Comparison Study of Erosion Wear and Hardness of GF/EP with Nano and Micro SiO_2 Hydride Composites

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ABSTRACT

The objective of this research is to study GF / EP nano and micro silicon dioxide (SiO_2)composites were prepared with different volume percentage of nano and micro SiO_2 powder (2,4,and 6 wt.%). Atomic force microscopy techniques was used to measure the grain size of nano SiO_2 powder (average diameter 38nm) and particle size analyzer techniques was used to measure the grain size of micro SiO_2 powder (average diameter 6.069µm). Erosive wear behavior of this composite under three different impingement angles 30°, 60° and 90°and three angular silica sand abrasive particle sizes approximately 425, 600 and 850 µm and hardness (shore D) were study.In general the erosion wear of micro composites have lower resistance erosion than nano based Material composites other. Erosion resistance increase as the volume fraction increase. Nano composites of GF / EP with SiO_2 have many advantages over micro composites from the view point of wear and hardness tests. The worn surface features of unfilled and filled G-E composites were examined using scanning electron microscopy (SEM) and results indicates more severe damage to matrix and glass fiber in unfilled composite system as compared to SiO_2 filled composites.

Key wards: GF / EP, SiO_2 composites, erosion wear, shore hardness.

دراسة مقارنة بلى التعريه والصلاده لمتراكبات الايبوكسي والياف الزجاج المدعمه بنانو ومايكرو ثاني اوكسيد السليكون(SiO_2)

الخلاصة

الهدف من هذا البحث هو دراسة متراكبات الايبوكسي والياف الزجاج المدعمه بنانو ومايكرو ثاني اوكسيد السليكون (SiO_2) مع نسبة حجمية مختلفة من نانو ومايكرو مسحوق SiO2(2و 4و6%). تم استخدام تقنيات مجهر القوة الذرية لقياس حجم مسحوق النانو SiO2 (متوسط قطرها 38nm) وتقنيات تحليل حجم الجسيمات كان يستخدم لقياس حجم مسحوق المايكرو SiO2 (متوسط قطرها µm 6.069). سلوك بلى التعرية من هذا المركبة تحت ثلاثة زوايا مختلفة 30 درجة، 60 درجة و 90 درجة وثلاث

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احجام من رمل السيليكا حوالي 425 و 600 و 850 ميكرون. ودراسة صلاده شور (D) .بشكل عام بلى التعريةالمركبة المايكرو يكون أقل مقاومة للتعريه من النانو استنادا المركبة المواد الأخرى.مقاومة البلى تزداد مع زياده الكسر الحجمي . المركبات النانويه من الايبوكسي والياف الزجاج مع SiO2 لديها العديد من المزايا على المركبات المايكرويه من وجهة نظر من بلى التعريه واختبار الصلادة. تم فحص السمات السطحية البالية من المواد المركبة GE باستخدام المجهر الإلكتروني الماسح (SEM) والنتائج تشير إلى المزيد من الضرر الشديد إلى الاساس والألياف الزجاجية في نظام الغير مدعمه بالمقارنة مع المركبة الحاويه على مركب SiO_2 .

INTRODUCTION

Polymer matrix composites (PMC_S) are the workhorse of the composite industries. They have excellent room –temperature properties at a comparatively low cost. The matrix consists of thermosetting resins and thermoplastics polymers. Most composites consist of a reinforcement component in the form of small – diameter fibers, whiskers, particles, and flakes [1]. Particulate filled polymers are used in very large quantities in all kinds of applications and despite the overwhelming interest in advanced composite materials, considerable research and development are done on particulate filled polymers even today [2]. Epoxy resins are used widely due to their good mechanical, thermal, and isolating properties. Many types of epoxy resins have been developed, including bisphenol- aliphatic cyclic, novolac types, etc. To further strengthen the properties of epoxy resins, the use of an additional phase has been a common practice [3]. Epoxy resins modified with inorganic particles, such as titanium dioxide, silica, alumina, fly ash, clay and so on have shown improved performances [4]. For inorganic/organic composites, the size of particles and the interfacial adhesion have great effect on the properties of the resin matrix. The well dispersed inorganic fillers in polymer matrices and compatibility between inorganic and organic phases are important to achieve an overall good performance [5]. In order to obtain the favored material properties for a particular application, it is important to know how the material performance changes with the filler content under given loading conditions. Wear is damage to a solid surface usually involving progressive loss of materials, owing to relative motion between the surface and a contacting substance or substances. It is a material response to the external stimulus and can be mechanical or chemical in nature. The effects of solid particle erosion have been recognized for a long time. In some cases, the solid particle erosion is a useful phenomenon, as in sand blasting and high-speed abrasive water jet cutting, but it is a serious problem in many engineering systems, including steam and jet turbines, pipelines and valves carrying particulate matter and fluidized bed combustion systems. It is a quite complex phenomenon since it involves several processes. Although the main process is the mechanical impact, caused by the impingement of solid particles on the target material, secondary processes, like thermal, chemical and physical reactions between the counterparts are taking place during erosion.

Barkoula N. M. and Karger-Kocsis J., (2002) have studied the influence of interfacial modification and relative fiber orientation (parallel, Pa and perpendicular, Pe) on the solid particle erosion Erosion has been investigated in unidirectional (UD) reinforced glass fiber (GF) epoxy (EP) composites. The interfacial modification is varied by (GF) sizing. The erosive wear behavior has been studied in a modified sandblasting apparatus

at three impact angles (30°, 60° and 90°).The results show a strong dependence of the erosive wear on the jet angle. The (GF/EP) systems presented a brittle erosion behavior, with maximum weight loss at 90° impact angle. It has been established that good fiber/matrix adhesion improved the resistance to erosive wear. On the other hand, the relative fiber orientation had a negligible effect except the erosion at 30° impact angle. High roughness of the eroded surfaces attributed to high erosion rates, i.e., low resistance to solid particle rosion[6].

