Chemistry and Materials Research
ISSN 2224- 3224 (Print) ISSN 2225- 0956 (Online)
Vol.7 No.4, 2015
www.iiste.org

Effect of Al_2O_3 and SiO_2 Nanopartical on Wear, Hardness and Impact behavior of Epoxy composites

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Abstract

A growing need for materials with good tribological and mechanical properties led to prepare , characterize and measure wear, hardness and impact properties of epoxy (EP) with different weight percentage of SiO_2 and Al_2O_3 nano particles (0.5%, 1%,1.5%,2%,2.5%,3%) . Silica and alumina nanoparticles have average diameter size 16.69 and 46.73 nm respectively measured by scanning probe microscope.A combination of two different techniques (high shear mixing followed by ultrasonication) was used to prepared the nanocomposites. Fourier transition infrared (FTIR) was used to characterize the nanoparticles (Al_2O_3 an SiO_2) .Wear rate, hardness and impact energy properties were measured for EP/ Al_2O_3, EP/ SiO_2 nanocomposites . Decreasing in wear values with addition of nanoparticles (especially nano Al_2O_3) were observed. Approximately 30% and 80% increasing in hardness values and impact energy were observed. An enhancement in whole measurement for all composites was observed, yet (EP/ Al_2O_3, EP/ SiO_2) composites with 2.5%nano Al_2O_3 show in general better hardness and impact results.

Keywords: Nanoparticles, Nanocomposites, wear, Impact, hardness.

Introduction

Polymeric composites have become main part of industrial applications due to their excellent thermal, mechanical and tribological properties apart from their easy process ability and low cost .Such materials are good candidates to form a special class of engineering tribo- materials due to their unique properties such as wear resistance self lubricant , impact resistance , corrosion resistance and ease of fabrication . They are utilized in numerous applications including seals, cutting tools, bearings and artificial prosthetic joints. For such applications and others, polymer matrix must with stand high mechanical and tribological loads, so fillers, fibers or particals and added to enhance its properties. Wear is defined as damage to a solid surface, generally involving progressive loss of material, due to relative motion between that surface and contacting substance or substances. The five main types of wear are abrasive, adhesive, fretting, erosion and fatigue wear, which are commonly observed in practical situations. The inherent deficiency of polymers could be altered successfully by using various special fillers (micro to nano-sized particles)[1,2].

Polymer nanocomposites, have been widely employed to replace the traditional metals and ceramics in microelectronic packaging, coatings, aerospace, automotive, food packaging and biomedical applications. This is mainly because of their adequate strength, lightness, versatility, ease of processing and low cost. By addition of lubricating and/or reinforcing fillers, the tribological properties of polymers are generally improved. Nanoparticles reinforced polymer composites have attracted more and more attentions. The extremely high specific surface area facilitates creating a great amount of interphase in composite and a strong interaction between the fillers and the matrix. Thus, the nanocomposites always have unique properties resulting from the nano-scale structures. Some nano-inorganic particles are demonstrated to have the ability in reducing the friction and improving the wear resistance of polymers. The addition of nanoparticles, such as SiO_2, Al_2O_3, Si_2N_4 and TiO_2, in epoxy is also for purposes of processing ability and mechanical properties [3, 4]. Fillers can improve tribological properties of polymers. One of the fillers that is used to reinforce polymers is SiO_2. Because of its rigidity and high stability, nano sized silica powders have widely been used to improve properties of polymer matrix composite materials [5] .

The present paper focuses on the wear and mechanical (impact energy andhardness) behavior of the Epoxy nano composites with different wt% of nano-sized SiO_2 and Al_2O_3 particles .

Experimental Part

Materials

High pure grads of nano Al_2O_3[46.73nm] and nano SiO_2[13.69nm] are supplied from Sigma Aldrich . Scanning probe microscope (Angst rum –Advanced Ltd, USA) was used to measure the nano average diameter as shown in Figures (1) and (2).

