TRIBOLOGICAL PROPERTIES OF SIC FILLED POLYMER BLEND NANOCOMPOSITES

Bahjat B. Kadhim[1], Zainab A. Jabur[2], and Fadhil K. Farhan[2]
[1]Assistant Professor, Dept. of Physics, College of Science,
AL- Mustansiriyah University, Baghdad, Iraq.
[2]Professor, Dept. of Physics, College of Education,
AL - Mustansiriyah University, Baghdad, Iraq.
[3]PhD. Student, Dept. of Physics, College of Education,
AL - Mustansiriyah University, Baghdad, Iraq.

ABSTRACT
Tribological characteristics of epoxy – unsaturated polyester composites reinforce with silicon carbide and ultra fine graphite particles were investigated in terms of friction – wear coefficients subject to changes in different silicon carbide volume fraction. Hand lay - up technique was used to prepare the composites as well as blend specimens using flash molds at standard conditions. Pin on Disc machine in conforming geometry was used to determine friction and wear coefficients of blend and nanocomposites specimens slide against un lubricated steel disc. Optical microscopy coupled with auxiliary micro – hardness, and densities were employed to aid interpretation of results. Experimental results show that ultra fine graphite particles improve the tribological characteristics of epoxy – unsaturated polyester nanocomposites. The coefficient of friction drops progressively and settles at constant values by succession of silicon carbide volume fraction for high normal loads. The wear coefficient was behaved as being lowest for high silicon carbide volume fraction. The friction – wear relationship displays two associated mechanisms, the first was ploughing wear mechanism, which is associated with run – in period, and the second was adhesion wear mechanism, which is associated with steady friction. The wear coefficients of nanocomposites are strongly dependent on graphite particles distribution, hardness, and silicon carbide as well as ultra fine graphite content. It can be concluded that the ultra fine graphite plays dual work, as a solid lubricating media within the contacting surfaces as well as good heat dispersion element.

KEYWORDS: Tribology, wear, Lubricant, silicon carbide, and Nanocomposites.

I.   INTRODUCTION

Nano particles are existed with diameters in the range of 1-100 nm. This new field of nanoscale is lying between the traditional fields of physics. Nano particle is the smaller in size and the higher in the surface-to-volume ratio. The chemical and mechanical properties of particle are influenced by the defects on the surface [1]. The incorporation of fillers into a polymer matrix has shown tremendous promise in increasing longevity and achieving the desired mix of tribological characteristics in dry sliding as well as lubricated. A large number of tribological studies have been reported to exhibit properties different from their micro scale counterparts. Since they have higher percentages of atoms on their surfaces, they are expected to be more active. In view of this, they would be expected to provide different tribological properties [2].

Wear resistance depends on the improvement of polymer composites by the particulate filler material [3, 4]. Nano composite is a class of materials with unique physical properties and wide application potential in diverse areas [5]. Novel properties of nano composites can be obtained by successful imparting of the characteristics of parent constituents to a single material [6]. These materials differ from both pure polymers and inorganic fillers in some physical and nano scale inorganic fillers is

opening pathways for engineering flexible composites that exhibit attractive mechanical, thermal, optical and electrical properties compared with conventional composites [7, 8]. Silicon carbide (SiC) is an important and attractive semiconductive material. Polymers are susceptible to damage by scratching and abrasive wear. Such processes impair the appearance and also reduce the mechanical strength by the introduction of flaws [9]. When nanoparticles are embedded in polymer, the resulted composite material is known as polymer nano composite. Nowadays, polymer composites are widely used in many situations where machine components are subjected to tribological loading conditions [10-14]. For such components, it is imperative to understand the wearing mechanism under specific sliding conditions. Furthermore, the ever-increasing demand for reliability and long life of machine parts (made of polymeric composite materials) are one of the main concerns that during design stage [14, 15]. In view of this, many researchers are interested to study the wear properties at different loadings and found that, different inorganic fillers show distinct effect on the wear behaviors of polymer composites, so the mechanism of filler in reducing wear has been largely focused [16-20]. The objective of this work is to investigate the friction and wear properties of particulate filled SiC composites sliding against a hardened stainless steel counter face. As a comparison, the friction and wear properties of plain SiC were also evaluated under identical test conditions. This work helps in understanding the function of different fillers in SiC composites.

