resist shear deformation become weak [16-19], therefore wear rate increases.

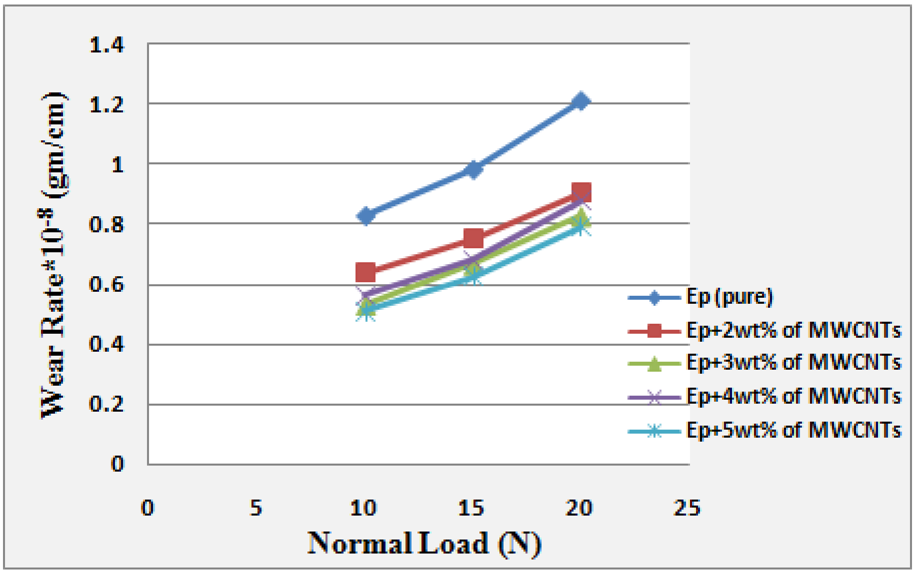

Fig. 4: The effect of applied load on wear rate for Ep/MWCNTs nanocomposites in natural condition.

It is seen from Fig. 5 that wear rate decreases with increasing weight fraction of MWCNTs because of that carbon nanotubes in the nanocomposites act as a rough surface relative to the counter surface against which they slide [14, 20]. During the wear test, MWCNTs dispersed uniformly in Ep/MWCNTs nanocomposites may be released from the nanocomposites and transferred to the interface between the nanocomposites and the steel counter face. So MWCNTs may serve as spacers that prevent the close touch between the steel counter face and the nano composites block, which slows the wear rate and reduces the friction coefficient [12].

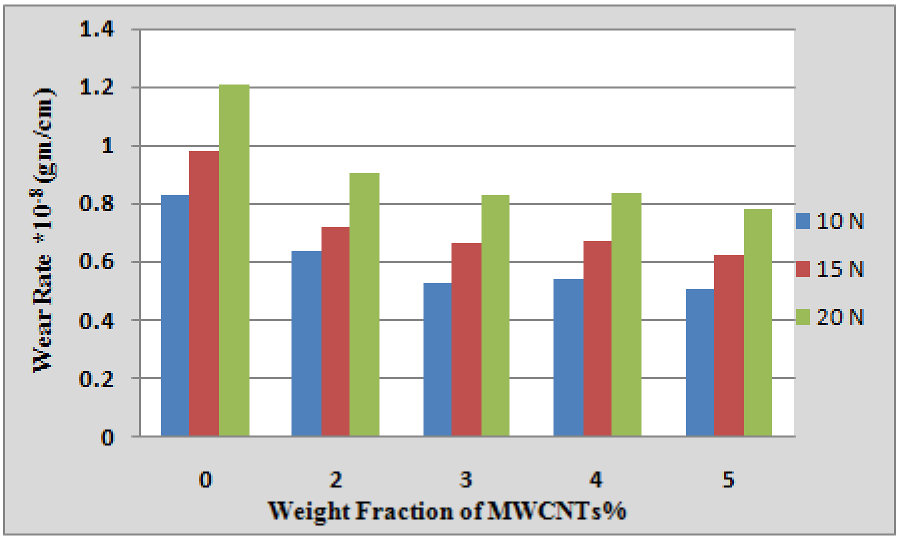

Fig. 5: The relation between the wear rate and weight fraction of MWCNTs in natural condition.