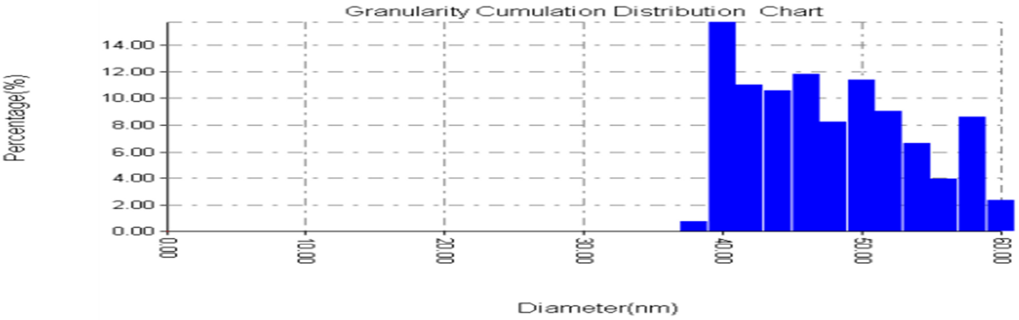

Fig (1): Scanning Probe Microscope of nano Al_2O_3.

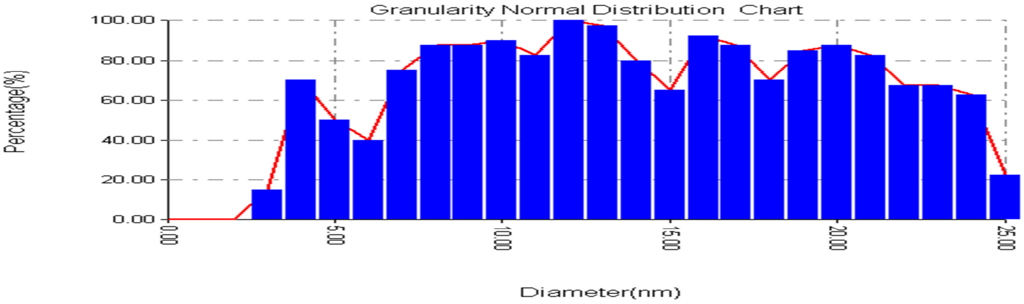

Fig (2): Scanning Probe Microscope of nano SiO_2.

Epoxy resin matrix used that was Nitofill, EPLV from Fosroc Company with Nitofill EPLV hardener.

Preparation method

Two different steps were used to prepare EP/nanocomposites with different weight percentage of nano particles (Al_2O_3, SiO_2) .The first step includes high shear mixing for fixed fine followed by ultra sonication for one hour.

Epoxy resin and hardener were taken into different two beakers and both degassed to remove trapped are bubbles and moistener. The nanoparticle was weight by Sartorius BL 210S (d = 0.1 mg) and manually mix with epoxy resin under gloves box in nitrogen atmosphere to avoid interact of silica nano particles with any unwanted particle from the environment specially interaction with water vapor because this type of interaction increase particles agglomeration and decrease any interaction (chemical or physical) of particles with polymer chain in the matrix. Then the nano silica and epoxy resin were mixed by shearing mixer at 800 rpm for 15 minutes to have good distribution. The second step was using ultrasonic homogenizer, Soniprep-150 MSE 150 watt, for 4 minutes to get good dispersion, and then let the sample container under vacuum to remove bubbles. The hardener mixed with nano silica and alumina /epoxy resin for 4 minute by ultrasonic homogenizer, using ultrasonic may cause to decrease viscosity and increase epoxy resin temperature then sample container should be putted in a cold water container to avoid high temperature which decrease time of gelling making the composite hard to mold, the third step was using vacuum system to remove the bubble before cast the composites in earlier prepared mold identically to ASTM [6].

Samples (EP, Six EP/Al_2O_3, and Six EP/SiO_2 nanocomposites) with different low weight percentage are classified in Table (1) .

