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Erosion Wear behavior of Micro material Reinforced polymer composites

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Abstract: In the present study, composites were prepared by Hand lay-up molding and investigated. The composites constituents were epoxy resin as the matrix, 3% volume fractions of Glass Fibers (GF) as reinforcement and 2%,4% and 6% volume fractions of micro powder ((Aluminum Oxide Al_2O_3, Silicon Oxide SiO_2 and Titanium Oxide TiO_2)) as filler. Study the erosion wear behavior. The results showed that the non – reinforced epoxy have lower resistance erosion than micro based Material composites other and the specimen (Epoxy+6%glass fiber+6% SiO_2) has higher resistance erosion than industrial based Material composites other. Erosion resistance increase with volume fraction increase

Keywords: Composites, Micro materials, Erosion wear, glass fiber.

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الخلاصة

تم في هذا البحث تحضير المتراكبات التقليدية والهجينة بواسطة طريقة القولبة اليدوية ودراستها. تتكون المواد المتراكبة من راتنج الايبوكسي كماده اساس و3% كسر حجمي من الياف الزجاج كمادة تقوية و 2%و4% و 6% كسر حجمي حشوه من مساحيق نانويه(اوكسيد السليكون, اوكسيد الالومينيوم,اوكسيد التيتانيوم) . دراسة سلوك بلى التعرية النتائج اظهرت بان الايبوكسي غير المقوى يمتلك مقاومة للتعرية قليلة من المواد المتراكبة التي اساسها مواد مايكرويه والعينة (الايبوكسي+6 %الالياف زجاج +6 %اوكسيد السليكون) تملك مقاومة للتعرية من المواد المتراكبة التي اساسها مواد نانويه. ومقاومة التعرية تزداد مع زيادة الكسر الحجمي .

1. Introduction

Epoxy resin is widely used in a variety of technical applications such as adhesives, protective coatings, sealants, and matrices for composite materials in aerospace and leisure industries [1]. This wide range of applications arises from characteristics of epoxy resins including high chemical and corrosion resistance, good mechanical and thermal properties, adhesion to various substrates, low shrinkage upon cure, flexibility, good electrical properties, and easy processability [1, 2]. However, despite these advantages, there are also some drawbacks: high water uptake, moisture absorption and brittle nature owing to their highly cross-linked structures, low wear resistance and high friction coefficient. Many of our technologies require materials with unusual combinations of properties that cannot be met by the conventional metal alloy, ceramics and polymeric materials. A composite is a multiphase material that is artificially made and chemically dissimilar and separated by distinct interface. One of these phases is termed the matrix which is continuous and surrounds the other phase often called the reinforcement phase which consists of three main divisions: particles, fibers and structure, which should be much stiffer and stronger than the matrix. Polymeric composite is considered the earliest type of composite that is used in the greatest diversity of composite applications as well as in the largest quantities in the light of suitable ambient temperature properties, ease of fabrication, low density, good ductility and low cost. Polymeric materials could be classified according to behavior with rising temperature in to (Thermosets, Thermoplastics) [3, 4, and 5]. Fiber –reinforced polymer (FRP) composites are widely used in design due to relatively low-density and reliable tailoring capability to provide the required strength and stiffness. Numerous possible capabilities and low noise make the (FRP) composites as better substitute over conventional metallic materials for tribological application. The different application areas are gears, cams, wheels, impellers, brakes, artificial prosthetic joints, seals, bushes, bearings, ect…. [6]. Solid particle erosion is one type of wear that causes. local damage combined with the progressive loss of original material from a solid surface due to micro mechanical interaction between that surface and solid particles. It has been reported that the surfaces of (FRP) equipments operating in erosion environments were impacted by the solid particles contained in the air or water, which destroy the materials. It was widely recognized that polymers and their composites had poorer erosion resistance than metals, and that polymer composites

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containing reinforcement fiber (FRP) usually erode faster than neat polymers. In other words, the reinforcement fiber could enhance the strength of polymer composites, but reduced the erosion resistance of the polymer composites in generally. In order to reveal the facts about erosion wear of polymer matrix composites, this study investigated some of the physical and mechanical properties of composites materials fiber reinforced polymer; then investigating the erosion behavior of these composites. It was feasible to prepare composites with high strength, low density and excellent erosion resistance by composites structure [7].