M.Bagci et.al (2011) have studied the erosion wear behavior of glass fiber reinforced epoxy composite material on which silicon oxide (15%) was added. Where three different impingement angles (30°, 60° and 90°), three different impact velocities (23, 34 and 53)m/s, two different abrasive particle sizes of aluminum approximately (200 and 400) μm and the fiber orientation of 45° (45/-45) were used. The results shown the specimens with silicon oxide added have exhibited resistance against abrasive particles and hence only slight deformation was encountered on the specimen surface. That is the filler material (silicon oxide) which forms a strong bond with the epoxy prevents the filler from deformation and this leads to low erosion wear rates. The erosion peak take place at impinging angle 30° [7].

Experimental procedure:

Sample preparation method

The basic materials used in the preparation of research samples consisting of glass fibers (Woven E- Glass Fiber) from the Tenax company, England, Epoxy and hardener type Euxit (50) base as the matrix from the (Al-Rakaez Building Materials in Amman**)** Made in Egypt in the form of transparent viscous liquid at room temperature which is a thermally hardened polymers (Thermosets) with a density of (1.05 gm / cm^3) were used in this study in ratio of 3:1 for with nano and micro SiO_2 to form nano and micro composites with three different weight percentage of SiO_2 (2, 4 and 6%) and 3% as volume fraction of glass fiber. The method used in the preparation of the samples in this research is the (Hand lay-Up Molding) because it is simple to use and can make different shapes and sizes of composites.

Atomic Force Microscopic (Afm)

The grain size of nano Silicon dioxide is(38 nm) was examined with an atomic force microscopy , a powerful tool for surface imaging at the nanometer to sub micrometer .Diameter is found for nano SiO_2 with average (AFM)as shown in Figure(1).

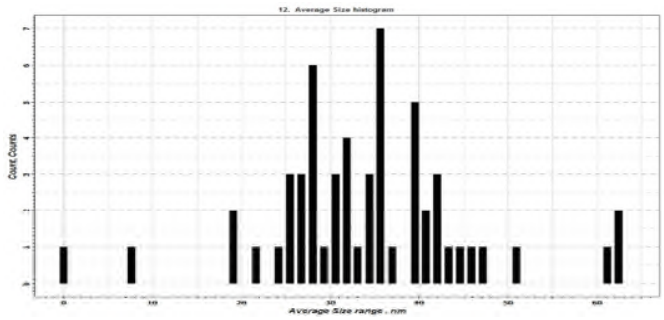

Figure (1) AFM of nano silicon dioxide

Particle size analyzer

The grain size of micro Silicon dioxide is(6.069µm) was examined with Particle size analyzer device.SiO_2 with average size is shown in Figure(2)

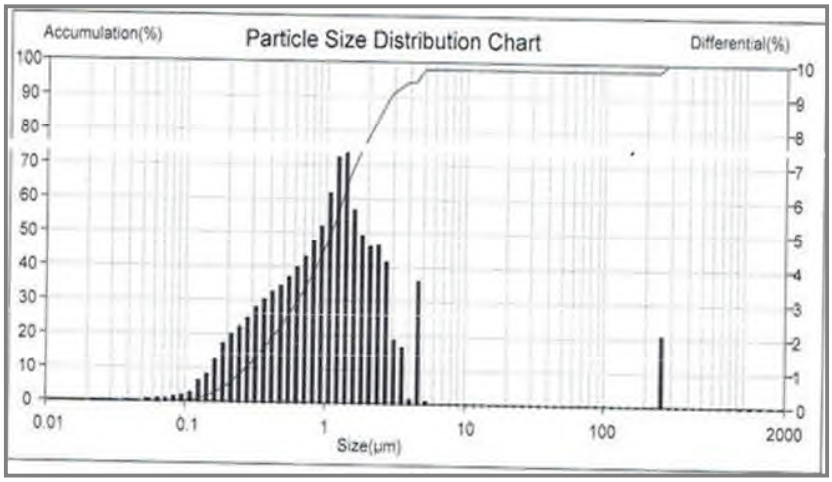

Figure (2) Particle size analyzer of micro silicon dioxide

X-ray diffraction

X-Ray Diffraction (XRD) used to find crystalline phases for the nano and micro powder materials. Figure (3 a and b) Shows the X- Ray Diffraction pattern confirmed that high intensities of Sharpe peaks could be obtained indicating a high Crystalline in the synthesized powder. All peaks could be indexed to a cubic structure for nano SiO_2 and (tetragonal) structure for micro SiO_2.

