

## Friction coefficient and biophysical properties for UPE-PMMA blend reinforced by nano-zinc oxide

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### Abstract

In this study, nanocomposite samples were prepared from (80 vol. % unsaturated polyester (UPE) with 20 vol. % Poly methyl methacrylate (PMMA)] blend matrix and reinforced by ZnO nanoparticles with average particle size of 72nm and with different percentage (0.0.2, 0.4, 0.6, 0.8 and 1vol. %) by using Ultrasonic dispersion technique to obtain a homogeneous mixture free of aggregates. The structure and particles size of nanoparticles were investigated by atomic force microscope (AFM) and energy dispersive x-ray Spectroscopy (EDX). Wear rate, coefficient of friction and heat of friction have been measured by (Pin-on-disc) technique. The surface morphology of nanocomposite samples was studied by scanning electron microscopic (SEM) to aid interpretation results of sliding wear, and distribution nanoparticle in polymer (base-matrix). Experimental results of Tribological and biophysical properties (Dry sliding wear rate) show that values decreases progressively with increasing load and percentage of fillers.

**Keywords:** wear, friction, nano-ZnO, nanocomposite

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### INTRODUCTION

Polymer may be defined as large molecule comprised of repeating structural units joined by covalent bonds. Since covalent bonds also connect the structural units together, polymers are distinguished from those solids and liquid wherein repeating units are held together by bonds, hydrogen bonds, dipole interactions or dispersion forces. Nanocomposite can be defined as combination of two or more materials (reinforcing elements, fillers) differing in form, or composition on a micro or Nano – scale (Gupta and Santosh 2004). Many composites materials are composed of just two phases; one is termed the matrix, which is continuant and surrounds the other phase, often called the dispersed phase. Dispersed phase geometry, means the shape of the particles and particle size distribution, and orientation. Nanocomposite materials are wide various applications; dispersion of Nano-percates fillers into polymer increasing interest in recent years. Nanocomposite can be obtained by successful imparting of the characteristics of origin constituents to a single material. Wear is the progressive loss of material from the operating surface of a body, caused by relative motion at the surface (Callister 2000). Wear may be broadly classified as mild or severe. In mild wear, the process occurs at the outer surface layers. The surfaces remain smooth and are usually covered by surface oxides generated during rubbing. Mild wear results in

small track debris, down to some nanometers. In severe wear, the contact is metallic, the surfaces are seriously deformed and the worn debris consists of particles up to some hundred micrometers. Therefore, this simplest classification is primarily a distinction based in the scale of size (Tang et al. 2006). The more traditional classification of wear is based on the relative type of motion or in the type of wear mechanism. Under the former classification, wear can be classified as wear by sliding, rolling, impact, oscillation and flow. Wear mechanisms, the more usual are: adhesion, abrasion, surface fatigue and tribochemical. Wear is related to interactions between surfaces and more specifically the removal and surface (Balazs et al. 2006). The need for relative motion between tow surfaces and initial mechanical contact between asperities is an important distinction between mechanical wear compared to other processes with similar outcomes. Three type's mechanisms of wear in Nano-composite: Adhesive, abrasive, and fatigue wear, each of these mechanisms dependent on the conditions of sliding that is, load, speed, and time (Salih and Salih 2009).

Zinc Oxide is semi conductive material and it has drawn enormous attention due to its excellent

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characteristics in optics, photonics, and electronics due to its unique characteristics. Many researchers and previous studies on this search them, study effect of Nanoparticles percentage on mechanical behavior of nano- $\text{SiO}_2$  polymer nanocomposite. Study the synthesis and biophysical properties of polymer/  $\text{ZnO}$  Nanocomposites Zinc Oxide was selected as filler of unsaturated polyester resin (UPE) blend with Poly methyl methacrylate (PMMA) and the Tribological properties of this NPCs were studied, the mechanism of filler action in reducing the wear of thermosetting resin is also discussed .Tribology applications has to be taken into account in the modern industry. Many Tribological components such as brakes, clutches, driving wheels, bolts, nuts, gears, cams, bearings and seals are applied in the machinery (Ramalho and Miranda 2006). The aim of this research is to study the wear, friction coefficient and biophysical properties of particulate filled polymer and study effect  $\text{ZnO}$  fillers on the sliding wear, the work will help in understanding the function of different volume content of nano- $\text{ZnO}$  on sliding wear analysis for a Polymer blend (Damarla and Tech 2004).