There are many studies about erosion wear behavior of composite material:

Patnaik A. et. al., (2007), had studied the solid particle erosion wear performance of a multi component hybrid composite consisting of polyester, glass fibers and alumina particles (average size 50 µm). Composites of three different compositions (0wt%, 10wt% and 20wt% of alumina filling). The design of experiments approach using Taguchi‟s orthogonal arrays has been used with impingement angle of (45^0, 60^0, and 90^0). The study reveals that glass-polyester composite without any filler suffers from greater erosion loss than the hybrid composite with alumina filling. Studying the influence of impingement angle on erosion rate of the composites filled with different percentage of alumina reveals the semi- ductile nature with respect to erosion wear. The peak erosion rate is found to be occurring at 60^0impingement angle under various experimental conditions [8].

M.Bagci et.al (2011) have studied the effect of addition silicon oxide particles to glass fiber and epoxy resin at an amount of 15% to the main material. Erosive wear behavior of this composite under three different impingement angles 30°, 60° and 90°, three different impact velocities 23, 34 and 53 m/s, two different angular Aluminum abrasive particle sizes approximately 200 and 400 µm and the fiber orientation of 45° (45/-45). The results shown that the materials with addition of silicon oxide filler material exhibited lower wear as compared to neat materials with no added filler material. That is; the added silicon oxide particles impose positive effects on erosive wear and thus decreasing the erosion rates, all composites regardless of their different features exhibit maximum erosion rates at 30° impingement angle and thus exhibiting similar behavior as that observed for ductile materials, large abrasive particles lead to an increase in wear. a marked increase in erosion rate was observed as the abrasive particle size increased from 200 to 400µm ,test specimens with (45/-45) fiber orientation are more wear resistant than their counter parts with 0/90 fiber orientation [9].

Ikram . et. al. (2013) used the epoxy with different volume fractions (1,2,3,4,5,7,10,15 and 20%) of microparticles TiO_2 (50 µm) and nanoparticles TiO_2 (50 nm) to prepare epoxy-microcomposites and epoxy-nanocomposites. The results clarified that the flexural strength, Young´s modulus and fracture toughness of nanocomposites increase at low volume fraction (less than 7 vol%). At higher volume fraction, both flexural strength and fracture toughness decrease, while the Young´s modulus is still higher than that of epoxy. The flexural strength and fracture toughness of epoxy-microcomposites decrease with increasing the volume fraction of TiO_2 microparticles, especially at high volume fraction, while Young´s modulus increases with increasing the volume fraction.[10]

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2. Erosion wear

Erosion wear, which arises from solid particle impacting, is one of the major failure modes that cause offshore structure damage. Erosion is found in a wide range of equipments in offshore industry, in which solid particles are entrained into fluid flow in the operating process, such as gas turbine, oil & gas pipeline, drilling platforms head of the plain and rocket, etc [11]. This damage mode affects not only operating process, but also safety and economics as well. Therefore, it is necessary to find a good predictive method to accurately predict the erosion rate for offshore equipment. The erosion mechanism is different in ductile and brittle materials as shows in fig. (1). A number of studies have been performed to reveal the erosion mechanisms of ductile and brittle materials [12, 13]. It is now known that brittle materials erode by cracking and chipping, while ductile materials erode by a sequence of micro-cutting, forging and fracture, etc [14]. Hence, erosion rate and mechanism are highly dependent on material types. Erosion rate of the volume loss (v) is defined by the following equation [15]

$$V = \frac{\varepsilon}{\rho} = \frac{W_L}{W_s * \rho}$$

where
ε: erosion rate of weight loss.
W_L: weight loss of the specimen (gm).
Ws: total weight (gm).
ρ: density of the tested material (g/cm^3) .

