Erosion Wear and Hardness of Glass Fiber / Epoxy with Nano and Micro TiO_2 Hybride Composites

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Abstract

The objective of this research is to prepare and study (Glass Fiber / Epoxy) with nano and micro Titanium dioxide (TiO_2) composites with different volume percentage of nano and micro TiO_2 powder of 2%, 4%, and 6% volume fraction. Atomic force microscopy techniques was used to measure the grain size of nano TiO_2 powder (average diameter was 46 nm) and particle size analyzer techniques was used. Erosive wear behavior of this composite under three different impingement angles of 30°, 60° and 90° and three angular silica sand abrasive particle sizes approximately 425, 600 and 850 μm and hardness (shore D) were studied. In general the erosion wear of micro composites have lower erosion resistance than other nano-based compounds. Erosion resistance increase as the volume fraction increase. Nano composites of GF / EP with TiO_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 TiO_2 filled composites. [DOI: 10.22401/ANJS.00.1.06]

Keywords: GF / EP, TiO_2 composites, erosion wear, shore hardness.

1. 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, and soon. 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 and Karger, (2002) have studied the influence of interfacial modification and relative fiber orientation (parallel, Pa and perpendicular, Pe) on the solid particle 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 of (30°, 60° and 90°).The results showed 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 particles erosion, [6].

In the present study, composites were prepared by Hand lay-up molding the composites constituents were epoxy resin as a matrix, 6% volume fractions of Glass Fibers (G.F) as reinforcement and 3%, 6% volume fractions of preparation industrial powder (calcium carbonate $CaCO_3$, potassium carbonate K_2CO_3 or sodium carbonate Na_2CO_3) as filler. The erosion wear behavior and coating by natural wastes (Rice Husk Ash) with epoxy resin after erosion were studied. The results showed that the non– reinforced epoxy have lower resistance erosion than industrial based Material composites and the specimen (Epoxy+6%glass fiber+6% $CaCO_3$) has higher resistance erosion than composites reinforced with sodium carbonate and potassium carbonate at 25cm, angle 30°, grin size of sand 850 µm, temperature 25 ^oC, 200 gm salt content in 3 liter of water and 15 hour. Coating specimen with mixed epoxy resin-RHA with particles size in the range (1.4-4.2) µm improves erosion wear resistance characteristics of the coated specimen, coating thickness was (16 ± 1) µm and after erosion in (15 hours) the thickness was (10) µm. Application of the work protection of pipes from erosion, these pipes include the sewage water, drainage pipe laboratory (hot water, chemicals and mineral oil), pipeline transportation of petroleum products and pipeline transportation of gas products, [7].

2. Experimental work

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 Epoxy (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 nano and micro TiO_2 to form nano and micro composites with three different weight percentage of TiO_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.

3. Results and discussions

a. Atomic Force Microscopic (AFM):

The grain size of nano titanium dioxide is 46nm was examined with an atomic force microscopy, a powerful tool for surface imaging at the nanometer to sub micrometer. Diameter is found for nano TiO_2 with Atomic Force Microscopic average as shown in Fig.(1).

b. Particle size analysis

The grain size of micro titanium dioxide is 0.346µm was examined with Particle size analyzer device. TiO_2 with average size is shown in Fig.(2).