2.1 Wear rate test of Ep/MWCNTs nanocomposites after immersion

The effect of applied loads on the wear rate after immersion (A. I.) was studied. The applied loads are (10, 15, 20) N, while disc type (iron disc), test time (10 min), rotational radius (5 cm), sliding speed (2.61 m/sec) are constant along test period. The wear rate was calculated using the weight method by applying Eqs. (1), (2) and (3). The experimental results for wear rate are shown in Table 3. Also we note that wear rate increases with increasing the applied load for all samples as shown in Fig. 6.

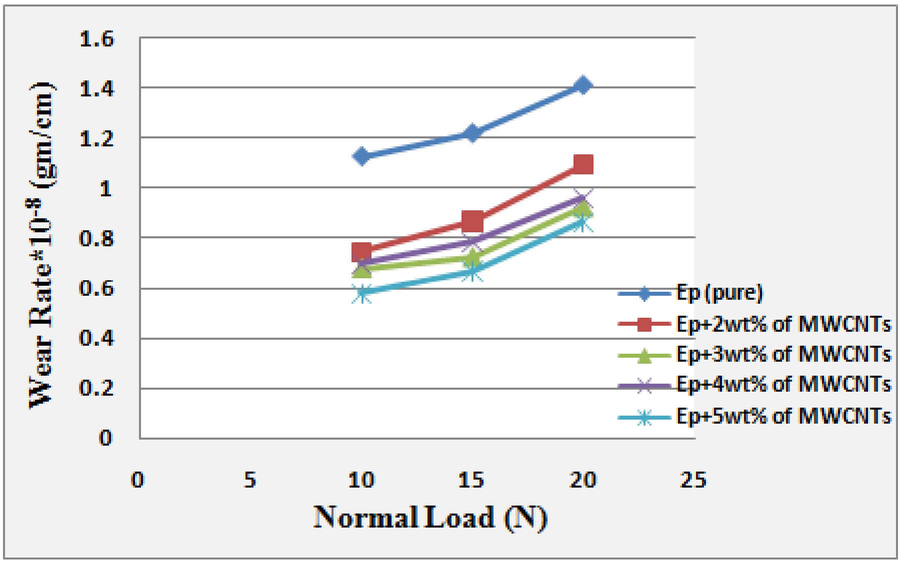

Fig. 6: The effect of applied load on wear rate for Ep/MWCNTs nanocomposites after immersion.

Table 3 shows that the wear rate of samples after immersion (A.I.) is greater than that at natural condition (N.C.). This is due to the fact that chemical solutions when entering the composite material through the capillary pores to interface which bond between CNTs and epoxy resin work breakdown bonds between them thus wear resistance will be reduced. Also penetration of the chemical solutions increases plasticity of material thus plastic deformation increases. Fig. 7 shows comparison between wear rate at natural condition and after immersion for sample (Ep + 3wt% of MWCNTs).