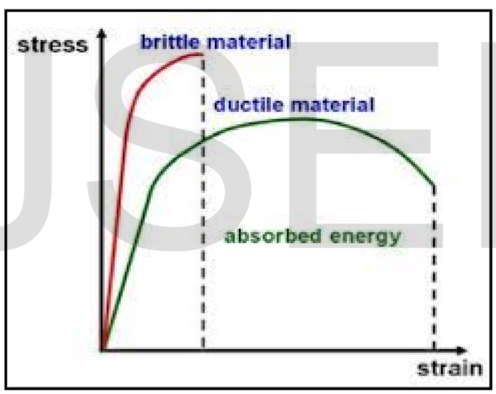

Fig.1. (behavior of brittle and ductile material)

3. 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, and epoxy resin (EUXIT 50 KI) base is used as the matrix. It is provided from **Al-Rakaez Building Materials** made in Egypt Arabic Made in Jordan 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).
All the required moulds for preparing the specimens were made from glass with dimensions of (150×150×5) mm. The inner face of the mould was covered with a layer of nylon (thermal paper) made from polyvinyl alcohol (PVA) so as to ensure no-adhesion of the resin with the mould.

3.1 Row Materials

Table (1) show the properties of row materials that used in the research:

Table (1) show the properties of row materials [16]

Materials	Density (gm/cm^3)	Modulus of Elasticity(GP)	Tensile strength(MP)	Thermal conductivity(W/M.K)
Epoxy	1.05	2.41	27.6-90	0.19
E-glass fiber	2.58	72.5	3450	1.3
Al_2O_3	4.05	380	282-551	39
SiO_2	2.7	73	104	141
Tio_2	4.23	259	354	11.8

4. Preparation of Composites

The composites samples were prepared from epoxy reinforced with glass fiber of (3%) volume fraction, and micro powder (Aluminum Oxide Al_2O_3, Silicon Oxide SiO_2 and Titanium Oxide TiO_2) with volume fraction of (2%,4% 6%). 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.

5. Erosion Wear test

This test is performed according to (ASTM G76) at room temperature [17, 18]. Samples have been cut into a diameter of (40mm) and a thickness of (5mm). Figure (6) shows standard specimens for erosion wear [19].

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 [20].

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,

6. Results and discussion

6.1 Erosion wear

The results of erosion wear for the pure Epoxy and nano-based materials composites are illustrated in Tables (2) to (10).

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 [21].

On impact the erodent particle kinetic energy is transferred to the composite body that leads to crater formation and subsequently material loss [8].

The results show, the nano-based materials composites give the lower erosion wear when they are compared with the other (Pure Epoxy and Epoxy +3%Glass Fiber) 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 [8].

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 micro powder and absorption of good amount of kinetic energy associated with the erodent by the filler powder.

From the Tables (2),(5),(8) it is clear that there is a pronounced effect of the addition of 3% glass fiber with 2% volume frication from (micro powder) percents on the erosion wear ,it can seen the specimen (Epoxy +3% Glass Fiber +2%TiO_2) give better erosion resistance than the composites filled with (2% Al_2O_3 and 2% SiO_2) at (15 hour) time , (30 cm) stand-off distance, (60°) angle, (425µm) grin size of sand ,(30Ċ) temperature, (300 gm) salt content in (2 liter) water content.

From the Tables (3),(6),(9) it is clear that there is a pronounced effect of the addition of 3% glass fiber with 4% volume frication from (micro powder) percents on the erosion wear ,it can seen the specimens (Epoxy +3% Glass Fiber +4% TiO_2) give better erosion resistance than the composites filled with (4% Al_2O_3 and 4% SiO_2) at (15 hour) time , (30 cm) stand-off distance, (60°) angle, (425µm) grin size of sand ,(30Ċ) temperature, (300 gm) salt content in (2 liter) water content.

From the Tables (4),(7),(10) 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 seen the specimens (Epoxy +3% Glass Fiber +6% TiO_2) give better erosion resistance than the composites filled with (6% Al_2O_3 and 6% SiO_2) at (15 hour) time , (30 cm) stand-off distance, (60°) angle, (425µm) grin size of sand ,(30Ċ) temperature, (300 gm) salt content in (2 liter) water content.