II.   THEORY

Recently the applications of polymers have rapidly increased generally in technology and also as materials for rubbing components in various machines and devices. This is particularly connected with low cost of materials and manufacturing in large amount of components. When the polymeric materials are rubbing in tribological contacts it is very useful and often the lubrication is not necessary. The friction coefficient can be similar to the lubricated metallic or ceramic contacts. This kind of contact is often called as unlubricated [21]. Since tribological phenomena involve the interaction between surfaces, it is important to reveal whether the metal particles are present on the composite surface. The metallic particles can be found on the surface of the composite and are well dispersed, with the exception of SiC (micro and nano sized) which tends to form agglomerates as large as 30 microns in diameter [22]. In general, the wear mechanisms of materials include adhesion, abrasion, fatigue, and impact, electrical and chemical wear. For polymeric materials adhesion, abrasion and fatigue wear are the dominant mechanisms. Although there is only little tendency of adhesion between ceramic materials and polymers, in many cases a film of transferred material can be formed on the ceramic surface (the hardest material) and thus adhesion can be stronger [23]. According to the conditions of the Pin – on disc machine the wear rate are calculated according to the following equation [24]:

$$W_R = \frac{\Delta W}{S_D}...........(1)$$

Where: ΔW, is the wear weight loss of the specimen before and after the wear test (gm), and S_D: is the sliding distance (cm). The wear coefficient can be used the equation:

$$W_{Coefficient} = \frac{V \bullet Hv}{L \bullet S_D}............(2)$$

H_V, Vickers hardness (N / mm^2), V, volume (kg/m^3), and L, load (N).

$$S_D = \pi \omega D t...............(3)$$

Where, t, is the sliding time (min). The sliding velocity is evaluated from the relationship:

$$V_s = \frac{\pi \omega D}{60}...............(4)$$

Where: D, is the circular sliding diameter (cm), and ω, is the number of revolutions of the rotating disc (rev. /min). The friction coefficient equation:

$$\mu = FL...............(5)$$

Where: L (load) applied on the sample (Newton). The frictional heating equation [24]:

$$H_{fr} = \frac{\mu L V_s}{C} \ldots\ldots\ldots(6)$$

Where, H_{fr}, frictional heating in (k) and C, heat capacity (J / k).

III.   EXPERIMENTAL

The nano silicon carbide (Nano- SiC) and ultra fine graphite (UFG) used for reinforced the blend matrix. The physical properties of nano silicon carbide and ultra fine graphite are illustrated in table (1) and (2) respectively [25].

Ultra fine graphite (UFG) powder is high-purity synthetic graphite that can improve the thermal and electrical conductivity of a wide variety of materials including paints, coatings, plastics, rubber and adhesives. Ultra fine graphite (UFG) powder is a product of Denko KK, Tokyo. Epoxy resin/ unsaturated polyester resin (80 vol. % / 20 vol. %) is the blend composition selected for investigation. The epoxy resin and unsaturated polyester resin were added together and thoroughly prepared mixed to obtain the polymer blend required. The mixture is stirred for 40 sec, then casting in Teflon mold and finally left overnight at room temperature for complete curing.

Nanocomposites are prepared by dispersing (Nano –SiC / UFG) kinetically by ultrasonication. To achieve better state of dispersion first the nanoparticales were treated with alcoholic medium (ethanol or acetone) for the deagglomeration of the particle bundles. The treated particles are then added to the blends resin and sonicated for 2 h at room temperature. Then the mixture is cured under vacuum at (363K) for 10 h followed by hardener addition by using simultaneous magnetic stirring (100 rpm), for an hour to homogenization. The prepared samples are treated at (353K) for 6 h in the oven to remove the moisture contents of the samples. The samples are placed between two metal plates under pressure to reduce porosity forming during hardening, before mechanical and thermal measurements, the surfaces of the specimens are mechanically polished to minimize the influence of surface flaws, mainly the porosity. To prepare the nano composite samples, molds are made from Teflon. The mold smeared by wax before the mixture is poured into the mold after homogeneity.