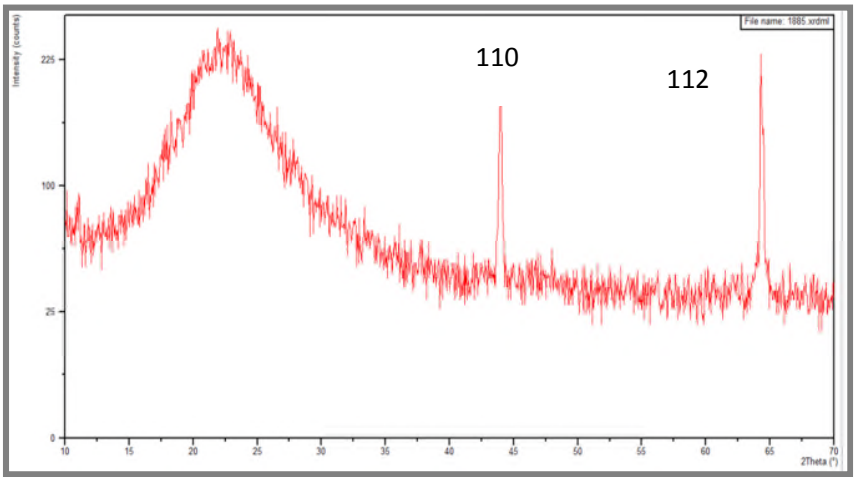

Figure (3) (a) X- Ray Diffraction of nano Silicon dioxide powder

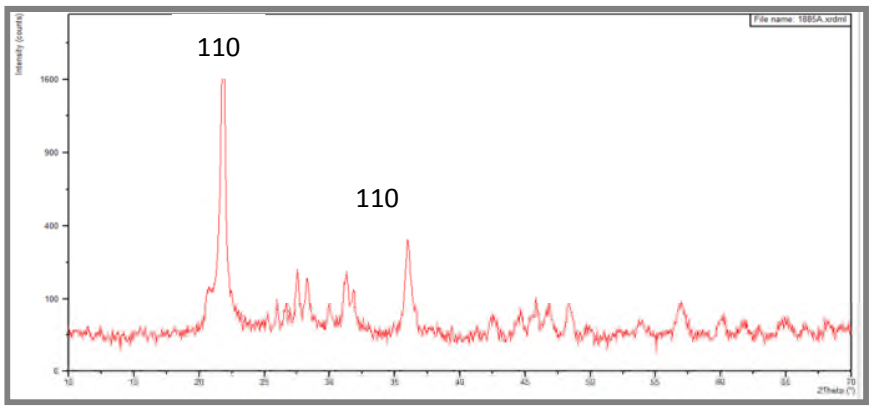

Figure (3) (b) X- Ray Diffraction of micro Silicon dioxide powder

Hardness test

This test is performed by using hardness (Shore D) and according to (ASTM DI-2240) standard at room temperature. Samples have been cut into a diameter of (40mm) and a thickness of (5mm). Figure (4) shows standard specimens for this test [8]. Figure (10) shows hardness device used in this research. For each specimen five hardness measurements were taken and the average hardness is calculated**.**

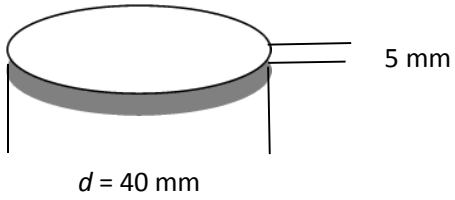

Figure (4): Hardness (Shore D) standard specimens [10].

Erosion wear test

This test is performed according to (ASTM G76) at room temperature [9, 10]. Samples have been cut into a diameter of (40mm) and a thickness of (5mm). Figure (6) shows standard specimens for erosion wear [11].The used device for erosion is locally manufactured; the Perspex tank has a dimensions of (40) cm in length, (20) cm in height, and (20) cm in width. the pump joints and valves connected to the chamber are made from steel and slurry as well as jet nozzle. The distance between the nozzle and the sample tube are (20, 25, 30) cm, pump diameter is (40) mm and the nozzle diameter (5mm). Erosion tests are performed by changing the angle between the fluid flow and the horizontal axis of the test specimen (α), at three levels (90°, 60°, 30°). It is operating flow

rate (35 L⁄min).The fluid used in the erosion tests are sand water contains a solid particles of abrasives with different sizes (425, 600,800) μm. In this work, an orthogonal array of the type (L_{18}) has been chosen since there are eight factors (variables) and three levels [12].During the erosion wear test, eight test factors for each type of composites are considered, these are: (1) Test time; (2) Reinforcement volume fraction; (3) Stand-off distance; (4) angle; (5) grin size ;(6) Temperature; (7) salt content; and (8) water content each at three levels,

Results and discussion

Hardness shore (d)

Hardness test type (Shore (D)) has been carried out on pure Epoxy before and after glass fiber and powder fillers were added and the average of five readings in each case was taken to obtain higher accuracy results.

Table (1) shows the values of hardness for the prepared (Pure Epoxy, Epoxy +3% glass fiber and nano) composites.

From figure (10) that can be noticed a pronounced effect of the addition of 3% glass fiber volume fraction percents on the hardness of the material. The addition of the fiber leads to an increase in the elasticity and a decrease in the matrix surface resistance to the indentation, thus specimen (Epoxy +3%G.F) have higher hardness than specimen (pure epoxy).And can be seen from figure a pronounced effect of the addition of 3% glass fiber with 2%, 4%and 6% volume fraction from (nano and micro powder) percents on the hardness of the material. Also can be seen that the hardness increases with increasing volume fraction. Adding the filler particles will raise the materials hardness due to increasing in material resistance against the plastic deformation. Result had revealed that the hardness of pure epoxy alone was (77 shore D) compared to maximum value of nanocomposite (84) at volume fraction of (6% SiO_2) with particle size is (38nm) and maximum value of microcomposites (82.2) at volume fraction of (6% SiO_2) with particle size is (6.069 μm) The reason of the increase in hardness is that SiO_2 contains an elements harder than the pure epoxy that lead to an increase in hardness.

Table (1): Hardness shore (D) of nano and micro composites.

Types of composite	Hardness Shore (D)
Epoxy	77
Epoxy +3% Glass fiber	78
(Nano Composites)	
Epoxy+3%GF+2% SiO_2	81
Epoxy+3%GF+4% SiO_2	83
Epoxy+3%GF+6% SiO_2	84
(Micro Composites)	
Epoxy+3%GF+2% SiO_2	79
Epoxy+3%GF+4% SiO_2	81
Epoxy+3%GF+6% SiO_2	82.2

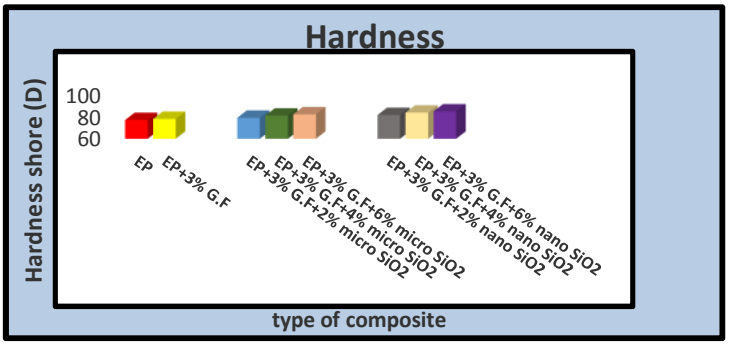

Figure (5): Hardness shore (D) of nano and micro composite.

Erosion wear

The results of erosion wear for the pure Epoxy and nano-based materials composites are illustrated in tables (1) to (3) and micro-based materials composites illustrate in tables (4) to 6)**.** Particle impingement produces rise in temperature of the surface which makes the matrix deformation easy because the high temperature known to occur in solid particle erosion invariably soften the matrix [13].

