Surface Hardness Modify and Improve Wear Properties of EP\ NanoZrO_2

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Abstract

The liquid and mechanical mixing method was used in addition to ultrasound technology to prepare samples according to standard conditions. The percentage of cementing with ceramic powder was adopted from 1% to 4% as a weight ratio, and by using mixing drivers, nanocomposites were prepared depending on the theoretical density of the components. The velvet density was measured using Archimedes' method, and the results showed a successive improvement and increase in density with the weight ratio of addition. The results of the particulate hardness test showed a significant improvement in the results of the prepared nanostructures compared to the base sample (pure epoxy). With regard to the properties of wear resistance (wear modulus) using the screw-on-disk method, the cemented samples showed a higher wear resistance compared to the base sample. The results were interpreted based on the values of density and hardness in addition to the properties possessed by the ceramic powder of high surface area and average granular size of 32 nanometers through scanning electron microscopy. In this work, nanostructures based on (a polymer) supported with nanoscale zirconium dioxide powder were developed.

Key Words: Nanocomposites, Hardness, Epoxy, ZrO2, Wear.

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Introduction

One of the most promising material in industrial applications that has been used in the past two decades is epoxy resin due to its high mechanical properties and its unique resistance to heat and chemicals, as well as has a good electrical insulation [**M. Alajmi, K.R. Alrashdan 2020**], [**Juana Abenojar, Belén Enciso 2020**]. Many studies have accomplished to improve the mechanical properties of epoxy resin by fabricate epoxy- nano material composites [**Yongfeng Bua, Meijuan Xub, Hongyu Liang 2021**], [**Tomas Grejta, kab Xiu Jiaa, Annaliese 2020**], **Mansour Rahsepar, Fatemeh Mohebbi 2018**]. Adding 4 wt.% nanoclay to the epoxy resin to produce nanoclay–epoxy composites (NECs) shows noticeable improvement of tensile strength about 57.4 MPa (6% more than neat epoxy). This improvement in tensile strength of (NECs) is highly believed due to generation of considerable amount of plastic deformation because of nanoclay addition. Mixing a nanofiller material together with the epoxy greatly reduces the wear rate of composite. nano particles play a role in protecting the composite material thus, the wear rate of NECs will be minimized. It was stated that adding of carbon nanocages (CNC) to epoxy enhance wear resistance by 51.9 % for CNC/EP nanocomposites. Farther more, the control of nano particles orientation has important to obtain more improvement in wear resistance.

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It was found that the oriented distribution of nanoparticles in composite matrix results high wear resistivity when the oriented nanoparticles is perpendicular to the sliding counter-surface [**Manjunath Shettara, C.S. 2020**].
Using of Tungsten Carbide (WC) nanoparticles (2 wt.%) with the pure epoxy improved both tensile and flexural strength of (WC)- EP composite [**M. Kameswara Reddy, V. Suresh 2020**]. Increasement of flexural strain, flexural modulus, impact, and hardiness values were reported when WO3- EP composite tested. It was noticed experimentally that using of WO3 (1–3 wt. %) as a Nano filler improves hardness value of composite more than neat epoxy resin [Shaymaa Mahdi Saliha, Noor 2020]. Hardness shore (D) of 84.3 ± 0.1 was achieved of glass fiber (GF)/ Epoxy with 6 wt.% nano alumina compared of Epoxy and Epoxy + 3% GF which had hardness (D) of 77 ± 2, 78 ± 2 respectively. This evolution in hardness value after adding nano aluminum- dioxide was occurred due to obstruction of plastic deformation caused by nano particles [**Shatha Riyad Ahmedizat, Aseel Basim 2020**]. Zirconia nanoparticles also used to enhance mechanical properties of epoxy resin because of its good adhesivity with matrix. TEM Inspection revealed that zirconia nanoparticles had significant scattering in epoxy-matrix [**Zhanjun Wu, Li Shuaidong 2018**]. The coefficient of friction and specific wear rates were detected to be reduced when 0.5 wt.% ZrO_2 used in epoxy/ ZrO_2 nanoparticles composite [**R.V. Kurahattia, A.O 2014**]. More enhancement in mechanical properties of epoxy- matrix composite can be gained by using surface modification of ZrO2 nanoparticles which makes ZrO_2 one of the most auspicious filler materials [**Jialiang Li, Cong Peng, Zhiwei Li 2016**].