Table (1) EP and EP/nanocomposites

Samples	*Symbols*
100%EP	***EP***
99.5EP/0.5 **n Al_2O_3**	***A 0.5***
99EP/1 n **Al_2O_3,**	***A 1.0***
98.5EP/1.5 n **Al_2O_3,**	***A 1.5***
98 EP/2 n **Al_2O_3,**	***A 2.0***
97.5EP/2.5 n **Al_2O_3,**	***A 2.5***
97EP/ 3n **Al_2O_3,**	***A 3.0***
99.5EP/0.5 **n SiO_2**	***S 0.5***
99EP/1 n **SiO_2**	***S 1.0***
98.5EP/1.5 n **SiO_2**	***S 1.5***
98 EP/2 n **SiO_2**	***S 2.0***
97.5EP/2.5 n **SiO_2**	***S 2.5***
97EP/ 3n **SiO_2**	***S 3.0***

Experimental techniques

1-Wear Test

Wear test was carried out in a pin-on-disc type friction and wear monitoring test rig (supplied by DUCOM) as per ASTM G 99. The counter body is a disc made of hardened ground steel hardness (269HB) with speed 500 rpm and track radius 6 cm. The specimen is held stationary and the disc is rotated while a normal load is applied through a lever mechanism. Series of test are conducted with sliding velocity of 12 cm/sec under normal loading of 20N. The material loss from the composite surface is measured (ΔW) and the wear rate is given as

\WR\ = ΔW/ S. D ………………(1)

WR: Wear rate (Kg/cm) , ΔW = W1-W2 ...: Weight difference(g)

And the sliding distance S.D=2 π r n t ……………..(2)

Where:

t: is the test time (sec) r: radius of center rotating n: number of cycle (500 rpm)

2- Impact Test

Charpy impact test machine was used to measure the absorbed energy of the samples and all tests were carried out at room temperature. The standard charpy specimens with , 10 mm× 10mm × 55mm were prepared .

3- Hardness test

Shore D hardness was used to measure the surface hardness , the indenter was attached to a digital scale that is graduated from 0 to 100 unit the usual method was to press dawn firmly and quickly on the indenter and recording the maximum reading as the shore D hardness measurement were taken directly from the digital scale reading. Hand –operated durometer was used to measure the surface hardness (shore D) of epoxy pure and composites (epoxy with SiO_2 and epoxy with Al_2O_3). Shore hardness of the samples were measured as per ASTM D2240. Hardness results are average of four measurements taken from different parts of the samples.

Results and Discussion

1-Wear test

The results of wear tests are shown in Table (2) . Wear rate results decrease five time nano Al_2O_3 weight percentage to 3% . This is because of presence of ceramic powders of SiO_2 which have high hardness [3, 6].This improvement in wear rates is more obvious for 3%SiO_2 comparing to pure Epoxy, which emphasis the role of SiO_2 in improvement of wear rate.

neat epoxy and Al_2O_3 and/ SiO_2 filled epoxy nanocomposites are shown in Table (2) it was observed that the wear rate values decreased with increasing filler loading for all the samples. Figure (3) shows wear rate as a function weight percentage. It may be noted that the resistance to wear is larger in Al_2O_3 filled epoxy compared to the SiO_2filled. The SiO_2 being much harder than the matrix epoxy .This is probably due to the fact that epoxy can easily remove at sliding surfaces (contact area) but in the composite case the ceramic nano particles act as a rough surface relative to the counter face against which they slide. Thus, the improvement in the tribological behavior of nanometer- filled epoxy composite is related to the improved characteristics of the transfer film. The results agree well with the reported by Kishore and Kumar about increasing wear rate by addition Al_2O_3 [7].