On impact the erodent particle kinetic energy is transferred to the composite body that leads to crater formation and subsequently material loss [14]. The results show, the nano-based materials composites give the lower erosion wear when they are compared with the epoxy, epoxy+3% G.F and micro-based materials composite. The reason is that the presence of reinforcement and filler powder in the matrix helps in absorbing the kinetic energy produced by the impacted erodent particles and therefore making the energy available for the plastic deformation of the matrix to become less [14].It is clear from these Tables that addition of powder fillers significantly reduces the rate of material loss. The reduction in material loss in particle filled composites can be attributed to improvement in the bulk hardness of the composite with addition of industrial powder and absorption of good amount of kinetic energy associated with the erodent by the filler powder. From the Tables (2),(3),(4) and Figure (6) it can be noticed that a pronounced effect of the addition of 3% glass fiber with 6% volume frication from (nano powder) percents on the erosion wear ,also can seen the specimen (Epoxy +3% Glass Fiber +6% SiO_2) give better erosion resistance than the composites filled with (2% SiO_2 and 4% SiO_2) at 15 hour) time , (30 cm) stand-off distance, (60˚) angle, (425µm) grin size of sand ,(30Ċ) temperature, (350 gm) salt content in (2 liter) water content.

From the Tables (5),(6),(6) and Figures (6) it is clear that there is a pronounced effect of the addition of 3% glass fiber with 6% volume frication from (micro powder) percents on the erosion wear ,it can noticed the specimens (Epoxy +3% Glass Fiber +6% SiO_2) give better erosion resistance than the composites filled with (2% SiO_2 and 4% SiO_2) at (15 hour) time , (30 cm) stand-off distance, (60˚) angle, (425µm) grin size of sand ,(30Ċ) temperature, (350 gm) salt content in (2 liter) water content. Which may be related to its lower grain size with a good distribution and bonding. Therefore, the observed values of erosion wear rate for second group (micro-particles) composite specimens are higher than values of first group (nano-particles) composite specimens. This is due to the erosion

wear rate increase with increasing particle size of the filler particles. Thus, erosion wear rate values decreased from (0.0068) for micro- SiO_2 composite to (0.00004) for nano-SiO_2 composite.

Thermoplastic matrix composites usually show ductile erosion while the thermosetting ones erode in a brittle manner. Thus the erosion wear behavior of polymer composites can be grouped into ductile and brittle categories although this grouping is not definitive because the erosion characteristics equally depend on the experimental conditions as on composition of the target material [14].The angle of impingement is usually defined as the angle between the eroded surface and the trajectory of the particle immediately before impact [15]. The state that the impingement angle is one of the most important parameters in the erosion process and for ductile materials the peak erosion occurs at 15° to 20° angle while for brittle materials the erosion damage is maximum usually at normal impact i.e. 90° angle and the loss of ductility may be attributed to incorporation of brittle fiber and particles [14]. In the present study the results show the peak erosion taking place at an impact angle of 30°.This clearly indicates that these industrial-based materials composites respond to solid particle erosion not in neither a purely ductile nor a purely brittle manner. This behavior can be termed as semi-ductile in nature. The loss of ductility may be attributed to the incorporation of glass fibers and industrial powder both of which are brittle, therefore the used glass fiber and filler (nano SiO_2) they give the lower erosion wear rate at an impact angle of 60°.This indicates that bonding in between composite constituents is also an important factor in determining and giving lower erosion

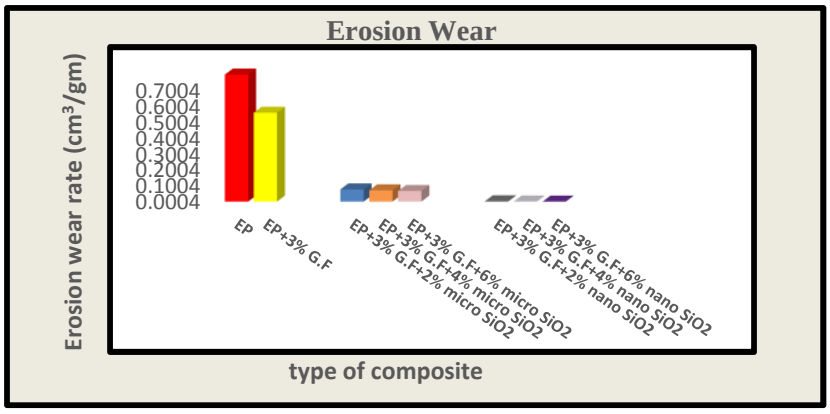

Figure (6): erosion wear rate of nano and micro composites at 15hr.

Morphology test

The changes in surface morphology were taken for the higher resistance specimens before and after erosion wear at time15 hour. Figure (7) (a) and (b) shows the SEM of the (epoxy+3% glass fiber) before and after erosion wear. From (7)(b) indicates unfilled glass fiber composite which depicts local removal of resin materials from the impacted surface which results exposure and damage of the fibers to the erosive environment.