Wear experiments have been conducted in the Pin-on-disc type friction and wear monitor which was used to evaluate the wear behavior of the nanocomposite, against hardened ground stainless steel disc with hardness (55HRC). In this test the flat end of cylindrical specimen 10 mm in diameter and 30 mm length was fixed in chuck jaws to prevent specimens from rotation during the test. Axial load was applied to the pins against the plane surface of the rotating disc. Each specimen was weighed before the experiment and after it by a digital balance having sensitivity of 0.001gm. The duration of the experiment was controlled by stop watch. The average value of the weight loss percentage as a function of test time was calculated.

Wear rate was estimated by measuring the mass loss in the specimen after each test and mass loss, in the specimen was obtained. Wear rate which relates to the mass loss to sliding distance, was calculated using the expressions. The wear rates are calculated according to the equation (1), and the specific wear rate is employed. This is defined as the volume loss of the composite per unit sliding distance and per unit applied normal load. Often the inverse of specific wear rate expressed in terms of the volumetric wear rate. The friction coefficient equation used (2). The frictional heating equation used (6). It is necessary to mention that the surface of all specimens under study were cleaned and grinded to become smoother (without scratches) before the test. Sensitive electronic balance (type-AE160 Metler, 4 digits) was used to measure the weights of samples before and after the wear test [26].

Table (1): The physical properties of nano Silicon carbide [25].

Physical Properties	Value
Density, kg/m^3	3200
Volume resistivity, Ohm - cm	103-105 at 25 ^{o}c
Dielectric constant	40
Coefficient of thermal expansion, k^{-1}	4.5 x10^{-6} at 20- 1000 ^{o}c
Melting point, k	2923-3223
Specific heat, Jk^{-1}kg^{-1}	670-710 at 25 ^{o}c

Thermal conductivity, $Wm^{-1`}k^{-1}$	90-160	at 20 °c
Compressive strength, MPa	1000-1700	
Hardness – Vickers, kgf/mm^2	2500	
Tensile modulus, GPa	200-500	
Morphology	Nearly spherical	
Color	Green	
Average particle size, nm	50	

Table (2): The physical properties of ultra fine graphite [25].

Crystal structure	Hexagonal , Diamond	
Boiling point, k	5273	
Density, kg/m^3	2250	
Melting point, k	3923	
Coefficient of thermal expansion, k^{-1}	0.6 - 4.3 x 10^{-6}	at 0-100 °c
Specific heat, $Jk^{-1}kg^{-1}$	712	at 25 °c
Thermal conductivity, $Wm^{-1`}k^{-1}$	80-240	at 0-100 °c

IV.   RESULTS AND DISCUSSION

Experimental data on the slide wear loss of filled and unfilled nano -SiC composite samples are shown in Figures (1,2,3,4,5 and 6) for different sliding time (5 ,10 and 15 mim) and sliding velocities (3.5, 3.48 and 3.46 m/s). Tables [3, 4 and 5] show the results pertaining to the coefficient of friction of filled and unfilled nano - SiC composite system. It can be observed from the Figures and Tables that there is a strong inter-dependence between the friction coefficients and wear loss irrespective of the loads and sliding velocities employed.

Table [3]: Data of Wear Rate and Friction Coefficient Values.

Data	$H_{frict.}$ *°c*	*M*	$W_{Coeff,}$ *10^{-3}*	W_s 10^{-9} *$m^3/N.m$*	W_R 10^{-5} *gm/cm*	*ΔW Gm*	*No. Sample*
Time=5min	26.15	0.0033	0. 54	0.023	0.277	0.0029	Blend
V_s = *3.5m/s*	26.5	0.0038	0. 46	0.00 96	0.123	0.0013	5% Sic
S_D=*1044.0cm*	26.64	0.0040	0. 543	0. 0097	0.134	0.0014	10%Sic
Load 10 N	26.7	0.0041	0. 024	0.00032	0.0047	0.0005	15%Sic

Table [4]: Data of Wear Rate and Friction Coefficient Values.