Experimental Details

Nanocomposite Preparation

Epoxy resin was used, which is composed of two hardened parts and a polymer (resin) from Emirati starch, which is transparent with a high viscosity and a density of 1.125 g/ cc. Regarding the support material, it is a ceramic nano-zirconium dioxide powder from 40nm to 32 nm and has a surface area of 54 g/ m2 of American origin with purity 98.999. In this work, the mixing ratio of the polymer with the hardener was used 2: 1 where the samples were prepared by means of liquid mixing supported by the ultrasound distribution technique for the purpose of homogenizing the powder within the polymer. Cementing, samples were formed in molds of Teflon according to standard conditions (Table 1).

Table 1. standard conditions of tasted samples.

Dimensions of wear rate		**Dimensions of hardness**		**density Dimensions**	
Height (cm)	Diameter (cm)	Height (cm)	Diameter (cm)	Height (cm)	Diameter (cm)
3	1	3	2	3	2

Practical Part

The Pin – on – Disc system was used to calculate the sliding wear and tear wear rate of the compounds (Figure 1). Models were created with dimensions of 1 cm in diameter and 3 cm in length. Using the following equations [**Harith I. Jaffer, Sinaa I. Hussaen 2011**], [**S. Zhang, Q. Hao, Y. Liu, L. Jin, F 2019**], the final wear rate Was calculated:

$$\mathbf{W_r = \Delta m / S_D} \quad \mathbf{(1)}$$

Where Wr is the wear rate (g/cm),

$$\mathbf{\Delta m = m_1 - m_2} \quad \mathbf{(2)}$$

Where **Δm** is Wear loss (g) before (**m_1**) and after (**m_2**) taste. Sliding distance can be calculated from following equation:

$$\mathbf{S_D = 2\pi . N. r. T} \quad \mathbf{(3)}$$

Where, **S_D** is Sliding distance (cm), **N** is 2950 (rive/min), **D** is Routing distance (cm) = 0.06 m, **T**: Sliding time (min) = (10 min). Volume Wear can be calculated from following equation:

$$\mathbf{W_v = W_r / \rho} \quad \mathbf{(4)}$$

Where, **W_v** is Volume Wear, **ρ** is Experimental density (g/cc), **H_V** is Number Hardiness (MPa). Wear Coefficient can be estimated from the formula as below:

$$\mathbf{W_{coeff} = Wv. H_V / L.S_D} \quad \mathbf{(5)}$$

Where, **L** is Load = 10 Newton

As far as density is concerned, the Archimedes method for measuring the density of nanocomposites and the dimensional process to ensure the precision of the measurements. Vickers hardness tool has also been used to measure the superposition 's surface micro hardness in which the results have been reported in mica units directly from the machine, using only a time of 20 seconds and a force of 0.5 Newton in which the equation should be used:

$$\mathbf{Hv = 1875\ p \backslash d^2\ (MPa)\ (6)}$$

With regard to the compression test, the results were obtained by the examination system, called the universal machine, where the models were formatted as cylinders with.

Figure 1. Pin-On-Disk wear testing apparatus

Results and Discussion

Table 2. shows a summary of the practical results of hardness and practical density. Vickers hardens method was used to calculate the particle hardness, while Archimedes' method was used to calculate the practical density values of the nanostructures according to the mixing rules. **Figure 2-3.** shows the behavior of hardness and density and through the curve there is a direct relationship and a high correlation between the two parameters, as their values increased when the support percentage of the ceramic powder increased (Nano zirconium dioxide). The gaps and surface defects of the base material (polymer) and the used zirconium dioxide has a high surface area and a granular size between 40 to 32 nanometers. All these reasons make the prepared nanostructures have a surface hardness and high density compared to the unsupported polymer [**Fadhil K. Farhan, Mohammed O. Kadhim 2019**].

Table 2. practical results of the physical properties of Nano-composites Epoxy \Nano ZrO_2.