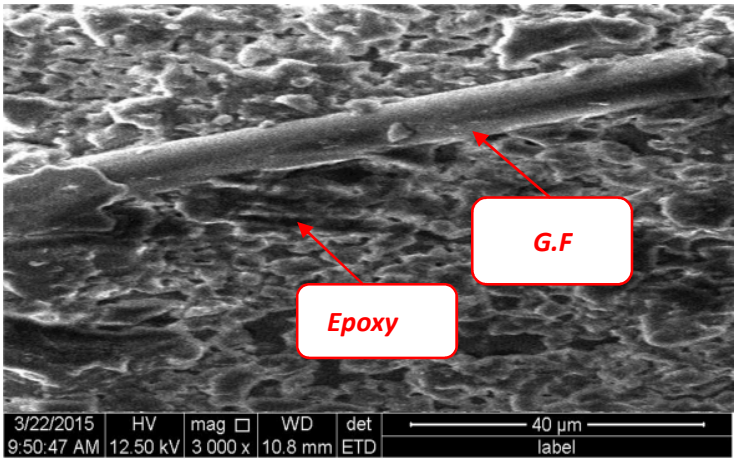

Figure (7) (a): SEM image of (epoxy+3%glass fiber) before erosion test

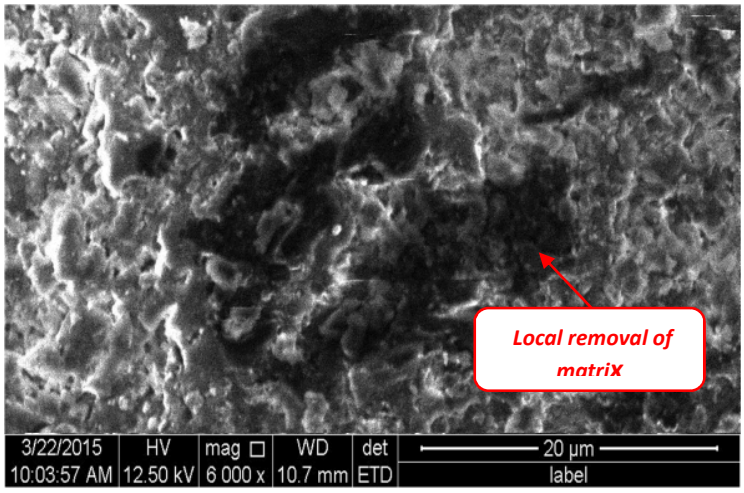

Figure (7) (b): SEM image of (epoxy+3% glass fiber) after erosion test at time 15hr

Figure (8) (a) and (b) shows the SEM of (epoxy+3% glass fiber+6% nano-SiO_2) before and after erosion wear. From figure (8) (a) that there is a clear agglomeration of silica particles with fibers in the matrix of epoxy and this indicates that the composite materials is strong enough. While the shape of sample after the erosion process for time15 hour shows a slight change in the sample and this indicates that nano silica with fibers decrease the erosion rate.

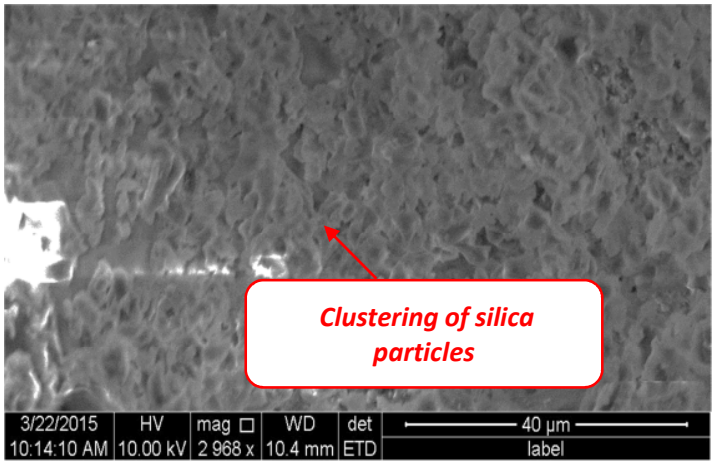

Figure (8) (a): SEM image of (epoxy+3% glass fiber+6%nano-SiO_2) Before erosion test

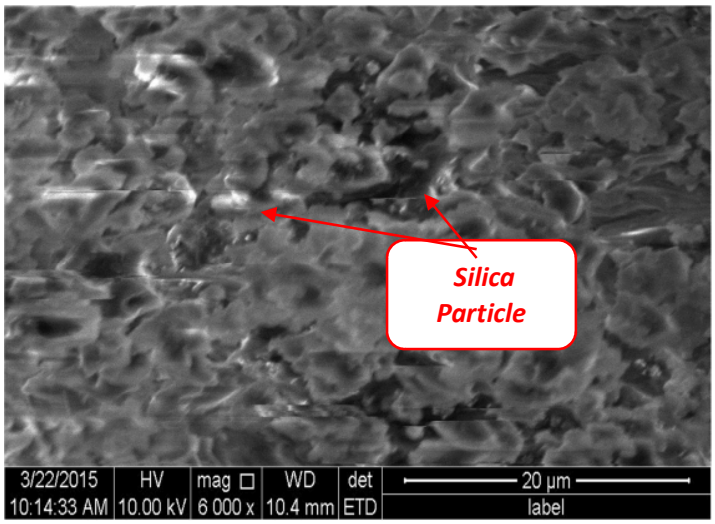

Figure (8) (b): SEM image of (epoxy+3% glass fiber+6% nano-SiO_2) After erosion test at time 15 hr.

CONCLUSION

1.The hardness of Nano composites have higher value than micro composites. Hardness increase with the increase in the volume fraction of the reinforcing fillers.

2.The Nano composite gives the lower erosion wear than micro composites. Nano composite (epoxy+3% glass fiber+6% nano SiO_2) give better erosion resistance at (30 cm) stand – off distance , (60^0) angle , (425 µm) grain size of sand , (30 Ċ) temperature , (350 gm) salt content in (2 liter) of water and (15 hour) time.

Table (5-5) Erosion wear of pure epoxy, epoxy +3% glass fiber and Epoxy +3%glass fiber +2% Nano SiO_2

Experiment	*Time (hour)*	*Filler content*	*Stand-off distance (cm)*	*Angle (Θ)*	*grin size (sand) (μ m)*	*Temperature (C)*	*Salt content (gm)*	*Water content (ml)*	*Total weight (WS) (gm)*	*Weight after erosion (WL) (gm)*	*Erosion rate (€) $W_L/W_S*\rho_t$ (cm^3/gm)*
1	10	Pure epoxy	20	30°	425 μ m	25	150	2	7.4567	6.8769	0.074
2	10	Pure epoxy	25	60°	600 μ m	30	250	2.5	7.4567	6.8540	0.076
3	10	Pure epoxy	30	90°	850 μ m	35	350	3	7.4567	6.8430	0.078
4	10	Epoxy+3% GF	20	30°	600 μ m	30	350	3	7.7963	7.4173	0.045
5	10	Epoxy+3% GF	25	60°	850 μ m	35	150	2	7.7963	7.4068	0.046
6	10	Epoxy+3% GF	30	90°	425 μ m	25	250	2.5	7.7963	7.5066	0.034
7	10	Epoxy+3%GF+ 2%Nano SiO_2	20	60°	425 μ m	35	250	3	8.1610	8.1500	0.0012
8	10	Epoxy+3%GF+ 2% Nano SiO_2	25	90°	600 μ m	25	350	2	8.1610	8.1487	0.0013
9	10	Epoxy+3%GF+ 2% Nano SiO_2	30	30°	850 μ m	30	150	2.5	8.1610	8.1454	0.0017
10	15	Pure epoxy	20	90°	850 μ m	30	250	2	7.4567	6.7675	0.088
11	15	Pure epoxy	25	30°	425 μ m	35	350	2.5	7.4567	6.7890	0.085
12	15	Pure epoxy	30	60°	600 μ m	25	150	3	7.4567	6.7785	0.086
13	15	Epoxy+3% GF	20	60°	850 μ m	25	350	2.5	7.7963	7.2843	0.060
14	15	Epoxy+3% GF	25	90°	425 μ m	30	150	3	7.7963	7.3173	0.056
15	15	Epoxy+3% GF	30	30°	600μ m	35	250	2	7.7963	7.3071	0.058
16	15	Epoxy+3%GF+ 2% Nano SiO_2	20	90°	600 μ m	35	150	2.5	8.1610	8.1402	0.0022
17	15	Epoxy+3%GF+ 2% Nano SiO_2	25	30°	850 μ m	25	250	3	8.1610	8.1398	0.0023
18	15	Epoxy+3%GF+ 2% Nano SiO_2	30	60°	425 μ m	30	350	2	8.1610	8.1440	0.0018

