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Study Effect of Residence Time on the Wear Rate for Polymer UBE / PMMA and Reinforced by the Nanometer ZnO

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Abstract : ***In this study, Tribologicalproperties (Wear, Friction, Dry lubricant), have been studied for (UPE/PMMA) bland polymer, reinforced with nano [ZnO](0vol %,1vol%2vol%, 3vol%, 4vol% and 5vol%). Ultrasonic dispersion technique used to prepare the nanocomposites specimens follow with cold – casting technique using flash Teflon molds standard conditions. [Pin-on-disc] technique is used to measure wear rate,coefficient of friction and heat of friction. Tribological properties (Dry sliding wear rate) results show that values decreases progressively by succession of increase load and volume fraction of fillers. Scanning electron microscopy used were employed to aid interpretation results of sliding wear, and distribution nanoparticle in base – matrix.***

Keyword: Tribological, dispersion, UPE/PMMA, nanocomposites

1. Introduction

Nano particles are entities with diameters in the range of 1-100 nm. This new field of nanoparticles is lying between the traditional fields of nanoparticles is lying physics. Therefore, a significant gap exists between these regimes with unique characteristics that neither obeys the law of physics nor quantum chemistry. The smaller is the particle, the higher is the surface-to-volume ratio. Thus more atoms t are once determined by the molecular structures are now end to reside on the surface than inside the particle itself. Particle chemical/mechanical properties that 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 properties in dry sliding. It is also attractive from processing consideration because the same processing methods as applicable to unfilled polymers can be used for filled polymers as well. A large number of tribological studies have been reported [2] 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, hopefully beneficial. The wear resistance of polymer composites filled with micro particles depends on the modification of transfer film by the particulate filler material [3, 4]. Because of their high reactivity, nanoparticles should influence the transfer film more proactively than the micro particles. nanocomposite is a class of materials with unique physical properties and wide application potential in diverse areas [5]. Dispersion of nano scaled inorganic fillers into an organic polymer to form polymer nanocomposites has gained increasing interest in recent years. Controlling the nanostructure, composition and morphology of nano composites plays an essential role in their applications. Novel properties of nanocomposites 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]. [TiO_2 ,ZnO] is an important and attractive semi conductive material. It has drawn enormous attention due to its fantastic characteristics in thermal and electronics .Polymers are widely used in aeronautics, automobiles, constructions, oil and gas industries, and so on. However, they 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]. Polymers scratch and abrasive properties are of practical importance and the use of reinforced polymer composites is becoming more common. 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 [16-18]. The objective of this work is to investigate the friction and wear properties of particulate filled [TiO_2 ,ZnO] composites.

2. The aim of the Study

1) Fabrication of[ZnO]reinforced resin UPE/PMMAbased nanocompositewith/without filler content.
2) Dry sliding wear of composite samples under various operating conditions.
3) Study effect of filler content on sliding wear analysis.

4) Besides the above all the objective is to develop new class of nanocomposites by incorporating [ZnO] reinforcing phases into a polymeric resin. Also this work is expected to introduce a new class of polymer composite that might find tribological applications.

3. Theory

Recently the application of polymers has 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 oilless[21. Since tribological phenomena involve the interaction between surfaces, it is important to reveal whether the metal particles are present on the composite surface. In our previous work we have shown that metallic particles can be found on the surface of the composite and are well dispersed, with the exception of SIC (micro and nanosized) 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]. Figure (1) show the apparatus used in this study. According to the conditions of the Pin – on – disc- machine the wear rate are calculated according to the following equation[24].

$$W_R = \frac{\Delta W}{SD} \quad \text{.....................(1)}$$

Where:

***ΔW*:** is the Wear weight loss of the specimen before and after the wear test (gm).

$\Delta W = W_1 - W_2$,

W_1: mass before Wear test (gm).

W_2: mass after Wear test (gm).

***SD*:** is the sliding distance (cm).

$SD = \pi . \theta . D . t$

D: is the circular sliding diameter(cm).