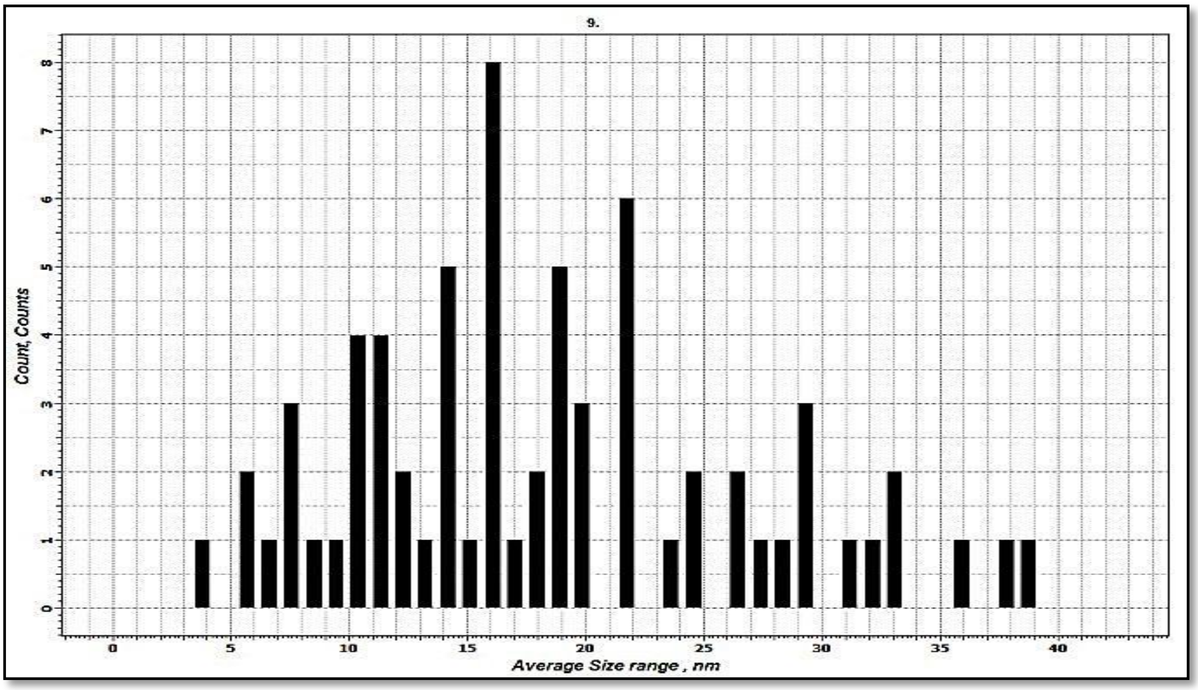


Fig.(1) AFM of nano titanium dioxide.

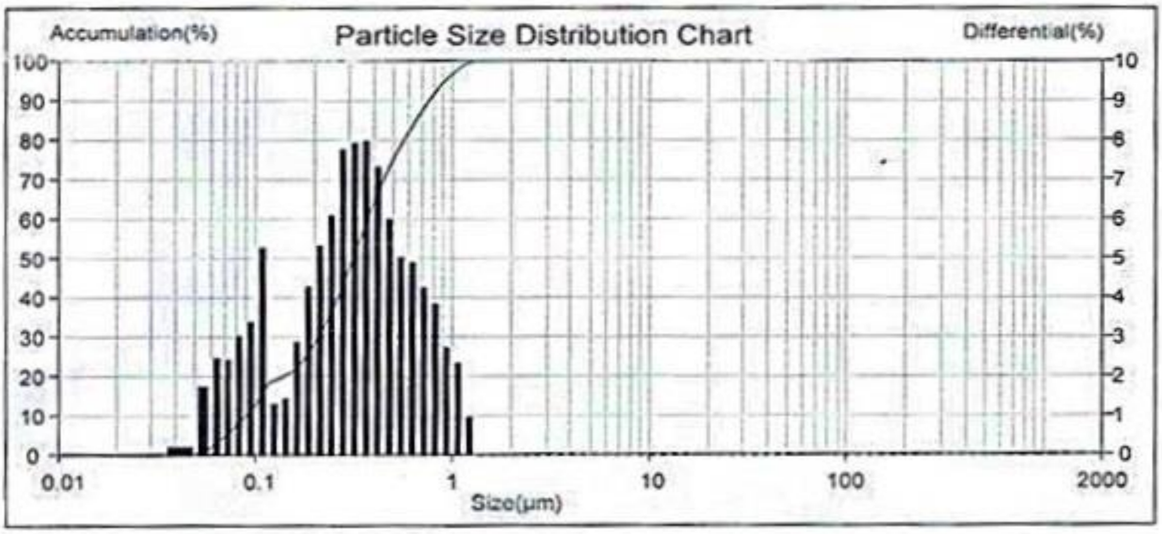


Fig.(2) Particle size analyzer of micro Tritium dioxide.