Which may be related to its lower grain size with a good distribution and bonding and since is hard, SiO_2 wear-resistant and has high strength and stiffness. Figure (2) show the erosion rate of nano composites.

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 [8].

The angle of impingement is usually defined as the angle between the eroded surface and the trajectory of the particle immediately before impact [22].

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 [8]. In the present study the results show the peak erosion taking place at an impact angle of 60°.

This clearly indicates that these micro-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

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semi-ductile in nature. The loss of ductility may be attributed to the incorporation of glass fibers and nano powder both of which are brittle, therefore the used glass fiber and filler (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 high erosion wear of (SiO_2) in micro-based materials composites may be related to the poor linkage between matrix material and fillers with the matrix.

Table (2): Erosion wear of pure epoxy, epoxy +3% glass fiber and Epoxy +3%glass fiber +2% Micro SiO2

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 (€) $W_L/W_S*\rho_r$ (cm^3/gm)
1	10	Pure epoxy	20	30°	425 µ m	25	150	2	7.4567	6.8739	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	0.0045
5	10	Epoxy+3% GF	25	60°	850 µ m	35	150	2	7.7963	7.4068	0.0046
6	10	Epoxy+3% GF	30	90°	425 µ m	25	250	2.5	7.7963	7.5066	0.0034
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+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 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 (3): Erosion wear of pure epoxy, epoxy +3% glass fiber and Epoxy +3%glass fiber +4% Micro SiO2

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 (€) $W_L/W_S*\rho_r$ (cm^3/gm)
1	10	Pure epoxy	20	30°	425 µ m	25	150	2	7.4567	6.8739	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	0.0045
5	10	Epoxy+3% GF	25	60°	850 µ m	35	150	2	7.7963	7.4068	0.0046
6	10	Epoxy+3% GF	30	90°	425 µ m	25	250	2.5	7.7963	7.5066	0.0034
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 (4): Erosion wear of pure epoxy, epoxy +3% glass fiber and Epoxy +3%glass fiber +6% Micro SiO2

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Experiment	Time (hour)	Filler content	Stand-off distance (cm)	Angle (Ɵ)	grin size (sand) (µ m)	Temperature (Ċ)	Salt content (gm)	Water content (ml)	Total weight (WS) (gm)	Weight after erosion (WL) (gm)	Erosion rate (€) $W_L/W_S*\rho_r$ (cm^3/gm)
1	10	Pure epoxy	20	30°	425 µ m	25	150	2	7.4567	6.8739	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	0.0045
5	10	Epoxy+3% GF	25	60°	850 µ m	35	150	2	7.7963	7.4068	0.0046
6	10	Epoxy+3% GF	30	90°	425 µ m	25	250	2.5	7.7963	7.5066	0.0034
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	0.060
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

Table (5): Erosion wear of pure epoxy, epoxy +3% glass fiber and
Epoxy +3%glass fiber +2% Micro Al_2O_3

Experiment	Time (hour)	Filler content	Stand-off distance (cm)	Angle (Ɵ)	grin size (sand) (µ m)	Temperature (Ċ)	Salt content (gm)	Water content (ml)	Total weight (WS) (gm)	Weight after erosion (WL) (gm)	Erosion rate (€) $W_L/W_S*\rho_r$ (cm^3/gm)
1	10	Pure epoxy	20	30°	425 µ m	25	150	2	7.4567	6.8739	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	0.0045
5	10	Epoxy+3% GF	25	60°	850 µ m	35	150	2	7.7963	7.4068	0.0046
6	10	Epoxy+3% GF	30	90°	425 µ m	25	250	2.5	7.7963	7.5066	0.0034
7	10	Epoxy+3%GF+ 2%Micro Al_2O_3	20	60°	425 µ m	35	250	3	8.5879	8.5217	0.0066
8	10	Epoxy+3%GF+ 2% Micro Al_2O_3	25	90°	600 µ m	25	350	2	8.5879	8.5209	0.0067
9	10	Epoxy+3%GF+ 2% Micro Al_2O_3	30	30°	850 µ m	30	150	2.5	8.5879	8.5199	0.0068
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 Al_2O_3	20	90°	600 µ m	35	150	2.5	8.5879	8.5119	0.0076
17	15	Epoxy+3%GF+ 2% Micro Al_2O_3	25	30°	850 µ m	25	250	3	8.5879	8.5109	0.0077
18	15	Epoxy+3%GF+ 2% Micro Al_2O_3	30	60°	425 µ m	30	350	2	8.5879	8.5129	0.0074