***ϴ*:** is the no. of revolutions of the rotating disc (rev. /min).

***t*:** sliding distance time (second).

And the Wear coefficient can be used the Archard's equation:

Archard's Wear equation relates the Wear volume W_v, to the normal load *L*, the sliding distance *SD,* and the inverse of hardness H_{VS}, through a proportionality constant $W_{coeff.}$, often referred to as the Wear coefficient.

$$W_v = \frac{WR_r}{\rho} \quad \text{..........................(2)}$$

$$W_{Coeff} = \frac{WR.HV}{SD.L} \quad \text{........................(3)}$$

W_V : is the wear volume loss of the specimen before and after the wear
test (mm^3).

ρ= density of sample (gm / cm^3)

$L_{(load)}$: normal load applied on the sample (Newton) .

The sliding velocity(m / s) is evaluated from the relationship:

$$Vs = \frac{(\pi D \theta)}{60} \quad \text{..... ....(4)}$$

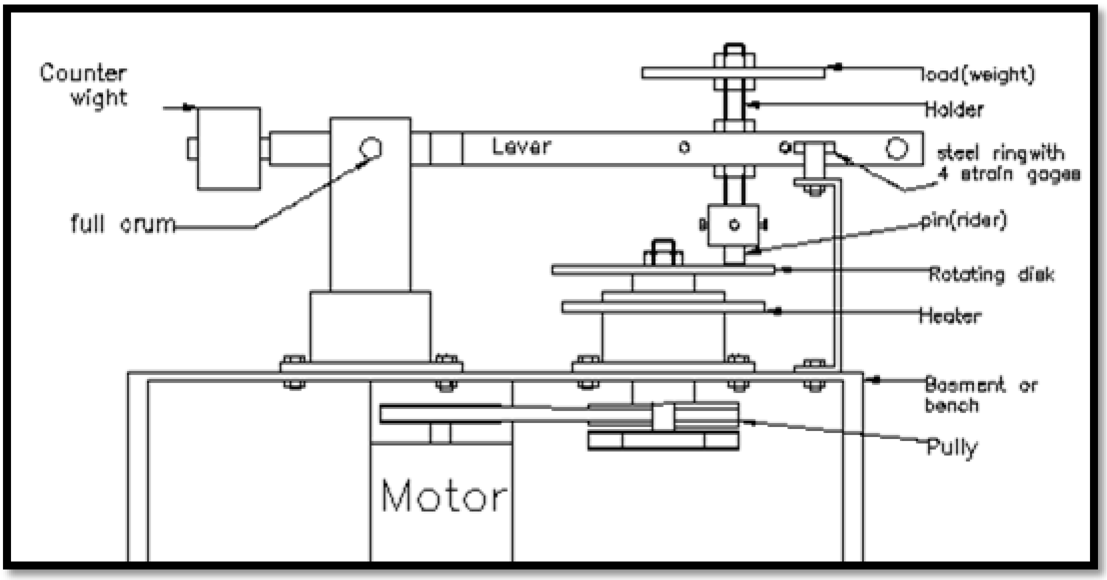

Figure 1: Pin – on- disc - machine [24]

4. Experimental

Nanocomposite preparation and standards

Nanocomposites are prepared by dispersing Nano[ZnO]kinetically by ultrasonication . To achieve better state of dispersion first the nanoparticales were treated with alcoholicmedium (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. To calculation the weight of blends resin and [Nano ZnO] used Sensitive electronic balance .

5. Testing Equipment and Techniques

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 composite, against hardened ground steel disc . The wear test was performed on Pin-on-disc apparatus. 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 stopwatch. The average value of the weight loss percentage as a function of test time was calculated. From weight loss of the specimens. [Pin - on – disc] test apparatus which produced by local company named (Al furat company) was used to measure the wear rates of the previous prepared samples, the used disc in this work is made from steel material with hardness(55HRC). The wear tests were performed in air at room temperature ~(25.C) with different variables included:- [26]

1) The applied loads: (5) Newton.
2) The distance from the centre of sample to the centre of disc (7cm).
3) The testing time (t): (5,10 ,15 and 20) min.
4) The distance sliding D= 7 cm

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 equation (1), and the specific wear rate is employed. This is defined as the volume loss of the nanocomposite 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 calculated using equation (2) . The wear rate coefficient using equation (4),

It is necessary to mention the following:

- 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 [27].