c. X-ray diffraction:

X-Ray Diffraction (XRD) used to find crystalline phases for the nano and micro powder materials. Fig.(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 tetragonal structure for nano TiO2 [8] and (tetragonal) structure for micro TiO2, [9].

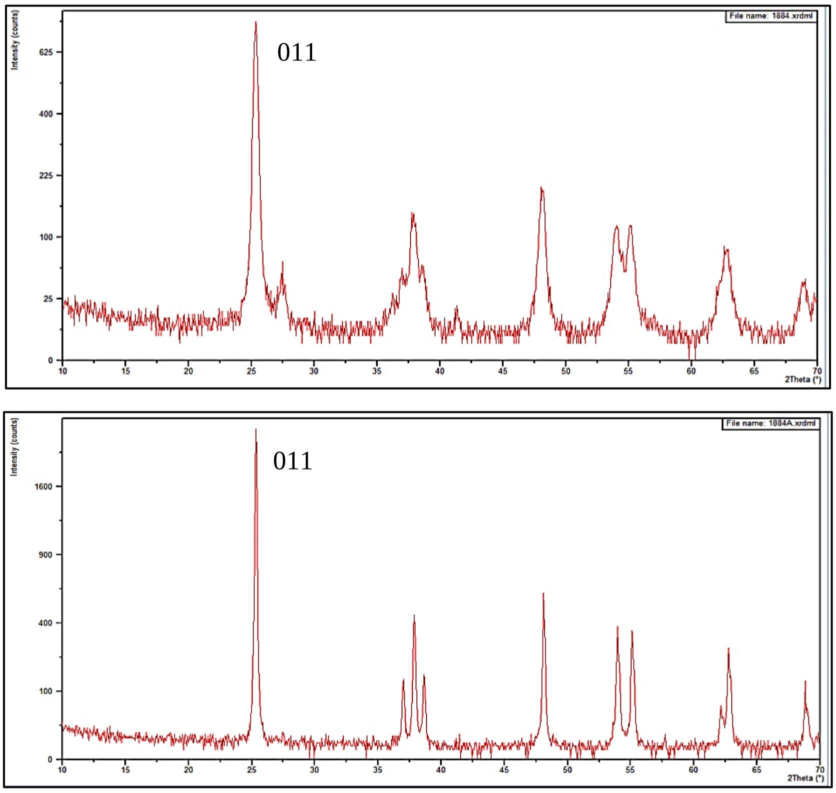


Fig.(3) (a) X-Ray Diffraction of titanium dioxide nano-powder (b) X-Ray Diffraction of Titanium dioxide micro-powder.

d. 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 (5 mm). For each specimen five hardness measurements were taken and the average hardness is calculated. 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 with nano and micro composites. 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). 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 nano composite (83.9) at volume fraction of (6% TiO_2) with particle size is (46nm) and maximum value of micro composites (83.2) at volume fraction of (6% TiO_2) with particle size is (0.346μm) The reason of the increase in hardness is that TiO_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% TiO_2	80.5
Epoxy+3%GF+4% TiO_2	82.7
Epoxy+3%GF+6% TiO_2	83.9
(Micro Composites)	
Epoxy+3%GF+2% TiO_2	80.4
Epoxy+3%GF+4% TiO_2	82
Epoxy+3%GF+6% TiO_2	83.2