Table (2) Erosion wear of pure epoxy, epoxy +3% glass fiber and Epoxy +3%glass fiber +4% Nano SiO

Experiment	Time (hour)	Filler content	Stand-off distance (cm)	Angle (Θ)	grin size (sand) (μ m)	Temperature (C)	Salt content (gm)	Water content (ml)	Total weight (WS) (gm)	Weight after erosion (WL) (gm)	Erosion rate (€) $W_L/W_S*\rho_t$ (cm^3/gm)
1	10	Pure epoxy	20	30°	425 μ m	25	150	2	7.4567	6.8769	0.074
2	10	Pure epoxy	25	60°	600 μ m	30	250	2.5	7.4567	6.8540	0.076
3	10	Pure epoxy	30	90°	850 μ m	35	350	3	7.4567	6.8430	0.078
4	10	Epoxy+3% GF	20	30°	600 μ m	30	350	3	7.7963	7.4173	0.045
5	10	Epoxy+3% GF	25	60°	850 μ m	35	150	2	7.7963	7.4068	0.046
6	10	Epoxy+3% GF	30	90°	425 μ m	25	250	2.5	7.7963	7.5066	0.034
7	10	Epoxy+3%GF+ 4%Nano SiO_2	20	60°	425 μ m	35	250	3	8.2920	8.2910	0.0001
8	10	Epoxy+3%GF+ 4% Nano SiO_2	25	90°	600 μ m	25	350	2	8.2920	9.2890	0.0003
9	10	Epoxy+3%GF+ 4% Nano SiO_2	30	30°	850 μ m	30	150	2.5	8.2920	8.2881	0.0004
10	15	Pure epoxy	20	90°	850 μ m	30	250	2	7.4567	6.7675	0.088
11	15	Pure epoxy	25	30°	425 μ m	35	350	2.5	7.4567	6.7890	0.085
12	15	Pure epoxy	30	60°	600 μ m	25	150	3	7.4567	6.7785	0.086
13	15	Epoxy+3% GF	20	60°	850 μ m	25	350	2.5	7.7963	7.2843	0.060
14	15	Epoxy+3% GF	25	90°	425 μ m	30	150	3	7.7963	7.3173	0.056
15	15	Epoxy+3% GF	30	30°	600μ m	35	250	2	7.7963	7.3071	0.058
16	15	Epoxy+3%GF+ 4% Nano SiO_2	20	90°	600 μ m	35	150	2.5	8.2920	8.2861	0.0006
17	15	Epoxy+3%GF+ 4% Nano SiO_2	25	30°	850 μ m	25	250	3	8.2920	8.2852	0.0007
18	15	Epoxy+3%GF+ 4% Nano SiO_2	30	60°	425 μ m	30	350	2	8.2920	8.2870	0.0005

Table (3) Erosion wear of pure epoxy, epoxy +3% glass fiber and Epoxy +3%glass fiber +6% Nano SiO_2

Experiment	Time (hour)	Filler content	Stand-off distance (cm)	Angle (θ)	grin size (sand) (μ m)	Temperature (C)	Salt content (gm)	Water content (ml)	Total weight (WS) (gm)	Weight after erosion (WL) (gm)	Erosion rate (€) $W_L/W_S*\rho_t$ (cm^3/gm)
1	10	Pure epoxy	20	30°	425 μ m	25	150	2	7.4567	6.8769	0.074
2	10	Pure epoxy	25	60°	600 μ m	30	250	2.5	7.4567	6.8540	0.076
3	10	Pure epoxy	30	90°	850 μ m	35	350	3	7.4567	6.8430	0.078
4	10	Epoxy+3% GF	20	30°	600 μ m	30	350	3	7.7963	7.4173	0.045
5	10	Epoxy+3% GF	25	60°	850 μ m	35	150	2	7.7963	7.4068	0.046
6	10	Epoxy+3% GF	30	90°	425 μ m	25	250	2.5	7.7963	7.5066	0.034
7	10	Epoxy+3%GF+ 6%Nano SiO_2	20	60°	425 μ m	35	250	3	8.3145	8.3144	0.00001
8	10	Epoxy+3%GF+ 6% Nano SiO_2	25	90°	600 μ m	25	350	2	8.3145	8.3143	0.00002
9	10	Epoxy+3%GF+ 6% Nano SiO_2	30	30°	850 μ m	30	150	2.5	8.3145	8.3142	0.00003
10	15	Pure epoxy	20	90°	850 μ m	30	250	2	7.4567	6.7675	0.088
11	15	Pure epoxy	25	30°	425 μ m	35	350	2.5	7.4567	6.7890	0.085
12	15	Pure epoxy	30	60°	600 μ m	25	150	3	7.4567	6.7785	0.086
13	15	Epoxy+3% GF	20	60°	850 μ m	25	350	2.5	7.7963	7.2843	0.060
14	15	Epoxy+3% GF	25	90°	425 μ m	30	150	3	7.7963	7.3173	0.056
15	15	Epoxy+3% GF	30	30°	600μ m	35	250	2	7.7963	7.3071	0.058
16	15	Epoxy+3%GF+ 6% Nano SiO_2	20	90°	600 μ m	35	150	2.5	8.3145	8.3140	0.00005
17	15	Epoxy+3%GF+ 6% Nano SiO_2	25	30°	850 μ m	25	250	3	8.3145	8.3139	0.00006
18	15	Epoxy+3%GF+ 6% Nano SiO_2	30	60°	425 μ m	30	350	2	8.3145	8.3141	0.00004