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

Epoxy +3%glass fiber +4% Micro Al_2O_3

Experiment	*Time (hour)*	*Filler content*	*Stand-off distance (cm)*	*Angle (Ɵ)*	*grin size (sand) (µ m)*	*Temperature (Ċ)*	*Salt content (gm)*	*Water content (ml)*	*Total weight (WS) (gm)*	*Weight after erosion (WL) (gm)*	*Erosion rate (€) $W_L/W_s*\rho_r$ (cm^3/gm)*
1	10	Pure epoxy	20	30°	425 µ m	25	150	2	7.4567	6.8739	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	0.0045
5	10	Epoxy+3% GF	25	60°	850 µ m	35	150	2	7.7963	7.4068	0.0046
6	10	Epoxy+3% GF	30	90°	425 µ m	25	250	2.5	7.7963	7.5066	0.0034
7	10	Epoxy+3%GF+ 4%Micro Al_2O_3	20	60°	425 µ m	35	250	3	8.6973	8.6327	0.0060
8	10	Epoxy+3%GF+ 4% Micro Al_2O_3	25	90°	600 µ m	25	350	2	8.6973	8.6314	0.0062
9	10	Epoxy+3%GF+ 4% Micro Al_2O_3	30	30°	850 µ m	30	150	2.5	8.6973	8.6304	0.0063
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 Al_2O_3	20	90°	600 µ m	35	150	2.5	8.6973	8.6225	0.0070
17	15	Epoxy+3%GF+ 4% Micro Al_2O_3	25	30°	850 µ m	25	250	3	8.6973	8.6218	0.0071
18	15	Epoxy+3%GF+ 4% Micro Al_2O_3	30	60°	425 µ m	30	350	2	8.6973	8.6234	0.0069

Table (7): Erosion wear of pure epoxy, epoxy +3% glass fiber and
Epoxy +3%glass fiber +6% Micro Al_2O_3

Experiment	*Time (hour)*	*Filler content*	*Stand-off distance (cm)*	*Angle (Ɵ)*	*grin size (sand) (µ m)*	*Temperature (C°)*	*Salt content (gm)*	*Water content (ml)*	*Total weight (WS) (gm)*	*Weight after erosion (WL) (gm)*	*Erosion rate (€) $W_L/W_s*\rho_r$ (cm^3/gm)*
1	10	Pure epoxy	20	30°	425 µ m	25	150	2	7.4567	6.8739	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	0.0045
5	10	Epoxy+3% GF	25	60°	850 µ m	35	150	2	7.7963	7.4068	0.0046
6	10	Epoxy+3% GF	30	90°	425 µ m	25	250	2.5	7.7963	7.5066	0.0034
7	10	Epoxy+3%GF+ 6%Micro Al_2O_3	20	60°	425 µ m	35	250	3	8.7863	8.7233	0.0056
8	10	Epoxy+3%GF+ 6% Micro Al_2O_3	25	90°	600 µ m	25	350	2	8.7863	8.7221	0.0058
9	10	Epoxy+3%GF+ 6% Micro Al_2O_3	30	30°	850 µ m	30	150	2.5	8.7863	8.7213	0.059
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 Al_2O_3	20	90°	600 µ m	35	150	2.5	8.7863	8.7130	0.0066
17	15	Epoxy+3%GF+ 6% Micro Al_2O_3	25	30°	850 µ m	25	250	3	8.7863	8.7121	0.0067
18	15	Epoxy+3%GF+ 6% Micro Al_2O_3	30	60°	425 µ m	30	350	2	8.7863	8.7143	0.0065