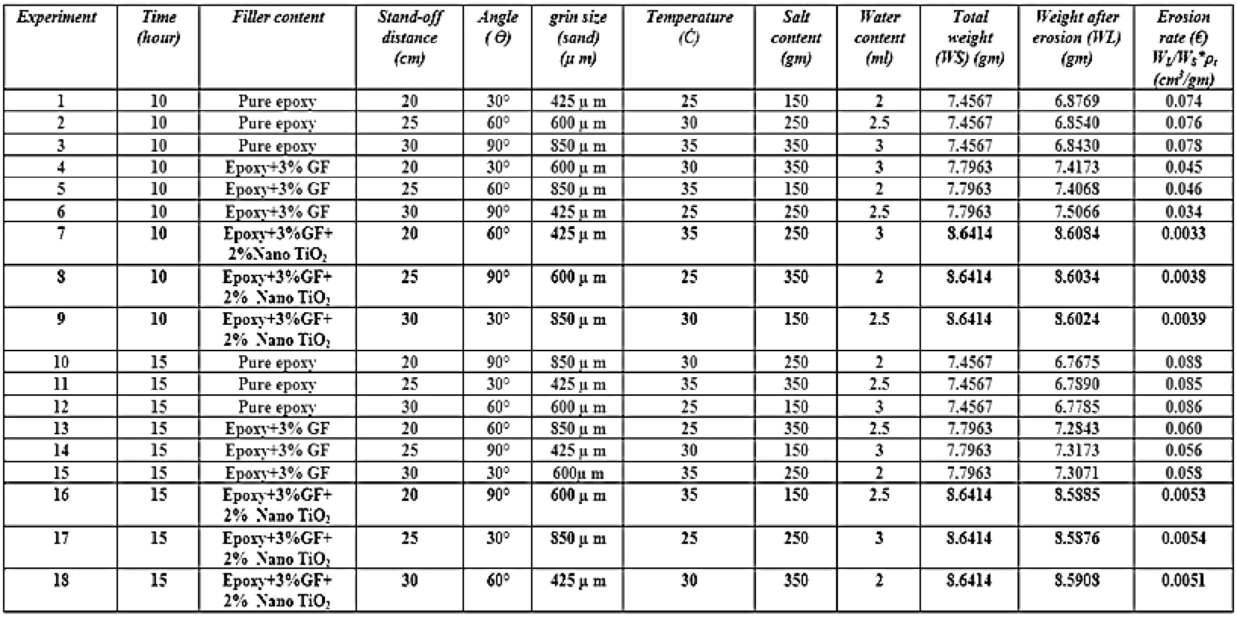
e. Erosion wear test:

This test is performed according to (ASTM G76) at room temperature, [10, 11]. Samples have been cut into a diameter of (40mm) and a thickness of (5 mm), [12].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 (5 mm). 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 (L18) has been chosen since there are eight factors (variables) and three levels [13]. 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. The results of erosion wear for the pure Epoxy and nano-based materials composites are illustrated in Tables (2) to (4) and micro-based materials composites illustrate in tables (5 to 7). 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, [14].

On impact the erodent particle kinetic energy is transferred to the composite body that leads to crater formation and subsequently material loss, [15]. 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, [15]. 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.