Is calculated wear rate is the weighed sample of the application of the law the following Equations:

$$W_R = \Delta W / S_D \quad (1)$$

Where:

$\Delta W$ , is the difference weight loss of the sample before and after the wear test (gm.),

$S_D$ : is the sliding distance (cm). The wear coefficient can be used the equation

$$W_{coeff} = \frac{Wv \cdot Hv}{SD \cdot L} \quad (2)$$

$$W_v = \frac{WR}{\rho} \quad (3)$$

$HV$ , Vickers hardness ( $\text{N} / \text{mm}^2$ )  $W_v$ , Wear volume ( $\text{kg}/\text{m}^3$ ),  $\rho$ , density and  $L$ , load (N)

$$SD = \pi \cdot \omega \cdot D \cdot t \quad (4)$$

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

$$V_s = (\omega \pi \cdot D) / 60 \quad (5)$$

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

$$\mu = F / L \quad (6)$$

Where:  $F$ : Friction force and  $L$  :( load) applied on the sample (Newton).The hardness of all samples is measured using a micro hardness tester. A total of 10 points on each of the Nano-  $\text{ZnO}$  composites are measured in order to get average readings. The unit and magnitude of the hardness are defined by Vickers hardness,  $Hv_s$  and determined by measuring the average diagonal length,  $S$  of the indentation (mm).The Vickers tests are classified as micro hardness tests in comparison with the Brunel and Rockwell macro hardness tests (Saiful et al. 2013). Hardness is

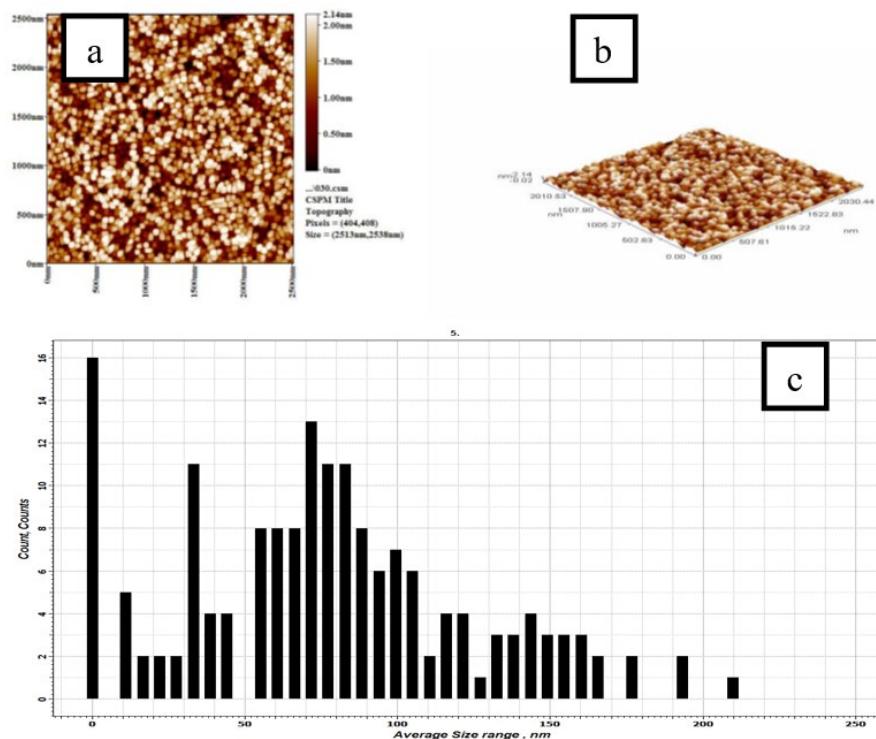
commonly correlated to biophysical properties of composite resins like mechanical strength, rigidity and resistance to intra softening Vickers hardness number (VHS) of materials is obtained by dividing the applied force  $L$ ,in Kgf, by the surface of the pyramidal depression yielding the relationship (Haddadi and Abbasi 2005).