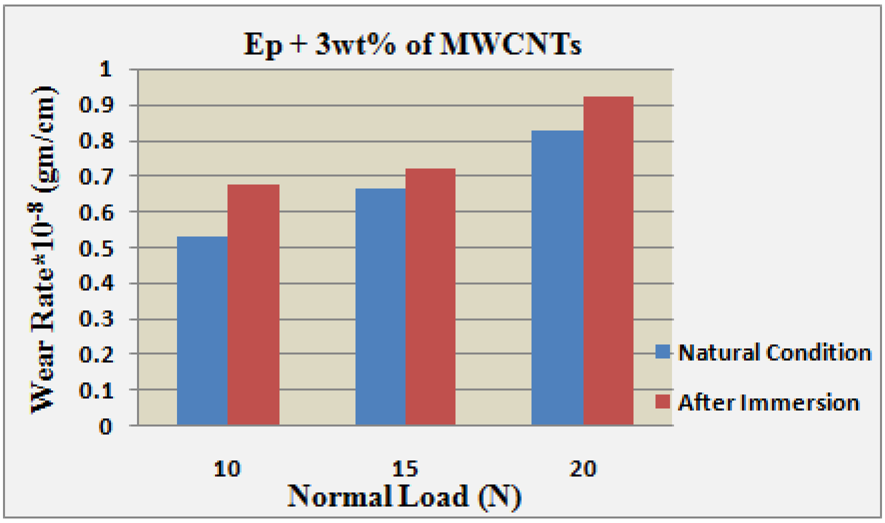

Fig. 7: Comparison between wear rate at natural condition and after immersion.

2. Optical microscopy examination

The sample surface (Ep + 4wt% of MWCNTs) before and after immersion in the base solution and also before and after wear test at the natural condition was studied by using optical microscopy. Fig. 8 shows the difference in topography of the sample surface before and after immersion. It is seen from Fig.8(a) that the sample surface seems coherent and this is indication that the procedure of mixing a homogeneous. We note from Fig.8(b) that the base solution (NaOH) penetrated into the sample, this is evident through the trace of white color compared to the Fig.8(a).

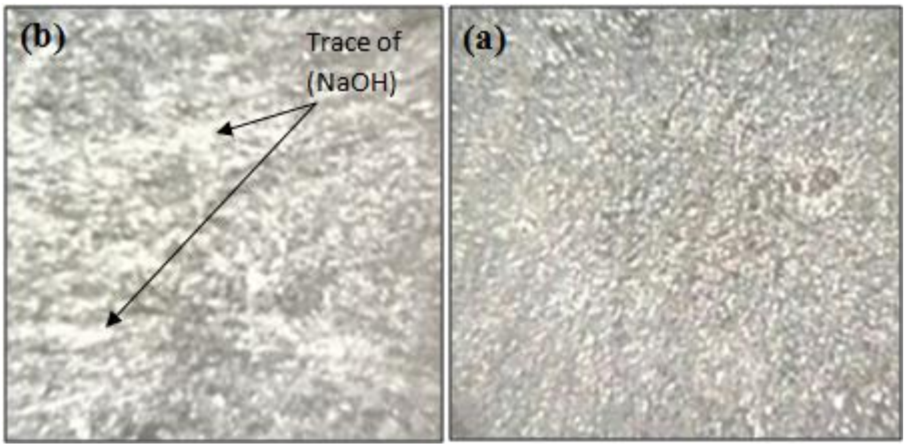

Fig. 8: The images of surface of sample (Ep + 4wt% of MWCNTs). (a) Before immersion. (b) After immersion.

Fig. 9 shows images of the sample surface before and after wear test at applied load (20N) in natural condition. The difference between sample surface before and after wear test is clear. It is seen from the Fig.9(b) how cracks and wear lines formed as result plastic deformation.