Samples	Density (g\ cm^3)	Hardness (MPa)
EP\0% NanoZrO_2	1.123	34
EP\1% NanoZrO_2	1.312	48
EP\2% NanoZrO_2	1.422	56
EP\3% NanoZrO_2	1.521	79
EP\4% NanoZrO_2	1.588	101

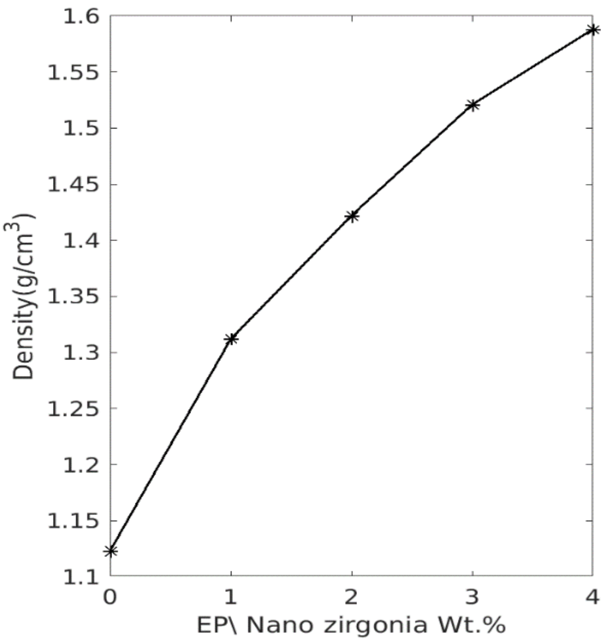

Figure 2. Variation of density with percentage rate of nano zirgonia

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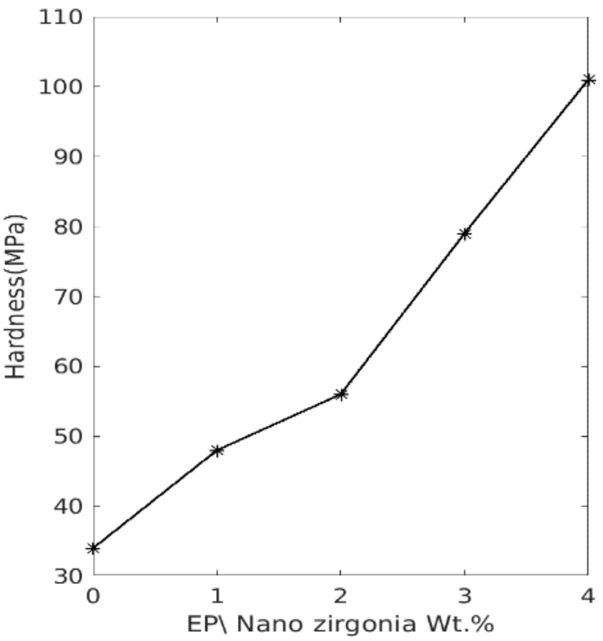

Figure 3. Variation of hardness with percentage rate of nano zirgonia

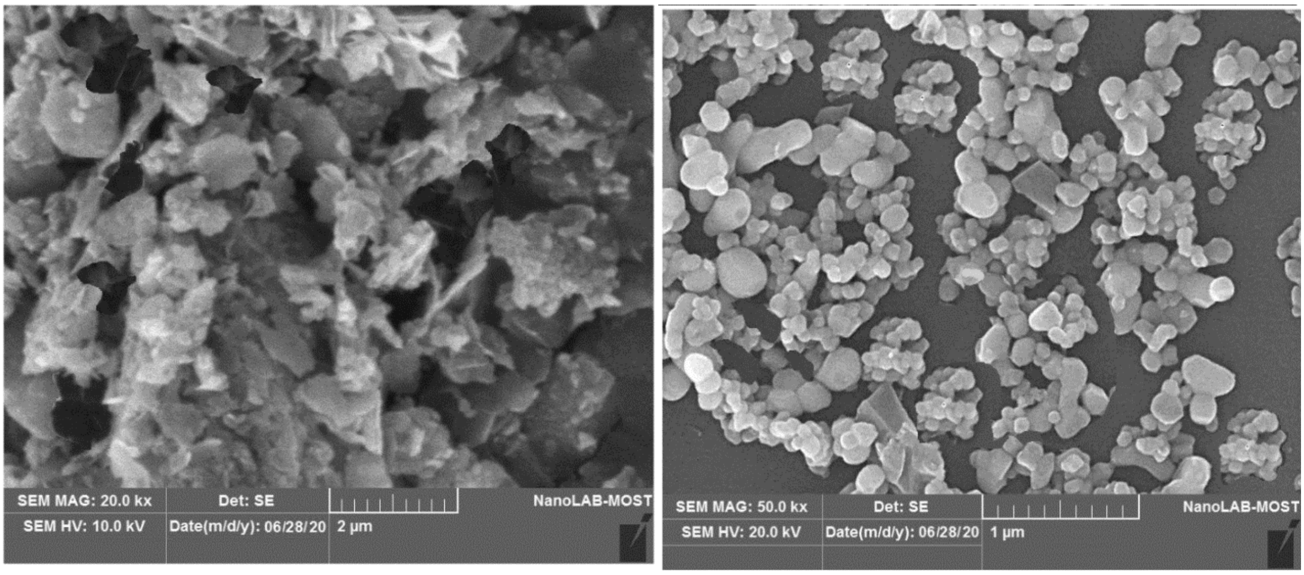

Figure 4. SEM-Images of NanoZrO_2 Powder.