$$HV_s = 1.8544 \times \frac{L}{S^2} \quad (7)$$

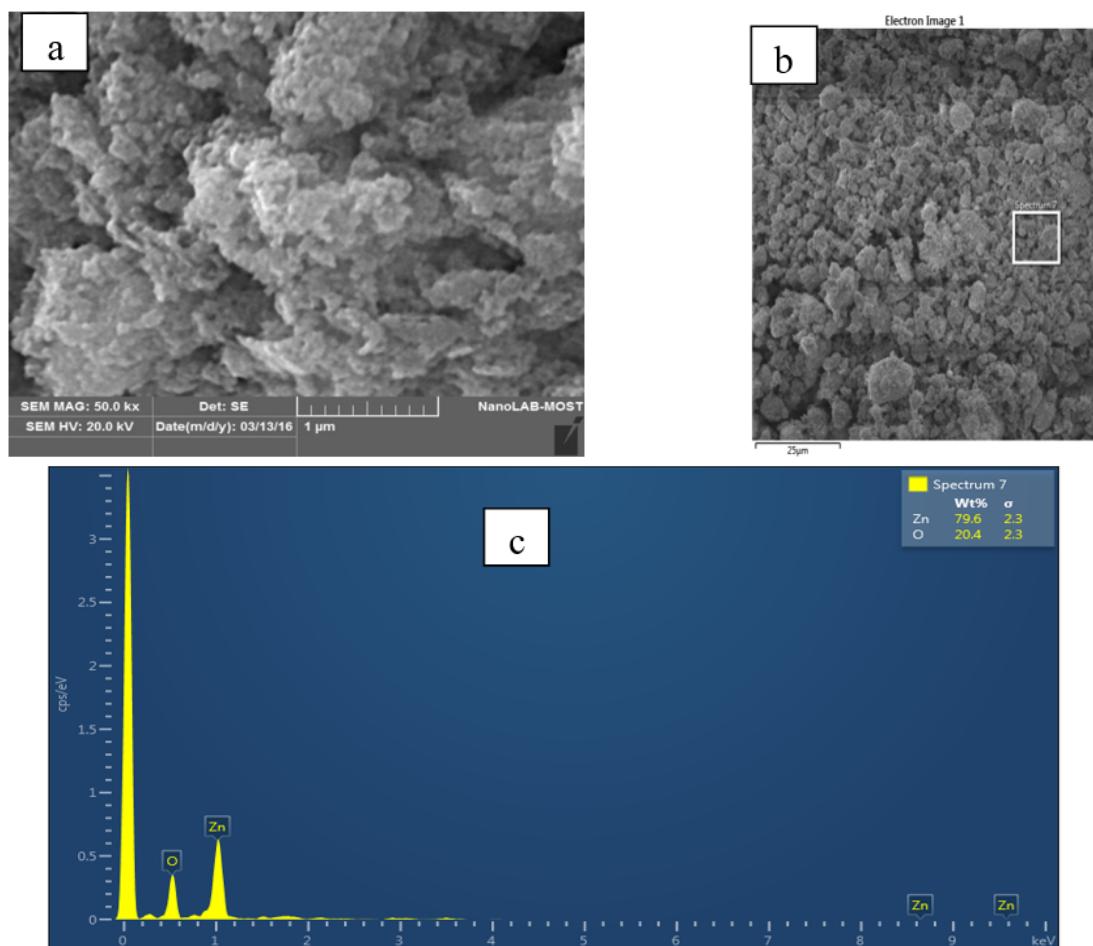
Where ( $S$ ) is the average length of diagonals in mm.