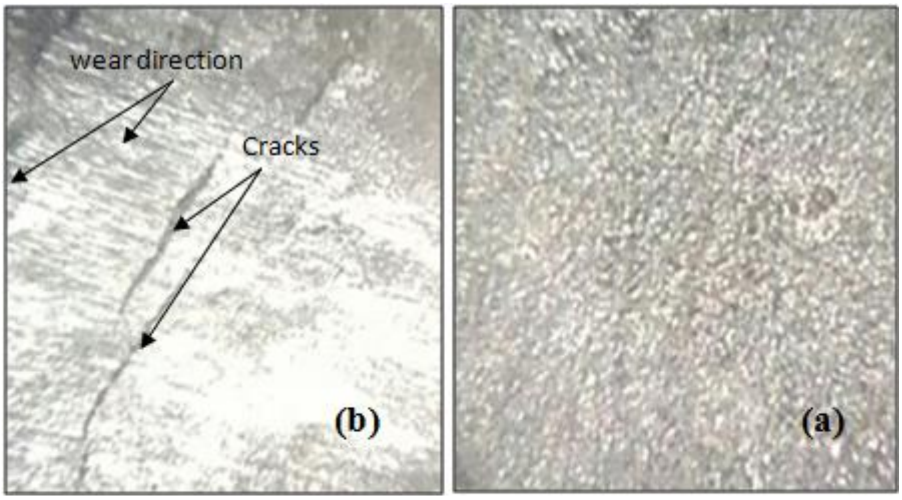

Fig. 9: The images of surface of sample (Ep + 4wt% of MWCNTs). (a) Before wear test. (b) After wear test.

Conclusions

1. Wear rate increases with increasing the applied load for all samples in natural condition and after immersion.

2. The effect of immersion in the base solution increased the wear rate for all samples compared to the natural condition.

3. Wear rate decreases with increasing weight fraction of MWCNTs.

References

[1] A. A. Moosa, A. Ramazani, M. N. Ibrahim, International Journal of Current Engineering and Technology, 6, 5 (2015) 125-134.

[2] G.Manjunatha, S.Rajesh, R.George, K.Naik, American Journal of Materials Science, 5, 3C (2015) 183-187.

[3] B. Mateusz Bryning, "Carbon Nanotube Networks in Epoxy Composites and Aerogels", PhD Thesis, University Of Pennsylvania, (2007).

[4] Mohammed Al-Bahrani, J. Zoltan Gombos, Alistair Cree, International Journal of Mechanical & Mechatronics Engineering IJMME- IJENS, 18, 01 (2018) 234-244.

[5] T. Yu, Y. Gong, T. Lu, L. Wei, Y. Li, Y. Mu, K. Liao, RSC Advances, 2, 4 (2012) 1466-1476.

[6] Y. Li, T. Yu, T. Pui, P. Chen, L. Zheng, K. Liao, Composites Science and Technology, 71, 14 (2011) 1665-1670.

[7] Q. Li, M. Zaiser, V. Koutsos, Physica Status Solidi (a), 201, 13 (2004) 89-91.

[8] W. Zhang, R. C. Picu, N.Koratkar, Nanotechnology, 19, 28 (2008) 1-5.

[9] Z. Li, R. Wang, R. J. Young, L. Deng, F. Yang, L. Hao, W. Jiao, W. Liu, Polymer, 54, 23 (2013) 6437-6446.

[10] J. N. Coleman, U. Khan, Y. K. Gun'ko, Advanced materials, 18, 6 (2006) 689-706.

[11] S. Bal, Bulletin of Materials Science, 33, 1 (2010) 27-31.

[12] B. Dong, Z. Yang, Y. Huang, H. L. Li, Tribology Letters, 20, 3-4 (2005) 251-254.

[13] A. Nemaa, I. A Al-Razaq, E. E. Kader, Diyala Journal of Engineering Sciences, 7, 3 (2014) 106-119.

[14] R. Khalid Al-Rawi, H. Noor Madhi, Iraqi Journal of Science, 57, 4C (2016) 2891-2897.

[15] A. Nadia Ali, I. Sinaa Husaen, H.I. Jaffer, Baghdad Science Journal, 8, 2 (2011) 689-693.

[16] N.A. Ali, S.I. Husaen, H.I. Jaffer, Iraqi Journal of Physics, 10, 18 (2012) 98-104.

[17] M. Z. Abdullah, O. H. Ahmed, S. A. Maki, A. M. Hessian, Ibn AL-Haitham Journal for Pure and Applied Science, 26, 1 (2017) 179-184,

[18] V. K. Srivastava, International Journal of Composite Materials, 6, 4 (2016) 95-99.

[19] L. J. Cui, H. Z. Geng, W. Y. Wang, L. T. Chen, J. Gao, Carbon, 54, 10 (2013) 277-282.

[20] R. Bobbili, V. Madhu, Engineering Science and Technology, an International Journal, 19, 1 (2016) 8-14.