Table (4) Erosion wear of pure epoxy, epoxy +3% glass fiber and Epoxy +3%glass fiber +2% Micro SiO_2

Experiment	*Time (hour)*	*Filler content*	*Stand-off distance (cm)*	*Angle (θ)*	*grin size (sand) (μ m)*	*Temperature (C)*	*Salt content (gm)*	*Water content (ml)*	*Total weight (WS) (gm)*	*Weight after erosion (WL) (gm)*	*Erosion rate (€) $W_L/W_S*\rho_t$ (cm^3/gm)*
1	10	Pure epoxy	20	30°	425 μ m	25	150	2	7.4567	6.8769	0.074
2	10	Pure epoxy	25	60°	600 μ m	30	250	2.5	7.4567	6.5540	0.076
3	10	Pure epoxy	30	90°	850 μ m	35	350	3	7.4567	6.8430	0.078
4	10	Epoxy+2% GF	20	30°	600 μ m	30	350	3	7.7963	7.4173	0.045
5	10	Epoxy+3% GF	25	60°	850 μ m	35	150	2	7.7963	7.4068	0.046
6	10	Epoxy+3% GF	30	90°	425 μ m	25	250	2.5	7.7963	7.5066	0.034
7	10	Epoxy+3%GF+ 2%Micro SiO_2	20	60°	425 μ m	35	250	3	8.4767	8.4107	0.0068
8	10	Epoxy+3%GF+ 2% Micro SiO_2	25	90°	600 μ m	25	350	2	8.4767	8.4095	0.0069
9	10	Epoxy+3%GF+ 2% Micro SiO_2	30	30°	850 μ m	30	150	2.5	8.4767	8.4084	0.0070
10	15	Pure epoxy	20	90°	850 μ m	30	250	2	7.4567	6.7675	0.088
11	15	Pure epoxy	25	30°	425 μ m	35	350	2.5	7.4567	6.7890	0.085
12	15	Pure epoxy	30	60°	600 μ m	25	150	3	7.4567	6.7785	0.086
13	15	Epoxy+2% GF	20	60°	850 μ m	25	350	2.5	7.7963	7.2843	0.060
14	15	Epoxy+3% GF	25	90°	425 μ m	30	150	3	7.7963	7.3173	0.056
15	15	Epoxy+3% GF	30	30°	600μ m	35	250	2	7.7963	7.3071	0.058
16	15	Epoxy+3%GF+ 2% Micro SiO_2	20	90°	600 μ m	35	150	2.5	8.4767	8.4007	0.0078
17	15	Epoxy+3%GF+ 2% Micro SiO_2	25	30°	850 μ m	25	250	3	8.4767	8.3992	0.0080
18	15	Epoxy+3%GF+ 2% Micro SiO_2	30	60°	425 μ m	30	350	2	8.4767	8.4017	0.0077

Table (5) Erosion wear of pure epoxy, epoxy +3% glass fiber and Epoxy +3%glass fiber +4% Micro SiO_2

Experiment	*Time (hour)*	*Filler content*	*Stand-off distance (cm)*	*Angle (Θ)*	*grin size (sand) (μ m)*	*Temperature (C)*	*Salt content (gm)*	*Water content (ml)*	*Total weight (WS) (gm)*	*Weight after erosion (WL) (gm)*	*Erosion rate (€) $W_L/W_S*\rho_t$ (cm^3/gm)*
1	10	Pure epoxy	20	30°	425 μ m	25	150	2	7.4567	6.8769	0.074
2	10	Pure epoxy	25	60°	600 μ m	30	250	2.5	7.4567	6.8540	0.076
3	10	Pure epoxy	30	90°	850 μ m	35	350	3	7.4567	6.8430	0.078
4	10	Epoxy+3% GF	20	30°	600 μ m	30	350	3	7.7963	7.4173	0.045
5	10	Epoxy+3% GF	25	60°	850 μ m	35	150	2	7.7963	7.4068	0.046
6	10	Epoxy+3% GF	30	90°	425 μ m	25	250	2.5	7.7963	7.5066	0.034
7	10	Epoxy+3%GF+ 4%Micro SiO_2	20	60°	425 μ m	35	250	3	8.5837	8.5187	0.0063
8	10	Epoxy+3%GF+ 4% Micro SiO_2	25	90°	600 μ m	25	350	2	8.5837	8.5175	0.0064
9	10	Epoxy+3%GF+ 4% Micro SiO_2	30	30°	850 μ m	30	150	2.5	8.5837	8.5165	0.0065
10	15	Pure epoxy	20	90°	850 μ m	30	250	2	7.4567	6.7675	0.088
11	15	Pure epoxy	25	30°	425 μ m	35	350	2.5	7.4567	6.7890	0.085
12	15	Pure epoxy	30	60°	600 μ m	25	150	3	7.4567	6.7785	0.086
13	15	Epoxy+3% GF	20	60°	850 μ m	25	350	2.5	7.7963	7.2843	0.060
14	15	Epoxy+3% GF	25	90°	425 μ m	30	150	3	7.7963	7.3173	0.056
15	15	Epoxy+3% GF	30	30°	600μ m	35	250	2	7.7963	7.3071	0.058
16	15	Epoxy+3%GF+ 4% Micro SiO_2	20	90°	600 μ m	35	150	2.5	8.5837	8.5086	0.0072
17	15	Epoxy+3%GF+ 4% Micro SiO_2	25	30°	850 μ m	25	250	3	8.5837	8.5077	0.0073
18	15	Epoxy+3%GF+ 4% Micro SiO_2	30	60°	425 μ m	30	350	2	8.5837	8.5095	0.0071

Table (6) Erosion wear of pure epoxy, epoxy +3% glass fiber and Epoxy +3%glass fiber +6% Micro SiO_2