## MATERIALS AND METHODS

The ( $\text{ZnO}$  nanoparticles) 72 nm diameter and purity 99.5% manufacturer (Nanjing Nano technology), used for reinforced (UPE/PMMA) blend matrix. Nano powder was analysis using Atomic Force Microscope (AFM) as shown Fig. 1 and scanning electron microscope (SEM) instrument equipped with an energy dispersive X-ray (EDX) spectroscopy as shown Fig. 2 before dispersion process in blend matrix. Nanocomposite samples have been prepared by adding well dispersed nanoparticles to the polymer blend. The zinc oxide nanopowder has been dispersed in acetone using ultrasonic probe for 30 min. Then the suspension was added to 80 vol. % unsaturated polyesterresin (UPE) blended with 20 vol. % Poly methyl methacrylate (PMMA). The mixtures have been further ultrasonication for another 30 min. and cold casted in Teflon molds ( $d=10\text{mm}$ ,  $l=30\text{mm}$ ). For curing, the samples have been placed in oven for 8hr. at  $100^\circ\text{C}$  to be ready for various tests and measurements (Schimidt and Driscol 2007).



**Fig. 1.** AFM images of a-Two dimensions of Nano-ZnO.b- Three dimensions of Nano-ZnO.c- Distribution chart of Nano-ZnO.



**Fig. 2.** (a, b and c)) SEM and EDX of ZnO nanostructures

**Table 1.** Exp. Tribological and biophysical properties test

Sample NO.	$\Delta W$ gm	$W$ Coef. $\times 10^{-5}$	$H_v$ MPa	$\mu$	$R_a$ $\mu m$
0% ZnO	0.4	0.030	11.0	0.30	0.48
0.2% ZnO	0.3	0.022	24.0	0.24	0.42
0.4% ZnO	0.3	0.015	31.0	0.22	0.33
0.6% ZnO	0.2	0.011	44.0	0.19	0.20
0.8% ZnO	0.4	0.050	76.0	0.26	0.23
1% ZnO	0.3	0.040	87.0	0.20	0.38

## EXPERIMENTAL

### Wear and Friction of Coefficient Test

Experiments have been conducted in the Pin-on-disc type tribometer system, which was used surface roughness ( $R_a$ )  $0.5 \mu m$ . The disc rotates with the, having speed (0- 2000) rpm with diameter 5cm-18cm, with sliding speed (0-10 m/sec) (Fadhil et al. 2017). Load is to be applied on pin (specimen). The system has a maximum loading of 200N. In this experimental the rod specimens 10 mm in diameter and 30 mm length was fixed in chuck jaws to prevent specimens from rotation 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. The wear rate and friction coefficient tests were performed in air at RT  $\sim$  (25.C°) with different parameter included (Mshkin and Pesetkii 2015):

At 20 Newton applied force, 30mm sliding distance, 30min sliding time. Equation (1), (2), (3) and (6) were used to calculate the wear rate, wear coefficient, wear volume and friction coefficient. The samples dimensions (5x 1x 0.5) cm preparation for test coefficient of friction and surface roughness, [oblique – surface] device used for measuring kinetic friction coefficient and digital surface roughness was used appointed of the surface roughness (Bahjat et al. 2015).