Table 3. and **Figure 5- 6.** illustrate a summary of the practical results for calculating the dry slip rate, in which the coefficients were calculated according to the relationships (2, 3, 4, 5), which are respectively (mass difference, Sliding distance, volumetric wear rate, wear coefficient), where A disk screw device(PIN – ON – DISC) was used with a torque of 2950 rpm, a slide time of 10 minutes, and a 10 Newton hammer bearing with a hardening disc of 68 HB Through the table and the figure, the results can be interpreted for the nanostructures, as they showed a significant decrease in the amount of corrosion and peeling as the proportion of the powder's reinforcement to the polymer increased. When calculating the weighted wear rate using equation 1, taking into account the slip distance and time, the results showed a significant improvement in the wear rate of the nanostructures compared to the unsupported sample, and this is due to the values of density and surface hardness as well as to the higher correlation between the powder and the polymer. With regard to the calculation of the volumetric wear rate, which depends on equation. 4, where the practical density values were taken into account in the calculation, the results showed accuracy in evaluating the wear rate of the gins up to the calculation of the wear factor, which was calculated using equation 5, which in turn represents a summary of the results to calculate the efficiency of samples and reduce The error rate in the measurement, which can determine the life span of the product and the extent of its effectiveness, and through the form that relates to the wear factor, we notice a clear decrease in the values of the wear factor, as it decreased $6.606 * 10^{-12}$ for the (polymer) sample to $1.606 * 10^{-14}$ the supported model by 4%, which is An improvement equivalent to more than 50%.

Table 3. practical results of Wear rate properties Nano-composites Epoxy \Nano ZrO_2.

Samples	weight loss g	Wear rate (g/cm)	Wear Volume	Wear Coefficient
EP\0% NanoZrO_2	0.675	$1.21*10^{-6}$	$1.08*10^{-6}$	$6.606*10^{-12}$
EP\1% NanoZrO_2	0.0456	$8*10^{-8}$	$6*10^{-8}$	$5.181*10^{-13}$
EP\2% NanoZrO_2	0.00876	$2*10^{-8}$	$1*10^{-8}$	$1.007*10^{-13}$
EP\3% NanoZrO_2	0.00345	$6.2*10^{-9}$	$4.08*10^{-9}$	$5.7*10^{-14}$
EP\4% NanoZrO_2	0.00078	$1.4*10^{-9}$	$8.84*10^{-10}$	$1.606*10^{-14}$

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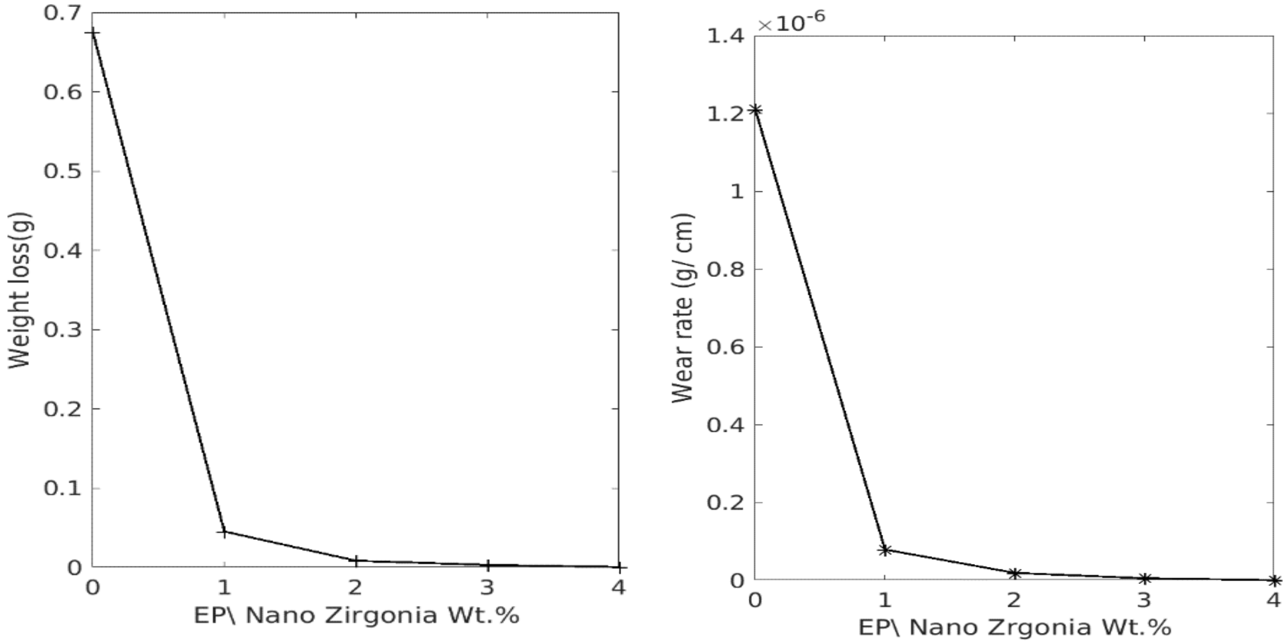