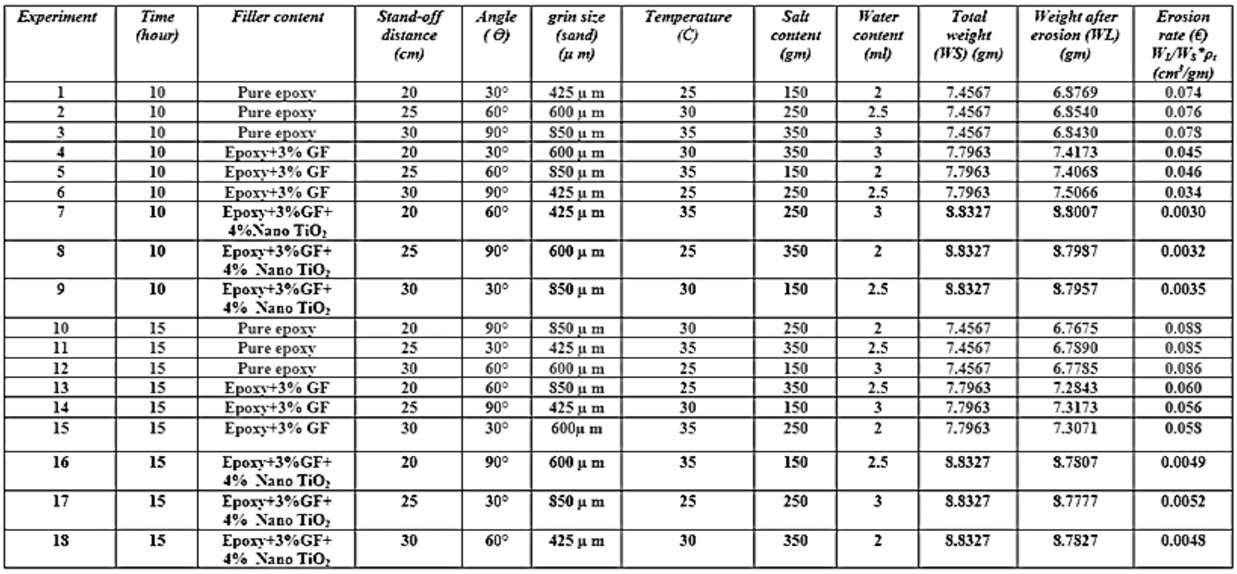
From the Tables it can be noticed that a pronounced effect of the addition of 3% glass fiber with 6% volume frication from (nano powder) percent on the erosion wear, also can be seen the specimen (Epoxy + 3% Glass Fiber +6% TiO_2) give better erosion resistance than the composites filled with (2% TiO_2 and 4% TiO_2) at 15 hour) time, (30 cm) stand-off distance, (60◦) angle, (425μm) grin size of sand, (30 Ċ) temperature, (350 gm) salt content in (2 liter) water content. From the Tables (5),(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) percent on the erosion wear, it can noticed the specimens (Epoxy +3% Glass Fiber + 6% TiO_2) give better erosion resistance than the composites filled with (2% TiO_2 and 4% TiO_2) at (15 hour) time, (30 cm) stand-off distance, (60◦) angle, (425μm) grin size of sand, (30 Ċ) 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-TiO_2 composite to (0.00004) for nano-TiO_2 composite. Thermo-plastic 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, [15]. The angle of impingement is usually defined as the angle between the eroded surface and the trajectory of the particle immediately before impact, [16]. 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, [15]. 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 TiO_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.

Table (2)
Erosion wear of (epoxy + 3%G.F + 2%Nano TiO_2) specimen



Experiment	*Time (hour)*	*Filler content*	*Stand-off distance (cm)*	*Angle (ϴ)*	*grin size (sand) (µ m)*	*Temperature (Ċ)*	*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 TiO_2	20	60°	425 µ m	35	250	3	8.6414	8.6084	0.0033
8	10	Epoxy+3%GF+ 2% Nano TiO_2	25	90°	600 µ m	25	350	2	8.6414	8.6034	0.0038
9	10	Epoxy+3%GF+ 2% Nano TiO_2	30	30°	850 µ m	30	150	2.5	8.6414	8.6024	0.0039
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 TiO_2	20	90°	600 µ m	35	150	2.5	8.6414	8.5885	0.0053
17	15	Epoxy+3%GF+ 2% Nano TiO_2	25	30°	850 µ m	25	250	3	8.6414	8.5876	0.0054
18	15	Epoxy+3%GF+ 2% Nano TiO_2	30	60°	425 µ m	30	350	2	8.6414	8.5908	0.0051