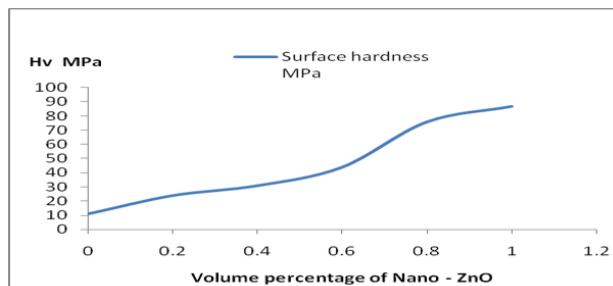
### Hardness Test

The hardness of all specimens is obtained using a Vickers diamond indenter. A valid tool for test the hardness of polymers. The load 0.4403 Newton is applied for time 20 s. In order to eliminate possible segregation effect a minimum of three hardness readings are taken for each specimen at different locations of the test samples. The operator of the test machine read the lengths of the diagonals immediately after each indentation, with a seconds (as short as 10 s) period of time elapsed between making and reading the indentations. Equation (7) using calculated Vickers hardness.

## RESULTS AND DISCUSSIONS

### Hardness Test

**Fig. 3** shows the hardness values with the ratio percentage of additives, figure shows the increase in the hardness values with increase the weight percentage ratio and this is due to the high surface hardness of

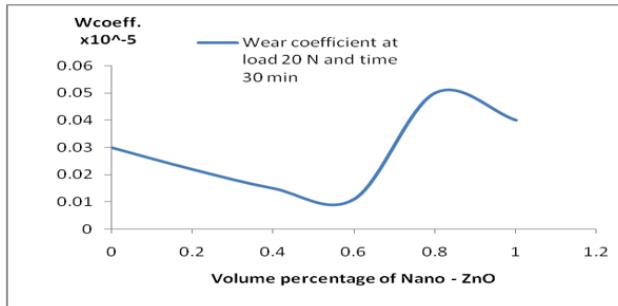


**Fig. 3.** Hardness variation function terms of Nano- ZnO loading present

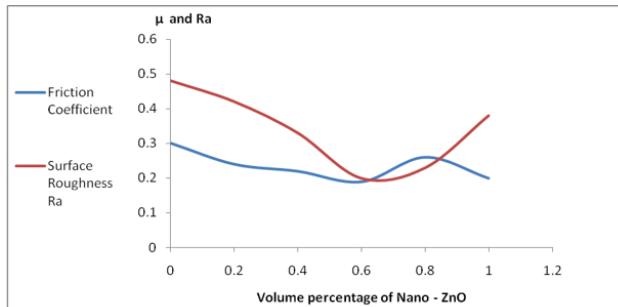
samples prepared and this reduced the wear and friction between the samples and the rotating disc. As well as the interface effect between the matrix and the Nano - ZnO, also the high adhesion between them this is agreement with.

### Wear Test

Conducting the wear test system are summarized in **Table 1** for total time (30 min), sliding velocity (1.58 m/s), sliding distance  $S_d$  (1582.6 m) and load applied 20 Newton . The results obtained for mass loss and the corresponding specific wear rate for all samples are shown in **Table 1** and **Figs. 4** and **5** the mass loss over distance and applied load have increasing trend for all samples of pure resin, Nano- ZnO resin composites with 0.2wt%, 0.4wt%, 0.6wt% and 1wt% Nano- ZnO contents. In **Fig. 4**, Nano-composites with 0.6wt% have the lowest mass loss. Generally, it can be observed that increasing the amount of Nano- ZnO content has increased the amount of accumulated mass loss (Poskus et al. 2004). As expected, pure resin has the highest cumulative mass loss. This is a result because of the irregular distribution and agglomeration winning nanoparticles as a result of applied pressure and the long of exposure to the dry time of the slide caused the generation of cracks and burns, and this led to an increase in wear and corrosion of the samples, which contain a high percentage of the nanoparticles rate this is agreement with. **Fig. 5** shown the coefficient of friction exhibits the same pattern of the coefficient of wear, because the mechanism is the same, as that means the greater the mass loss increased coefficient of friction. Energy dissipated decrease with increase percentage of Nano - ZnO and increase with slide lifetime, this is due to the fact that Nano - ZnO have high thermal diffusion and conductivity with added to have low heat capacity this is agreement with.