Data	$H_{frict.}$ *°c*	*M*	$W_{Coeff,}$ *10^{-3}*	W_s 10^{-9} *$m^3/N.m$*	W_R 10^{-5} *Gm/cm*	*ΔW Gm*	*No. Sample*
Time=10min	2556	0.0016	0. 350	0.0147	0.172	0.0036	Blend
V_s = *3.48m/s*	25.724	0.0019	0. 658	0.0137	0.177	0.0037	5% Sic
S_D=*2088 cm*	25.8119	0.0020	0. 660	0.01179	0.162	0.0034	10%Sic
Load 10 N	25.85	0.0021	0. 623	0.00836	0.124	0.0026	15%Sic

Table [5]: Data of Wear Rate and Friction Coefficient Values.

Data	$H_{frict.}$*°c*	*M*	$W_{Coeff,}$ *10^{-3}*	W_S 10^{-9} *$m^3/N.m$*	W_R 10^{-5} *Gm/cm*	*ΔW Gm*	*No. Sample*
Time=15min	25.35	0.0010	0.302	0.0128	0.15	0.0047	Blend
V_s =*3.46 m/s*	25.45	0.0012	0.369	0.0077	0.099	0.0031	5% Sic
S_D=*3122 cm*	25.55	0.0013	0.296	0.0053	0.073	0.0023	10%Sic
Load 10 N	25.60	0.0014	0.283	0.0038	0.057	0.0018	15%Sic

The SEM photographs of select combinations of filled and unfilled nano - SiC samples subjected to slide wear are shown in Figures (7, 8, 9 and 10) respectively. The wear properties are studied for 5 vol.%, 10 vol. %, and 15 vol.% nano - SiC filled blend composite and reported in Figure above it is observed that, the wear rate of neat blend decreased from (0.277 X 10^{-5}) gm /cm to (0.0047 X 10^{-5})

gm /cm at a load of 10N , time 5 min by reinforcing 15 vol.% of SiC nano particles. After this the wear rate increased to (0.172 X10^{-5}) gm/cm for blend and (0.124 X10^{-5}) gm /cm, respectively by reinforcing 15 vol.% of nano - SiC at load 10 N , time 10s as illustrated in Table [4]. From this, it is observed that the blend composite filled with 15 vol.% SiC nano particles exhibits lowest wear rate in comparison with the wear rate of pure blend. After increasing the percentage of SiC nano particles, again wear rate of blend composite is increased. The same trend is observed for 5 min, 10 min and 15 min time as shown in Figures above. This indicates that the filler content played a key role in the wear property of blend - based composites. From the SEM examinations (Figures 8,9,10 and 11) of SiC filled blend nano composites, it is clearly observed that the 5 vol.% and 10 vol.% SiC nano particles are mixed thoroughly in polymer matrix without any aggregation of SiC nano particles (Figure 9 and 10). The surface is also smooth for 5 vol.% and 10 vol.% SiC nano blend composites. From the SEM images (Figure 11), it is observed that, there is an aggregation of SiC nano particles in the polymer matrix by reinforcing 15 vol.% based on this examination, we infer that SiC at low percentages distributed uniformly on the subsurface of the blend composite, which reduces the destruction of blend during wear process. Also it can be observed, the higher percentages of reinforcing nano particles in the polymer matrix leads to aggregation.
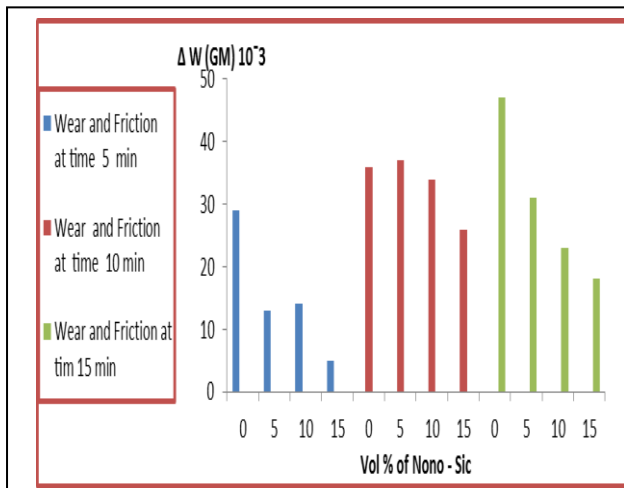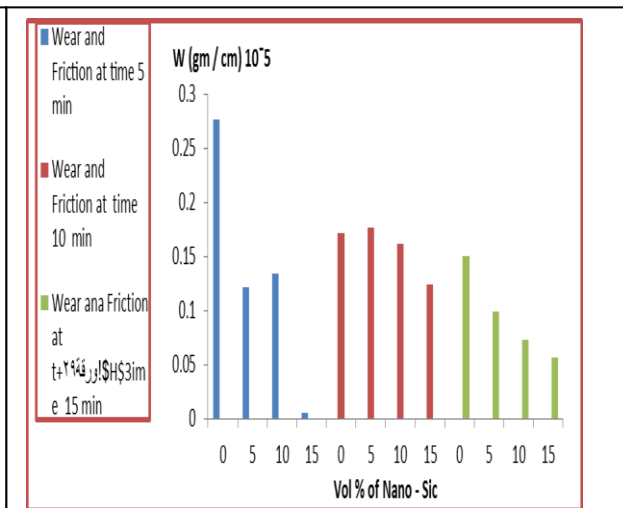