6. Results and discuses

Experimental data on the slide wear loss of filled and unfilled Nano[,ZnO]composite samples are shown in Figs(2,3,4and5) for different sliding time (5 ,10 ,15and 20N) and sliding velocity(3.48 m/s). Tables [1,2,3and 4] shows the results pertaining to the coefficient of wear rate of filled and unfilled Nano[ZnO]nanocomposite system. It is observed from the Figures and Table that there is a strong inter-dependence between the friction coefficient and wear loss irrespective of the loads and sliding velocities employed. The SEM photographs of select combinations of filled and unfilled Nano[ZnO]samples subjected to slide wear are shown in Figs. (6,7,8 and 9) respectively.The tribologicalproperties are studied for 0% ,1v%, 2v%,3%,4% and 5v% Nano [ZnO]filled nanocomposite it is different observedthat, because of variation in the amount of the additive and this is due to agglomeration winning in the polymer matrix. After this the wear rate increased for reinforcing of Nano ZnO atdifferent load and time 10 min see Tables and Figures (2,3,4and5) . From this, it is observed that the nanocomposite filled with 1vol% ZnOnanoparticles exhibits lowest wear rate in comparison with the wear rate of pure blend. It is also observed that, the wear rate difference is very low. There after increasing the percentage of,ZnOnanoparticles, wear rate of nanocomposite is increased. The same trend is observed for 5,10,15 and 20 load as shown in Figures(2,3,4and5). This indicates that the filler content played a key role in the wear property of blend - based nanocomposites and this a good agreement with reference [28].From the SEM examinations Figures(6 ,7,8 and 9) ofZnO filled nanocomposites, it is clearly observed that the 1 v% and 2 v% Sic nanoparticles are mixed thoroughly in polymer matrix without any aggregation of ZnOnanoparticles (Figure 7&8)). The surface is also smooth for 1v% and 2 v%NanoZnOnanocomposites. From the SEM images (Figure 9), it is observed that, there is an aggregation of ZnOnanoparticles in the polymer matrix by reinforcing 5wt%based on this examination, we infer that,ZnO at low percentages distributed uniformly on the subsurfaceof the blend nanocomposite, which reduces the destructionof blend during wear process. Also observed, the higher percentages of reinforcing nanoparticles in the polymer matrix leads to aggregation and this a good agreement with reference [28].

Table 1: [T =5, Load = 5N, S_D = **104405**cm]

Sample Code	ΔW gm	W_R 10^{-8} gm/cm	W_v 10^{-8} Cm^3/cm	$W_{coeff.}$ $\times 10^{-6}$	Density Kg/ m^3	Hardness MPa
Neat	0.004	3.831	3.28	0.5	1167	8.2
1% ZnO	0.0018	1.724	1.41	0.3	1220	11.3
2% ZnO	0.0032	3.06	2.45	0.6	1250	13.5
3% ZnO	0.0041	3.93	3.09	0.9	1270	15.6
4% ZnO	0.002	1.92	1.46	0.55	1310	19.8
5% ZnO	0.0049	4.69	3.55	0.18	1320	27

Table 2: [T10, Load = 5N, S_D =208810cm].

Sample Code	ΔW gm	W_R 10^{-8}gm/cm	W_v 10^{-8} cm^3/cm	$W_{coeff.}$ $\times 10^{-6}$	Density Kg/ m^3	Hardness MPa
Neat	0.0044	2.11	1.8080	0.7	1167	8.2
1% ZnO	0.0053	2.538	2.0803	1.1	1220	11.3
2% ZnO	0.0052	2.49	1.992	1.2	1250	13.5
3% ZnO	0.0049	2.346	1.847	1.3	1270	15.6
4% ZnO	0.0069	3.30	2.5190	2.4	1310	19.8
5% ZnO	0.0039	1.867	1.414	1.8	1320	27

Table 3: [T =15 Load = 5N, S_D = 313215cm].