Experiment	*Time (hour)*	*Filler content*	*Stand-off distance (cm)*	*Angle (Θ)*	*grin size (sand) (μ m)*	*Temperature (C)*	*Salt content (gm)*	*Water content (ml)*	*Total weight (WS) (gm)*	*Weight after erosion (WL) (gm)*	*Erosion rate (€) $W_L/W_S*\rho_t$ (cm^3/gm)*
1	10	Pure epoxy	20	30°	425 μ m	25	150	2	7.4567	6.8769	0.074
2	10	Pure epoxy	25	60°	600 μ m	30	250	2.5	7.4567	6.8540	0.076
3	10	Pure epoxy	30	90°	850 μ m	35	350	3	7.4567	6.8430	0.078
4	10	Epoxy+3% GF	20	30°	600 μ m	30	350	3	7.7963	7.4173	0.045
5	10	Epoxy+3% GF	25	60°	850 μ m	35	150	2	7.7963	7.4068	0.046
6	10	Epoxy+3% GF	30	90°	425 μ m	25	250	2.5	7.7963	7.5066	0.034
7	10	Epoxy+3%GF+ 6%Micro SiO_2	20	60°	425 μ m	35	250	3	8.6987	8.6345	0.0059
8	10	Epoxy+3%GF+ 6% Micro SiO_2	25	90°	600 μ m	25	350	2	8.6987	8.6336	0.0060
9	10	Epoxy+3%GF+ 6% Micro SiO_2	30	30°	850 μ m	30	150	2.5	8.6987	8.6327	0.0061
10	15	Pure epoxy	20	90°	850 μ m	30	250	2	7.4567	6.7675	0.088
11	15	Pure epoxy	25	30°	425 μ m	35	350	2.5	7.4567	6.7890	0.085
12	15	Pure epoxy	30	60°	600 μ m	25	150	3	7.4567	6.7785	0.086
13	15	Epoxy+3% GF	20	60°	850 μ m	25	350	2.5	7.7963	7.2843	0.060
14	15	Epoxy+3% GF	25	90°	425 μ m	30	150	3	7.7963	7.3173	0.056
15	15	Epoxy+3% GF	30	30°	600μ m	35	250	2	7.7963	7.3071	0.058
16	15	Epoxy+3%GF+ 6% Micro SiO_2	20	90°	600 μ m	35	150	2.5	8.6987	8.6247	0.0068
17	15	Epoxy+3%GF+ 6% Micro SiO_2	25	30°	850 μ m	25	250	3	8.6987	8.6237	0.0069
18	15	Epoxy+3%GF+ 6% Micro SiO_2	30	60°	425 μ m	30	350	2	8.6987	8.6255	0.0067

REFERENCES

[1]. Z.U.Haque and D.T.Turner, "Influence of Particulate Fillers on the indention Hardness of a Glassy cross-Linked Polymer",J.of Materials Science, ,(1987),Vol.22,P.3379.

[2].Hussain, M., Oku, Y., Nakahira, A., Niihara, K,." Effects of wet ball milling on particle dispersion and mechanical properties of particulate epoxy composites", Material. (1996)Letters, 26:177-184.

[3].Zhang, Man., "A Review of the Epoxy Resin Toughening", Syracuse University, New York, (2003).

[4].SUBHRAJIT,"process and characterization of titinia filled epoxy –glass fiber composites" .MSc-thesis, department of mechanical engineering, National institute of technology (2009).

[5].Dean D., Walker R., Theodore M., Hampton E., Nyairo E, "Chemorheology and properties of epoxy/layered silicate nanocomposites", Polymer. (2005) Vol. 46, p. 3014 .

[6].Bagci M., Imrek H., and Omari M. Khalfan " Effects of Silicon Oxide Filler Material and Fibre Orientation on Erosive Wear of GF/EP Composites " , World Academy of Science, Engineering and Technology , Vol.54 , PP.976-980 ,(2011) .

[7].Barkoula N.-M. and Karger-Kocsis J. " Solid Particle Erosion of Unidirectional GF Reinforced EP Composites with Different Fiber/Matrix Adhesion " , Journal of Reinforced Plastics and Composites , No. 15 ,Vol. 21, PP.1377-1387 , (2002) , (doi: 10.1106/07316840203779) .

[8].Annual Book of ASTM Standard "Standard Test Method for Plastics Properties-Durometer Hardness D 2240", Vol. 09.01, (1988).

[9].Anu Gupta, Ajit Kumar, Amar Patnaik, Sandhyarani Biswas ," Effect of Filler Content and Alkalization on Mechanical and Erosion Wear Behavior of CBPD Filled Bamboo Fiber Composites", Journal of Surface Engineered Materials and Advanced Technology, No.2 ,PP.149-157 , (2012) , (doi.org/10.4236/jsemat.2012.23024) .

[10].Sandhyarani Biswas "Erosion Wear Behaviour of Copper Slag Filled Short BambooFiber Reinforced Epoxy Composites ", Mechanical Engineering Department, National Institute of Technology, Rourkela, India ,(2012) .

[11].Annual Book of ASTM Standard, "Standard Practice for Conducting Erosion Tests by Solid Particle Impingement Using Gas Jet", G 76-83), Vol. 03.02, (1988).

[12].Shyam Kumar Karna, Dr. Ran Vijay Singh, Dr. Rajeshwar Sahai" Application of Taguchi Method in Indian Industry", Issue11, Vol. 2,PP.389, November (2012).

[13].Tewari U.S., Harsha A.P., Häger A.M. & Friedrich K.," Solid particle erosion of unidirectional carbon fiber reinforced polyetheretherketone composites", Wear Elsevier, Issue 11-12, Vol.252 ,PP. 992-1000,(2002), (doi:10.1016/S0043-1648(02)00063-7).

[14].Patnaik A., Satapathy A. & Mahapatra S. S., "Implementation of Taguchi method for tribo-performance of hybrid composites", Dep. of mechanical Eng., National Institute of Technology, Rourkela, PP. 779- 788, (2007).

[15].Tewari U.S , Harsha A.P. , Hager A.M. ,Friedrich K." Solid particle erosion of carbon fiber- and glass fiber-epoxy composites", composites Science and Technology, Vol.63, pp.549-557 (2003).