Table (2) Wear rate of EP and its nanocomposites

Samples	***K(g/cm)***
EP	$1.1*10^{-7}$
A 0.5	$2.4*10^{-8}$
A 1.0	$2.1*10^{-8}$
A 1.5	$1.6*10^{-8}$
A 2.0	$1.1*10^{-8}$
A 2.5	$2.0*10^{-8}$
A 3.0	$2.1*10^{-8}$
S 0.5	$4*10^{-8}$
S 1.0	$3.1*10^{-8}$
S 1.5	$2.7*10^{-8}$
S 2.0	$2.1*10^{-8}$
S 2.5	$2.0*10^{-8}$
S 3.0	$2.6*10^{-8}$

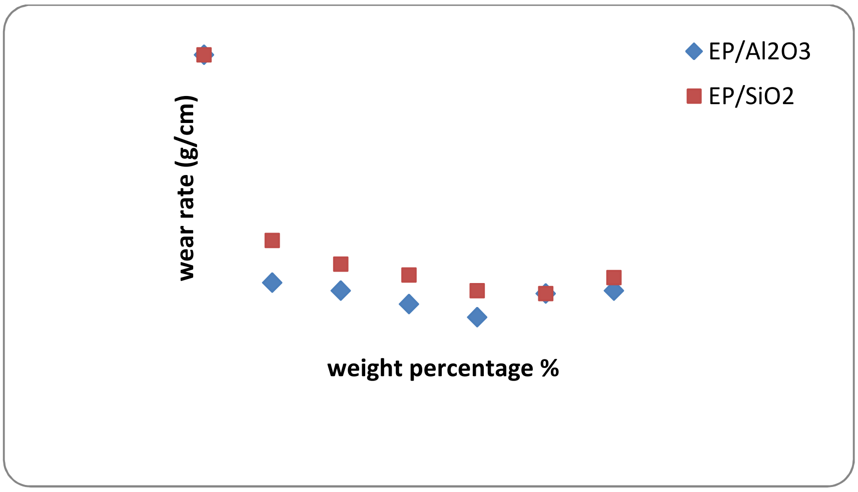

Fig. (3) Wear rate as a function weight percentage of nanoparticles

2-Charpy Impact test

Charpy impact energy values of different composites recorded during the impact tests are given in Table (3). It shows that the resistance to impact loading of epoxy composites improves with addition of nano Al_2O_3 compared to the unfilled and EP/SiO_2 nanocomposites .An increasing in Gc could be due to inducting plastic deformation around epoxy matrix caused by nanoparticles [8]

In general it is noted that the impact energy is directly proportional tom the weight content of the reinforcement material as shown in Table (3). In fact, there is almost a constant rate of increase in impact energy with the increase of reinforcement material content. It is also noted that the material toughness of alumina composites are significantly higher than those of silica composites with equivalent reinforcement content. This is justified by the reports that the physicochemical interaction between the particle and the matrix plays a significant role in the obtained composites. Moreover the strong chemical bonding improves the mechanical properties of the composites such high increase in Gc values (88%-80%)could be due to generation of more interfacial surface due to nanoparticles with high module lead to absorb higher mechanical stresses .Nanoparticles act s strong stress concentrators which resist crack propagation [9]

Table (3) Impact energy of EP and its nanocomposites

Samples	*Gc(kJ/m²)*
EP	9.07
A 0.5	*12.1*
A 1.0	*13.2*
A 1.5	*14.5*
A 2.0	*14.9*
A 2.5	*15.6*
A 3.0	*17.4*
S 0.5	11.2
S 1.0	*11.8*
S 1.5	*12.5*
S 2.0	*13.6*
S 2.5	*14.8*
S 3.0	*16.4*