Table (8): Erosion wear of pure epoxy, epoxy +3% glass fiber and

Epoxy +3%glass fiber +2% Micro TiO2

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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 (€) $W_L/W_s*\rho_r$ (cm^3/gm)
1	10	Pure epoxy	20	30°	425 μ m	25	150	2	7.4567	6.8739	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	0.0045
5	10	Epoxy+3% GF	25	60°	850 μ m	35	150	2	7.7963	7.4068	0.0046
6	10	Epoxy+3% GF	30	90°	425 μ m	25	250	2.5	7.7963	7.5066	0.0034
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 (9): Erosion wear of pure epoxy, epoxy +3% glass fiber and

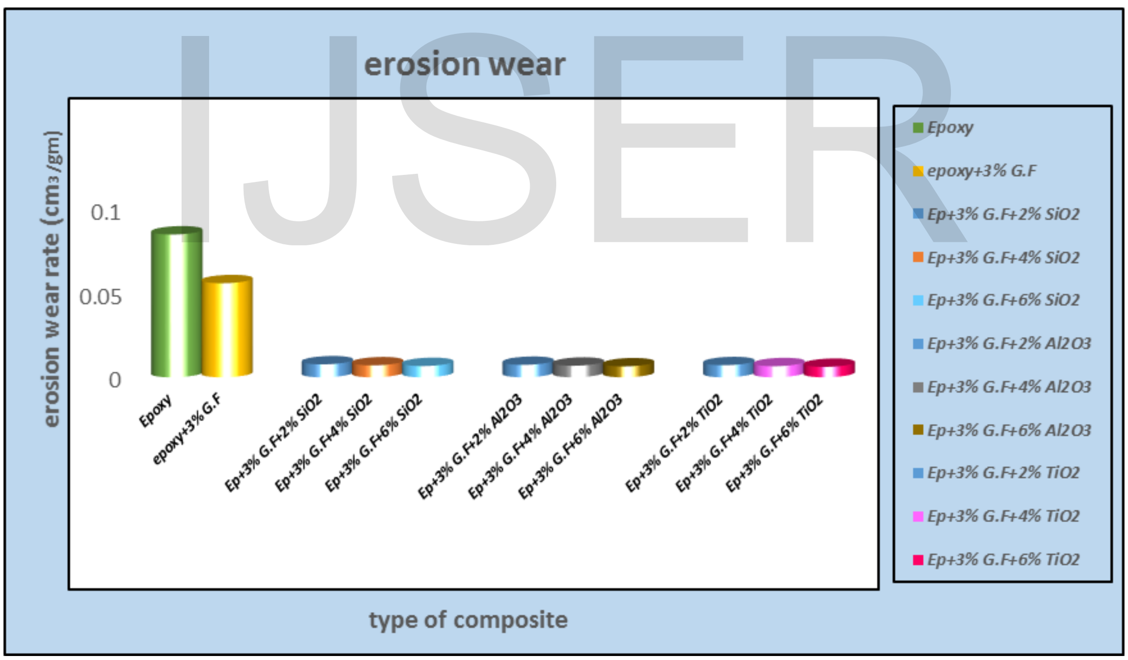
Epoxy +3%glass fiber +4% Micro TiO2

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 (€) $W_L/W_s*\rho_r$ (cm^3/gm)
1	10	Pure epoxy	20	30°	425 μ m	25	150	2	7.4567	6.8739	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	0.0045
5	10	Epoxy+3% GF	25	60°	850 μ m	35	150	2	7.7963	7.4068	0.0046
6	10	Epoxy+3% GF	30	90°	425 μ m	25	250	2.5	7.7963	7.5066	0.0034
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 (10): Erosion wear of pure epoxy, epoxy +3% glass fiber and