Fig.1: Wight loss Values at varying time (min).
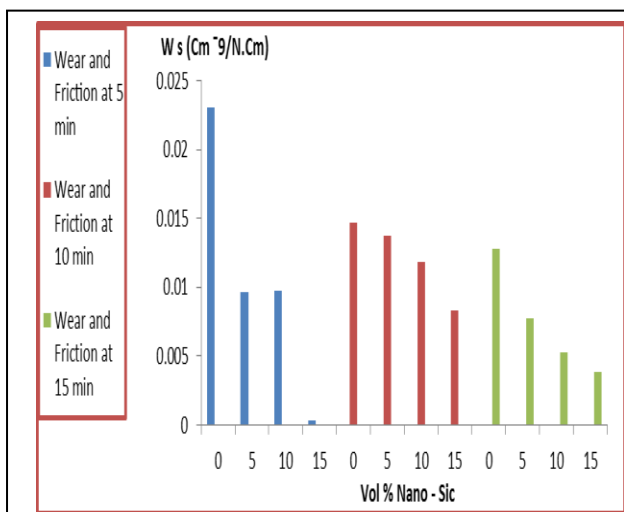

Fig .2: Wear Rate Values at varying time (min).
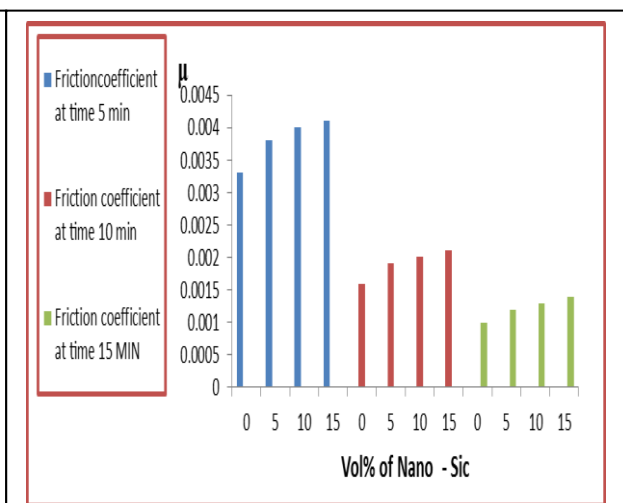

Fig.3: Specific wear rate Values at varying time.