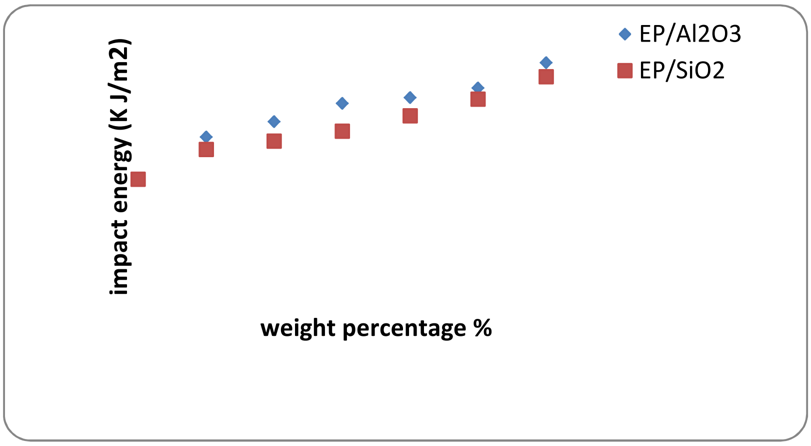

Fig.(4) impact energy as a function of weight percentage of nanoparticles

3- Hardness test:

Table (4) lists the experimental measurements of Shore-D hardness of neat epoxy and different wt% of Al_2O_3 and SiO_2 epoxy nanocomposites. From the table, it can be observed that the incorporation of nanofillers into epoxy showed significant improvement in the hardness of composites.It can be observed that the hardness of composite improves more than (70 %) by addition of 3% Al_2O_3 nano powders. The hardness improves gradually by addition of more powders. This could be due to bond strength achieved between Al_2O_3 and Epoxy. Therefore, this development in hardness can support the improvement of wear resistance that was achieved in this investigation. Al_2O_3 has a much greater surface hardness because of its ceramic nature. Therefore, the contribution of Al_2O_3 into epoxy increased the hardness. Figure (5) the hardness values increase with increasing weight percentage of nanofiller (Al_2O_3 and SiO_2)and hence the nanoparticles might impose better resistance against epoxy segment motion under indentation[5] .figure (5) shows an enhancement of increase in hardness values represent the ability of materials to stand firm to the local surface deformation[7, 8, 9].

SiO_2 have high hardness and by increasing wt% of SiO_2 nano particles hardness values increase by about 60% and EP/SiO_2 nano composites show higher hardness then EP/Al_2O_3 comparable hardness values were reported by Nikje et.al[10] for nanosilica reienforced epoxy were nano SiO_2 was treated by coupling agent.

Table (4) Hardness of EP and its nanocomposites

Samples	*Hardness*
EP	51
A 0.5	*64*
A 1.0	*69*
A 1.5	*72*
A 2.0	*78*
A 2.5	*83*
A 3.0	*85*
S 0.5	61
S 1.0	*66*
S 1.5	*70*
S 2.0	*77*
S 2.5	*78*
S 3.0	*81*

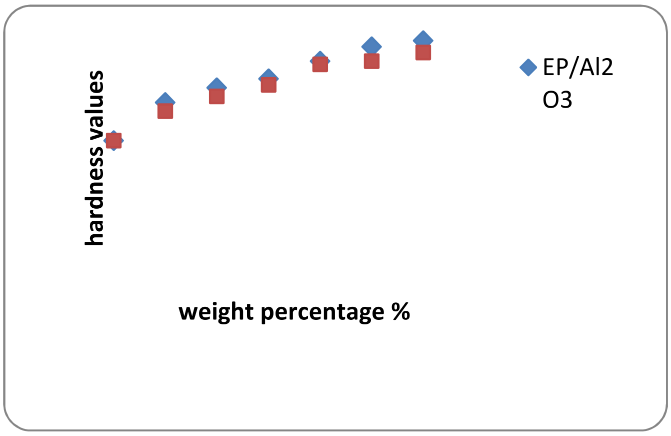

Fig.(5) Hardness values as a function of weight percentage of nanoparticles

Conclusions

Addition of low weight percentage of Al_2O_3, and SiO2 nano particles to EP decrease wear rate and increase impact energy and hardness of Ep/SiO_2 and EP/Al_2O_3 nanocomposites .

EP/Al_2O_3 nanocomposites in general show highest wear resistance, impact, and hardness values especially for composites with 3% wt percentage of Al_2O_3 nanoparticles.

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