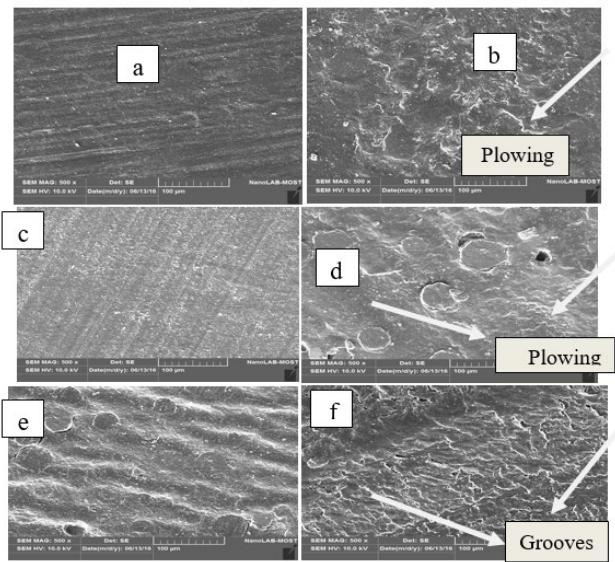
**Fig. 4.** Wear Coefficient variation function terms of Nano-ZnO loading present



**Fig. 5.** Friction Coefficient and Surface roughness variation in terms of Nano-ZnO loading present

### SEM Analysis Wear Test

**Fig. 6**, shows the samples before the wear test and show all the samples surfaces regularly. Sample (0.6wt. %) shows homogeneous distribution of Nano-zinc oxide with a polymer. While the sample (1wt. %) note the existence of the collection and conglomerate because of its high added Nano-ZnO powder. Micrographs of the neat polymer blend worn surface after sliding against a stainless steel counter-face under 20 N applied load and a 1.5m/s sliding velocity for different sliding time are presented in **Fig. 6**. The surface of the neat polymer blend suffers from fragmentation. This is mainly due to the influence of the thermo-mechanical loading in the rubbing region. Additionally, there is a softening process taking place. At this long sliding time and distance, there is the appearance of fracture on the surface, which is due to the high shear loading in the interface, associated with the high temperature. Such behavior has been reported in agreement. Have been tested under adhesive wear loading. **Fig. 6** 0.6wt% and 1wt% loading Nano-ZnO NPs shows the micrographs of the worn surfaces, after sliding against a stainless steel counter-face, indicating that there is a sign of micro-cracks can be seen on the micrograph. From the literature, the high content of the fillers, Nano-ZnO, in the



**Fig. 6.** SEM images of (a) Neat polymer before wear test (b) Neat polymer after wear test (c) 0.6vol. % Nano-ZnO before wear test (d) 0.6vol. % Nano-ZnO after wear test (e) 1 vol. % Nano-ZnO before wear test (f) 1 vol. % Nano-ZnO after wear test

composite may act as a crack (grooves and plowing) and be a weak area on the composite surface, as reported by agreement. There is no good integration between the two surfaces due to presence the Nano-ZnO on the surface of the composites. **Fig. 6** After sliding wear shows that there is a de-bonding between the fillers, and its surroundings, and also cracks on the surface. This is due to the rougher surface of the counter-face associated with the high thermo-mechanical loading. Further, there is plowing process that occurs in the resinous region.

### CONCLUSIONS

The points can be concluded from the research study:

1. Add Nano-zinc oxide to polymer blend less than 1wt% reduces the wear rate and friction coefficient compared with control neat sample.
2. There is a strong correlation between the hardness of the additive and wear rate, so decreases wear rate with increase hardness of the additive.
3. Coefficient of friction and wear Coefficient decreases with decreasing the surface roughness.

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