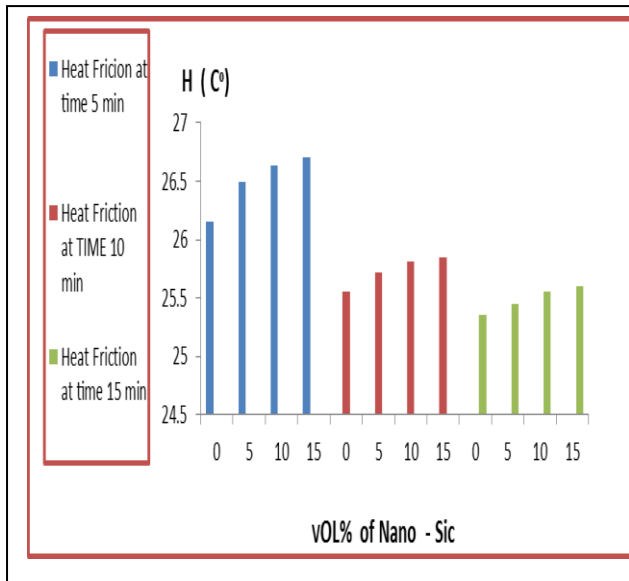Fig. 4: Friction coefficient Values at varying time.
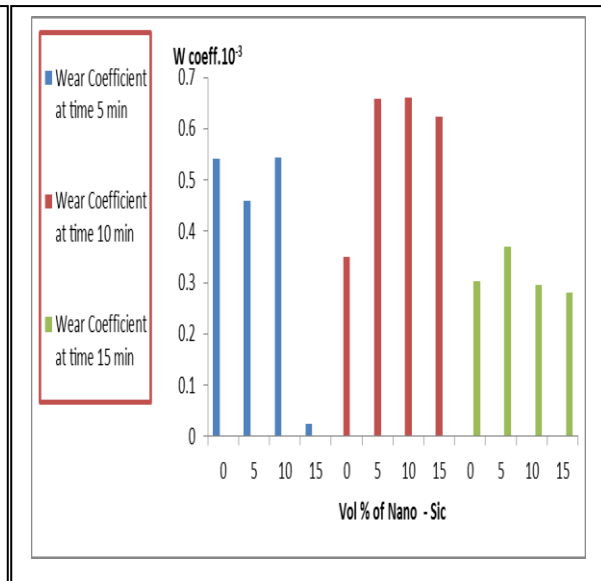
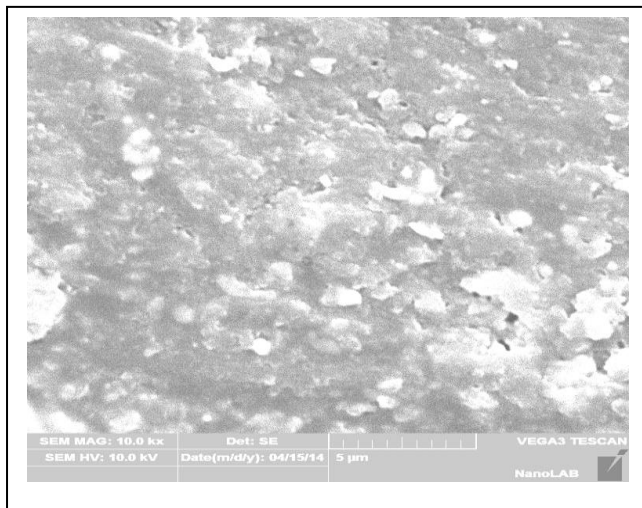**Fig .5:** Heat Friction Values at varying time.   **Fig .6.** Wear Coefficient Values at varying time.

Fig. 7: SEM image of pure blend.   **Fig. 8:** SEM image - 5% SiC.
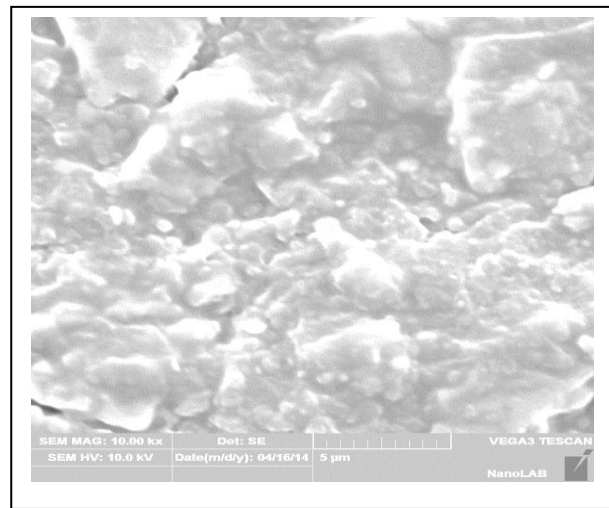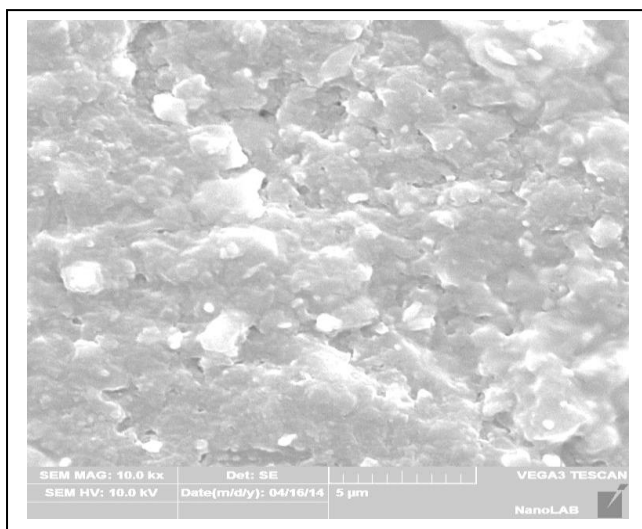