Table (3)
Erosion wear of (epoxy + 3%G.F + 4%Nano TiO_2) specimen



Experiment	*Time (hour)*	*Filler content*	*Stand-off distance (cm)*	*Angle (ϴ)*	*grin size (sand) (µ m)*	*Temperature (Ċ)*	*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 TiO_2	20	60°	425 µ m	35	250	3	8.8327	8.8007	0.0030
8	10	Epoxy+3%GF+ 4% Nano TiO_2	25	90°	600 µ m	25	350	2	8.8327	8.7987	0.0032
9	10	Epoxy+3%GF+ 4% Nano TiO_2	30	30°	850 µ m	30	150	2.5	8.8327	8.7957	0.0035
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 TiO_2	20	90°	600 µ m	35	150	2.5	8.8327	8.7807	0.0049
17	15	Epoxy+3%GF+ 4% Nano TiO_2	25	30°	850 µ m	25	250	3	8.8327	8.7777	0.0052
18	15	Epoxy+3%GF+ 4% Nano TiO_2	30	60°	425 µ m	30	350	2	8.8327	8.7827	0.0048

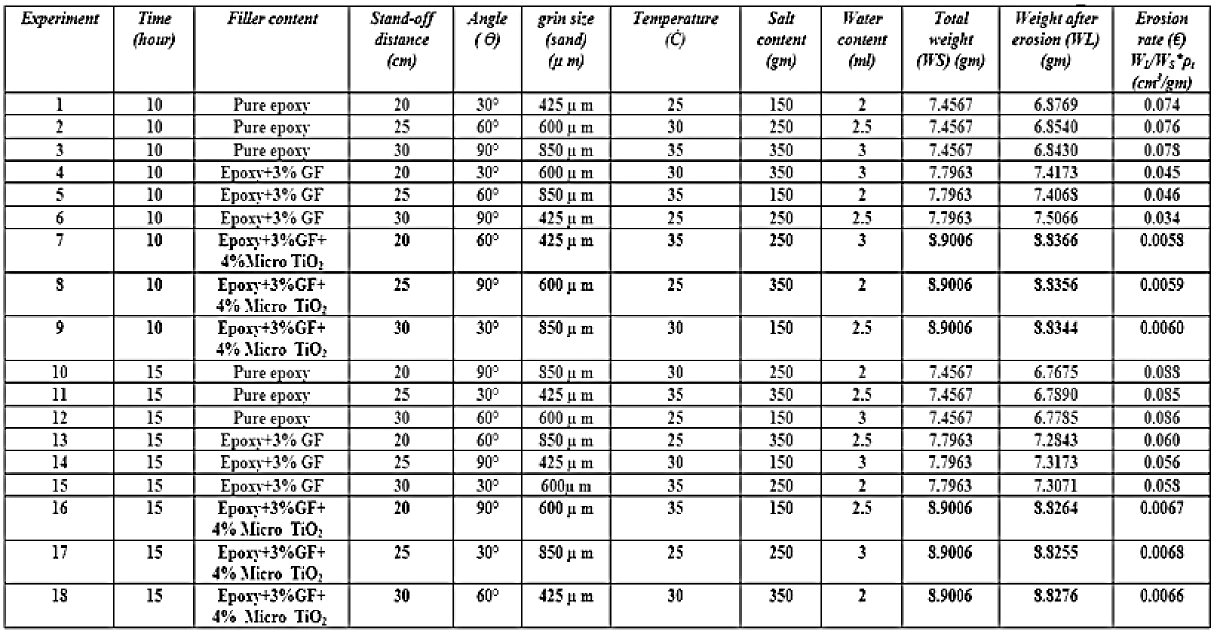
Table (4)
Erosion wear of (epoxy +3%G.F+6%Nano TiO_2) specimen