Sample Code	ΔW gm	W_R 10^{-8} gm/cm	W_v $10^{-8}cm^3$/cm	$W_{coeff.}$ $\times 10^{-6}$	Density Kg/ m^3	Hardness MPa
Neat	0.0022	0.7	0.6	0.03	1167	8.2
1% ZnO	0.0069	2.2	1.8	0.012	1220	11.3
2% ZnO	0.0109	3.48	2.7	0.023	1250	13.5
3% ZnO	0.0482	1.53	1.20	0.011	1270	15.6
4% ZnO	0.0081	2.59	1.97	0.024	1310	19.8
5% ZnO	0.0152	4.85	3.67	0.632	1320	27

Table 4: [T =20 Load = 5N, S_D = 417620cm].

Sample Code	*ΔW gm*	W_R $10^{-8}gm/cm$	W_v $10^{-8}mm^3/cm$	$W_{coeff.}$ $\times 10^{-6}$	*Density* Kg/m^3	*Hardness MPa*
Neat	0.0634	0.154	0.131	0.00514	1167	8.2
1% ZnO	0.059	0.1141	0.0935	0.0051	1220	11.3
2% ZnO	0.0132	0.032	0.0256	0.0016	1250	13.5
3% ZnO	0.0181	0.043	0.0338	0.0025	1270	15.6
4% ZnO	0.0212	0.0507	0.0387	0.0036	1310	19.8
5% ZnO	0.0138	0.033	0.025	0.0032	1320	27