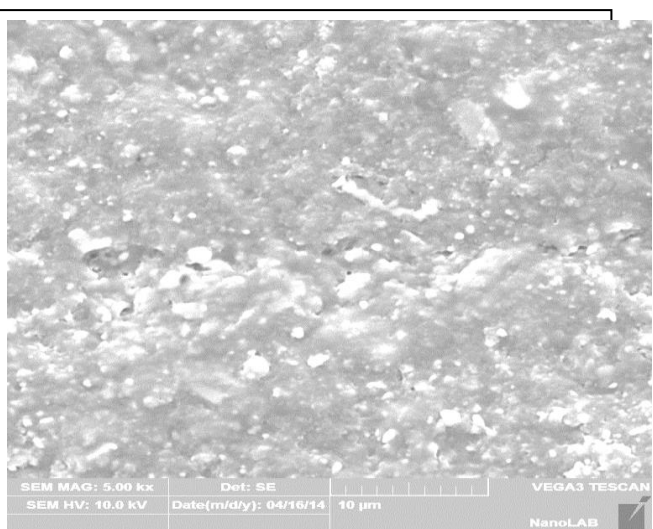**Fig.9:** SEM image - 10% SiC.   **Fig. 10:** SEM image - 15% SiC.

V. CONCLUSIONS

It can be noticed that the (blend) resin has higher wear rates compared with the Nano – SiC composite. The wear rates increases for both materials with increase of the applied load, at higher applied load, the wear rates of the all materials under study increase when the sliding velocity and time test is increased. It is clear that the order of magnitude of experimental wear rates is about in the range (10-9) gm/cm. The wear and friction coefficient it is clear decreased with increase the time and percentage of nano – SiC.

ACKNOWLEDGEMENTS

REFERENCES

[1] K.J. Klabunde, *et al.* 1996. Nanocrystals as Stoichiometric Reagents with Unique Surface Chemistry. J. Phys. Chem. 100: 12142-12153.

[2] M.R. Scanlon, R.C. Cammrata. 1994. Mechanical Properties of nano composite granular metal thin films. J. Appl. Phys. 76(6): 3387-3393.

[3] Z.P. Lu, K. Friedrich. 1995. On sliding friction and wear of PEEK and its composites. Wear. 181-183(2): 624-631.

[4] J. Vande Voort, S. Bahadur. 1995. The growth and bonding of transfer film and the role of CuS and PTFE in the tribological behavior of PEEK. Wear. 181-183(1): 212-221.

[5] Balazs AC, Emrick T, Russel TP. 2006. Nanoparticle polymer composites: where two small worlds meet. Science. 314: 1107-1110.

[6] Tang EJ, Cheng GX, Ma XL. 2006. Preparation of nano-ZnO/PMMA composite particles via grafting of the co polymer onto the surface of Zinc oxide nano particles powder technol. 161: 209-214.

[7] Lin Y, Boker A He JB, Sill K, Xiang HQ, Abetz C, *et al*. 2005. Self-directed self-assembly of nano particle / copolymer mixtures. Nature. 434: 55-59.

[8] Zhnag MQ, Yu G, Zeng HM, Zhang HB, Hou YH. 1998. Two step percolation in polymer blends filled with carbon black. Macromolecules. 31: 6724-6726.

[9] M.J. Adams *et al*. 2001. An experimental study of the nano scratches behavior of poly (Methyl methacrylate). Wear. 251: 1579-1583.