Experiment	*Time (hour)*	*Filler content*	*Stand-off distance (cm)*	*Angle (α)*	*grin size (sand) (μ m)*	*Temperature (Ċ)*	*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 TiO_2**	20	**60°**	**425 μ m**	35	250	3	**9.1765**	**9.1485**	0.0025
8	**10**	**Epoxy+3%GF+ 6% Nano TiO_2**	**25**	**90°**	**600 μ m**	**25**	**350**	**2**	**9.1765**	**9.1465**	**0.0026**
9	**10**	**Epoxy+3%GF+ 6% Nano TiO_2**	**30**	**30°**	**850 μ m**	**30**	**150**	**2.5**	**9.1765**	**9.1453**	**0.0027**
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 TiO_2**	**20**	**90°**	**600 μ m**	**35**	**150**	**2.5**	**9.1765**	**9.1340**	**0.0038**
17	**15**	**Epoxy+3%GF+ 6% Nano TiO_2**	**25**	**30°**	**850 μ m**	**25**	**250**	**3**	**9.1765**	**9.1317**	**0.0040**
18	**15**	**Epoxy+3%GF+ 6% Nano TiO_2**	**30**	**60°**	**425 μ m**	**30**	**350**	**2**	**9.1765**	**9.1365**	**0.0035**

Table (5)
Erosion wear of (epoxy +3%G.F+2% Micro TiO_2) specimen

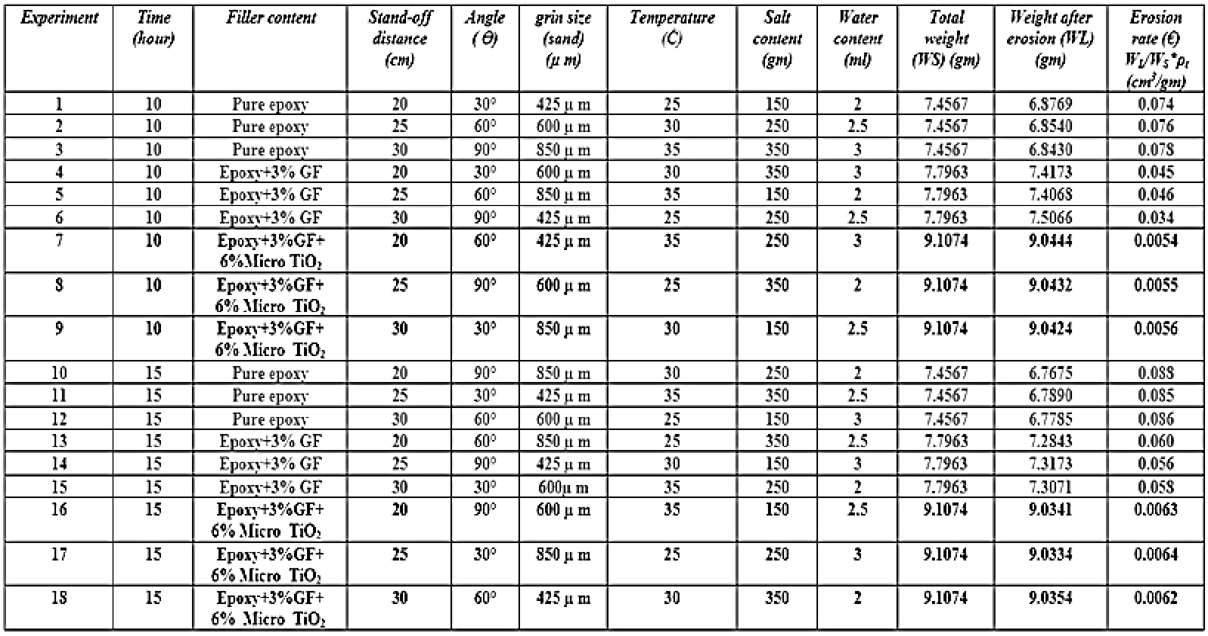
Experiment	*Time (hour)*	*Filler content*	*Stand-off distance (cm)*	*Angle (Ө)*	*grin size (sand) (μ m)*	*Temperature (Ċ)*	*Salt content (gm)*	*Water content (ml)*	*Total weight (WS) (gm)*	*Weight after erosion (WL) (gm)*	*Erosion rate (€) $W_L/W_S*\rho_t$ (cm^3/gm)*
1	10	Pure epoxy	20	30°	425 μ m	25	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%Micro TiO_2**	**20**	**60°**	**425 μ m**	**35**	**250**	**3**	**8.7698**	**8.7048**	**0.0062**
8	**10**	**Epoxy+3%GF+ 2% Micro TiO_2**	**25**	**90°**	**600 μ m**	**25**	**350**	**2**	**8.7698**	**8.7035**	**0.0064**
9	**10**	**Epoxy+3%GF+ 2% Micro TiO_2**	**30**	**30°**	**850 μ m**	**30**	**150**	**2.5**	**8.7698**	**8.7018**	**0.0066**
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% Micro TiO_2**	**20**	**90°**	**600 μ m**	**35**	**150**	**2.5**	**8.7698**	**8.6958**	**0.0071**
17	15	**Epoxy+3%GF+ 2% Micro TiO_2**	**25**	**30°**	**850 μ m**	**25**	**250**	**3**	**8.7698**	**8.6933**	**0.0073**
18	15	**Epoxy+3%GF+ 2% Micro TiO_2**	**30**	**60°**	**425 μ m**	**30**	**350**	**2**	**8.7698**	**8.6948**	**0.0072**