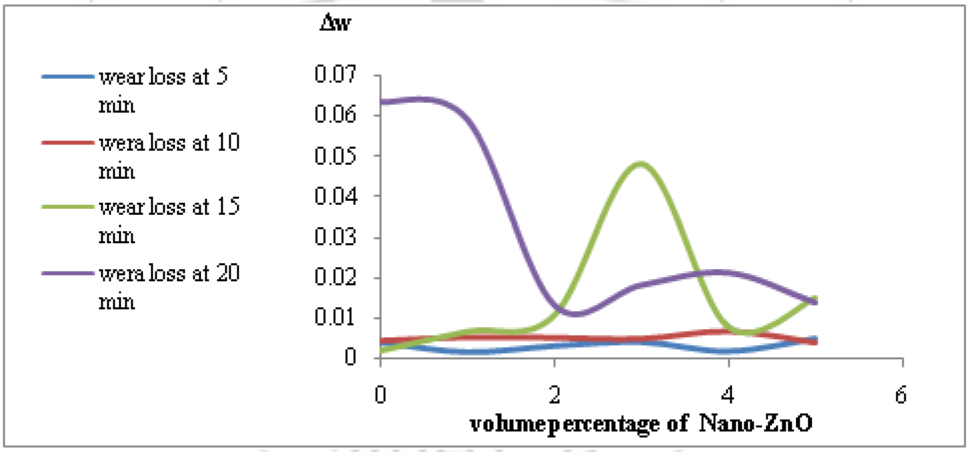

Figure 2: Wear Loss Values

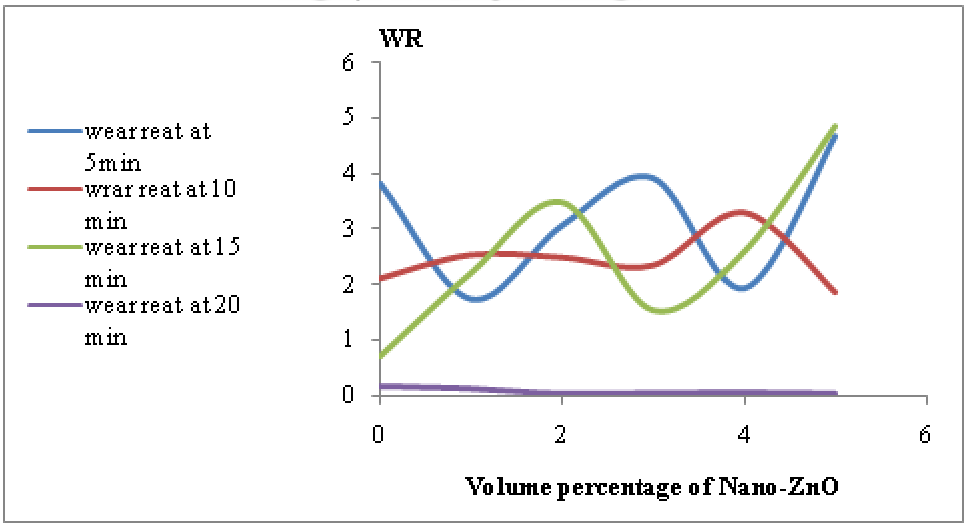

Figure 3: Wear Rate Values

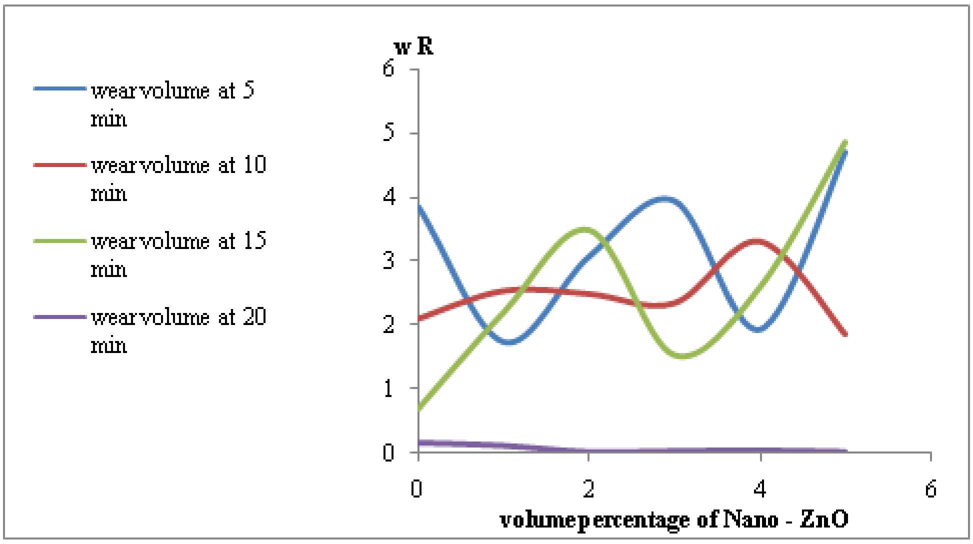

Figure 4: Wear Volume Values

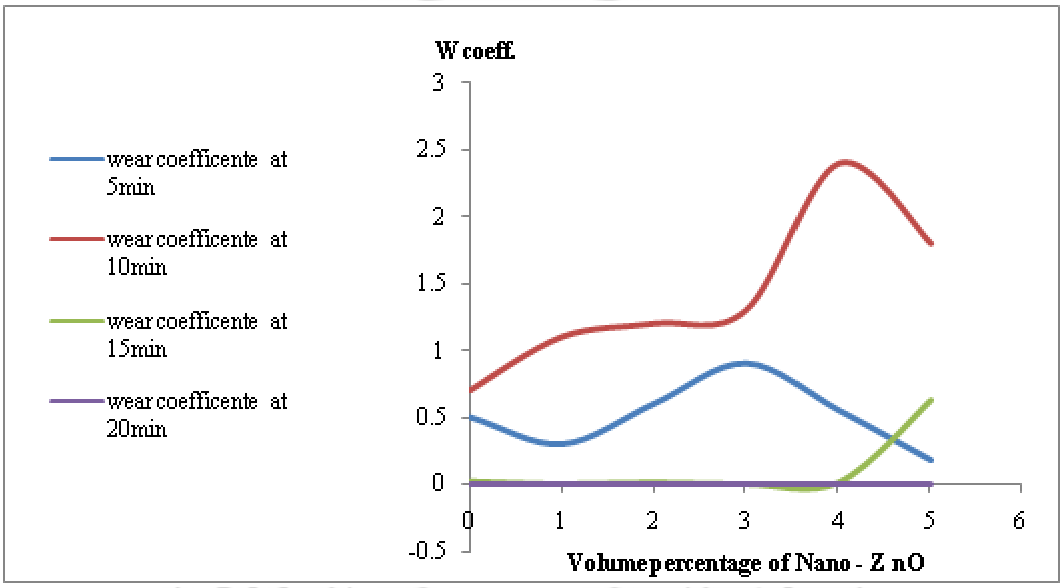

Figure 5: Wear coefficient value

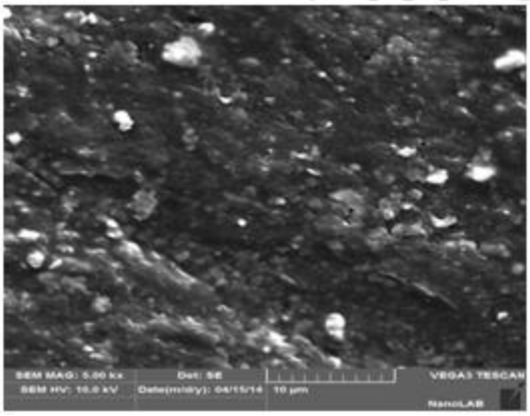

Figure 6: SEM of neat

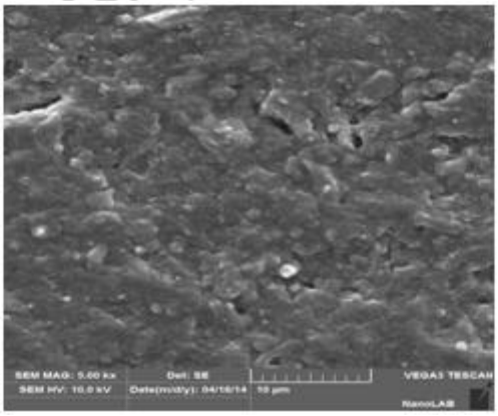

Figure 7: SEM of 1% Nano- ZnO

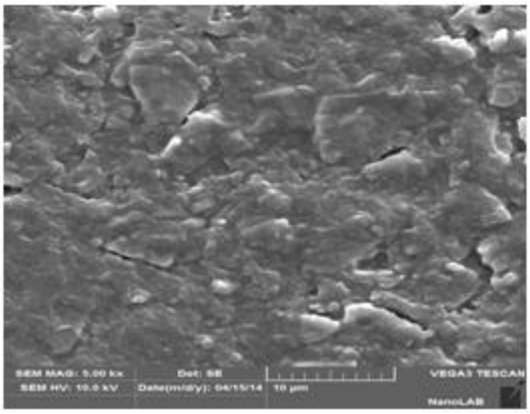

Figure 8: SEM of 3% Nano- ZnO

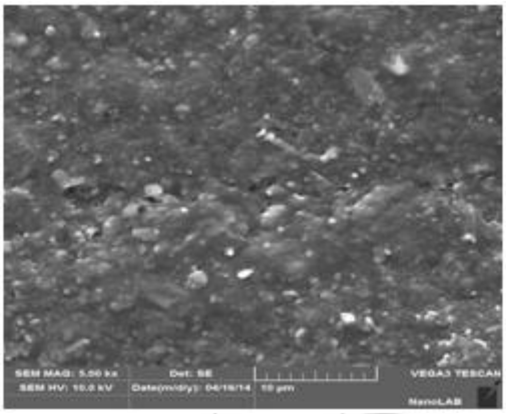

Figure 9: SEM of 5% Nano- ZnO

7. Conclusions

The following points can be concluded from the present study:

1) It can be noticed that the (blend) resin has higher wear rates compared with the [ZnO] nanocomposite .
2) The wear rates increases for both materials with increase of the applied load, at higher applied load, the wear rates of all materials under study increase when the sliding velocity and time test is increased .
3) It is clear that the order of magnitude of experimental wear rates is about in the range(10^{-5}) gm/cm.
4) The wear and friction coefficient decreased with increase the time and percentage ZnO].

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