[10] Chand N, Naik A Neogi S. 2002. Three - body abrasive wearof short glass fibre polyster composite. Wear. 242(1-2): 38-46.

[11] Edwards KL. 1998. An overview of the technology of the fibre-reinforced plastics for design purposes. Mater design. 19(1-2): 1-10.

[12] Tripathy BS, Furey MJ. 1993. Tribological behavior of unidirectional graphite-epoxy and carbon-PEEK composites. Wear. 162-164: 385-396.

[13] Kishore, Sampathkumaran P, Seetharamu S, Vynatheya S, Murali A, Kumar RK. 2000. SEM observations of the effect and velocity and load on the sliding wear characteristics of glass fabric-epoxy composites with different fillers. Wear. 237(1): 20-27.

[14] Hasim P, Nihat T. 2002. Effect of load and speed on the behavior of woven glass fabrics and aramid fibre-reinforced composites. Wear. 252(11-12): 979-984.

[15] Srivastava VK, Pathak JP. 1996. Friction and wear properties of bushing bearing of graphite filled short glass fibre composite in dry sliding. Wear. 145-150.

[16] Z.-Z. Zhang, Q.-J. Xue, W.-M. Liu, W.C. Shen. 1997. Wear. 210: 151.

[17] L. Yu, W. Liu, Q. Xue. 1998. J. Appl. Polym Sci. 68: 1643.

[18] L. YU, S. Bahadur, A. Kapoor. 1998. Waer. 214: 54.

[19] Dr. Awham M. H.*, Sadeer [Study of The Wear Rate of Some Polymer Materials In Different Conditions], Applied Science Department, University of Technology/ Baghdad (2010).

[20] B. Aldousiri,1 A. Shalwan [A Review on Tribological Behaviour of Polymeric Composites and Future Reinforcements], Received 28 May 2013; Accepted June (2013).

[21] Samyn P.: Tribophysical interpretation of scaling effects in friction and wear for polymers, Ph.D. Dissertation, Ghent University,(2006).

[22] W.Brosto w, A.Buchman, E.Buchman, and O.Olea-Mejia, *Polymer Eng. Sci.*48, 1977 (2008).

[23] M.H.Cho,S.Bahadur , and J.W .Andere gg, *Tribol. Internat.* 39, 1436 (2006).

[24] M. Salih, M. M. Salih, "American J. of Appl. Sci.,Vol.6, No.5, PP. (1028-1030),(2009).

[25] Handbook Goodfellow GmbH Postfach 13 43 D-61213 Bad Nauheim Germany April 2012.
[26] ASTM standards Annual hand book of, Section 3,03,02, ASTM G-99 Phildelphia, USA. (1995).

Authors Biographies

Bahjat B. Kadhim received his Bachelor Degree in Physics from AL- Mustansiriyah University, Baghdad, Iraq in 1989 and his Master Degree in Material Science from Dept. of Physics, College of Science, University of Baghdad in 2000. His Ph.D from Dept. of Physics, College of Science, University of Baghdad in 2006. His research interests are Polymer nanocomposites, Simulation and Computations. Presently he is working as an Assistant Professor, Dept. of Physics, College of Science, AL- Mustansiriyah University, Baghdad, Iraq.

Zainab A. Jabur received her Bachelor Degree in Physics from Basrah University, Baghdad, Iraq in 1986 and her Master Degree in Materials Science from AL- Mustansiriyah University in 1997. Her Ph.D from Dept. of Physics, College of Science, AL- Mustansiriyah University in 2003. His research interests are Materials Science and Polymer namocomposites. Presently she is working as a Professor, Dept. of Physics, College of Education, AL- Mustansiriyah University, Baghdad, Iraq.

Fadhil K. Farhan received his Bachelor Degree in Physics from AL- Mustansiriyah University, Baghdad, Iraq in 1989 and his Master Degree in Materials Science from AL- Mustansiriyah University in 2012. His Ph.D from AL- Mustansiriyah University, Baghdad, Iraq in 2015. His research interests are Materials Science and Polymer namocomposites. Presently he is working as a doctor, Dept. of Physics, Ministry of Science and Technology, Baghdad, Iraq.