a b

Figure 5. Variation of (a) weigth loss and (b) wear rate with wt.% of nano ZrO_2.

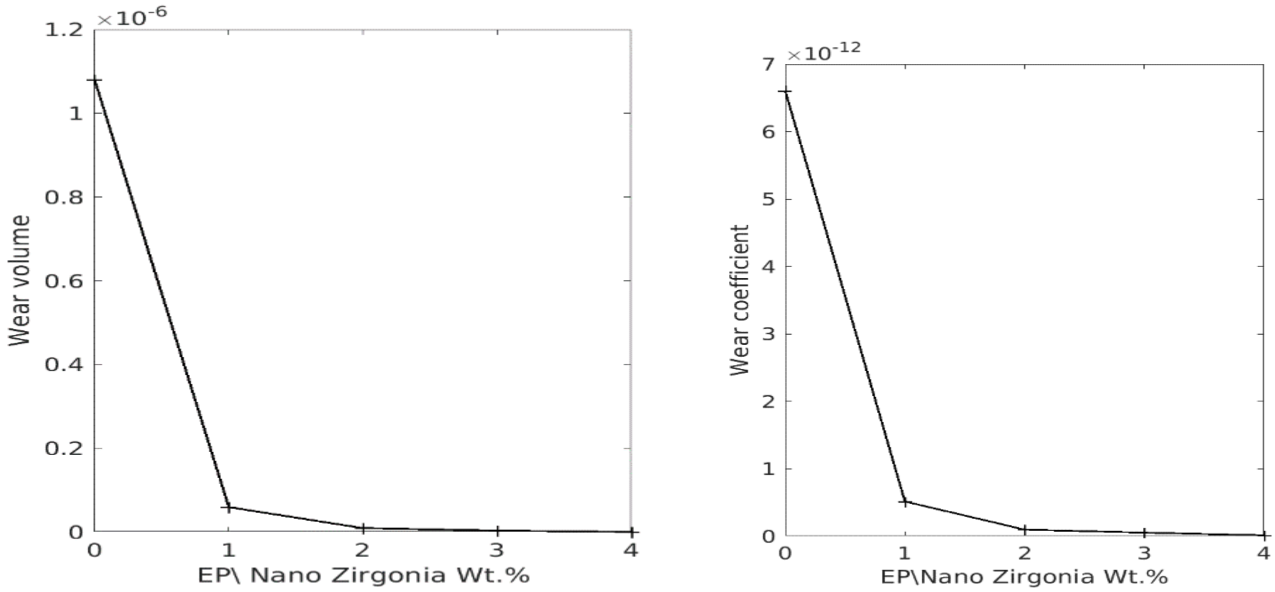

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Figure 6. Variation of (a) wear volume and (b) wear coefficient with wt.% of nano ZrO_2.

Conclusion

Through the practical results of the research, the following can be summarized:

1. The hardness and high-density values showed a significant effect on the wear resistance of the nanocomposites remarkably for all ratios.
2. The weighted percentages of the ceramic powder of 4% as a maximum in this work led to a significant decrease in the values of the wear parameters, with an improvement rate of more than 60%.
3. The high surface area and low granular size of the Nano ceramic powder have a great influence on all of the aforementioned properties.

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