Table (6)
Erosion wear of (epoxy + 3%G.F + 4% Micro TiO_2) specimen



Experiment	Time (hour)	Filler content	Stand-off distance (cm)	Angle (Θ)	grin size (sand) (μ m)	Temperature (Ċ)	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 TiO_2	20	60°	425 μ m	35	250	3	8.9006	8.8366	0.0058
8	10	Epoxy+3%GF+ 4% Micro TiO_2	25	90°	600 μ m	25	350	2	8.9006	8.8356	0.0059
9	10	Epoxy+3%GF+ 4% Micro TiO_2	30	30°	850 μ m	30	150	2.5	8.9006	8.8344	0.0060
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 TiO_2	20	90°	600 μ m	35	150	2.5	8.9006	8.8264	0.0067
17	15	Epoxy+3%GF+ 4% Micro TiO_2	25	30°	850 μ m	25	250	3	8.9006	8.8255	0.0068
18	15	Epoxy+3%GF+ 4% Micro TiO_2	30	60°	425 μ m	30	350	2	8.9006	8.8276	0.0066

Table (7)
Erosion wear of (epoxy +3%G.F+6% Micro TiO_2) specimen



Experiment	Time (hour)	Filler content	Stand-off distance (cm)	Angle (Θ)	grin size (sand) (μ m)	Temperature (Ċ)	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 TiO_2	20	60°	425 μ m	35	250	3	9.1074	9.0444	0.0054
8	10	Epoxy+3%GF+ 6% Micro TiO_2	25	90°	600 μ m	25	350	2	9.1074	9.0432	0.0055
9	10	Epoxy+3%GF+ 6% Micro TiO_2	30	30°	850 μ m	30	150	2.5	9.1074	9.0424	0.0056
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 TiO_2	20	90°	600 μ m	35	150	2.5	9.1074	9.0341	0.0063
17	15	Epoxy+3%GF+ 6% Micro TiO_2	25	30°	850 μ m	25	250	3	9.1074	9.0334	0.0064
18	15	Epoxy+3%GF+ 6% Micro TiO_2	30	60°	425 μ m	30	350	2	9.1074	9.0354	0.0062

4. Conclusions

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 TiO_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. The reason of the increase in hardness is that TiO_2 contains an elements harder than the pure epoxy that lead to an increase in hardness.

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