Epoxy +3%glass fiber +6% Micro TiO2

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 (€) $W_L/W_s*\rho_r$ (cm^3/gm)
1	10	Pure epoxy	20	30°	425 μ m	25	150	2	7.4567	6.8739	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	0.0045
5	10	Epoxy+3% GF	25	60°	850 μ m	35	150	2	7.7963	7.4068222	0.0046
6	10	Epoxy+3% GF	30	90°	425 μ m	25	250	2.5	7.7963	7.5066	0.0034
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



Reference

1- Distasio JI. ***"Epoxy resin technology"***, development since, New Jersey: Noyes Data, (1982).
2- May CA. ***"Epoxy resins: chemistry and technology"***, New York: Marcel Dekker, (1988).

3- Lubin G., ***''Handbook of Composite''***, Society of Plastic Engineering, SPE, Van Nostrand Reinhold VNR, New York, (1982).
4- Callister W.D., ***''Materials Science and Engineering''***, 6th edition, University of Utah, John Wiley and sons. Inc., (2003).
5- Weeton J.W., ***''Engineering's Guide to Composite Materials''***, published by American Society for Metals ASM, U.S.A., (1987).
6- Chittaranjan Deo and Acharya S.K.***"Effects of fiber content on abrasive wear of lantana Camara fiber reinforced polymer matrix composite "***, Indiana Journal of Engineering and Materials Sciences ,Vol.17, PP.219-223 ,(2010)
7- Qian D. N. , Bao L. M., Takatera M. Y. & Yamanaka A. H., ***" Development of FRP composites with excellent erosion resistance by solid particles"*** , Department of Bioscience and Textile Technology, Interdisciplinary Graduate School of Science and Technology Shinshu University, PP. 1-6, (2010).
8- Amar Patnaik, Alok Satapathy and Mahapatra S. S., ***"Implementation of Taguchi method for tribo-performance of hybrid composites"***, Eighth Int. Conference on Opers. & Quant. Management, Department of Mechanical Engineering, National Institute of Technology, Rourkela, PP. 779- 788, (2007).
9- 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) .
10- Ikram A., Muhannad .M. and Harith I.,***"Mechanical Properties of Micro and Nano TiO_2/Epoxy Composites"***, international Journal of Mining & Mechanical Engineering, No. 2, Vol.1, PP.2320-4060, (2013).
11- Keles, Ozgul and Inal, O.T., ***"A Review on Solid Particle Erosion of Ductile and Brittle Materials***", Recent Res. Devel. Mat. Sci, Vol.3, PP. 499–528. (2002).
12- Finnie I., ***"Erosion of surfaces by solid particles***", Wear, Vol.3 ,PP. 87–103,(1960).
13- Liu Z.G., Wan S., Nguyen V.B., Zhang Y.W. , ***"Finite element analysis of erosive wear for offshore structure "***,13th International Conference on Fracture,PP.1-8 , (2013) .
14- Yu-Fei Wang, Zhen-Guo Yang., ***"Finite element model of erosive wear on ductile and brittle Materials*** ". Wear, Vol.265, PP.871–878, (2008).
15- Qian D. N. , Bao L. M., Takatera M. Y. & Yamanaka A. H.," **Development of FRP composites with excellent erosion resistance by solid particles",** Dep. of Bioscience and Textile Tech., Interdisciplinary Graduate School of Science and Tech. Shinshu University,PP. 1-6, (2010).
16- William D. Callister, Jr."***Materials science and engineering,An introduction***" ,John Wiley and sons, Inc. U.S.A. (2000).
17- 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)
18- Sandhyarani Biswas ***"Erosion Wear Behaviour of Copper Slag Filled Short BambooFiber Reinforced Epoxy Composites "***, Mechanical Engineering Department, National Institute of Technology, Rourkela, India ,(2012) .
19- 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).
20- Shyam Kumar Karna, Dr. Ran Vijay Singh, Dr. Rajeshwar Sahai***" Application of Taguchi Method in Indian Industry"***, Issue11, Vol. 2,PP.389, November (2012).
21- 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).
22- 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).