

Erosion Wear behavior of Industrial Material Reinforced Epoxy Resin Composites and its Coating with Natural Based Material

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Abstract

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. Studied the erosion wear behavior and coating by natural wastes (Rice Husk Ash) with epoxy resin after erosion. 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° , grain size of sand $850\mu\text{m}$, temperature 25°C , 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 $(16 \pm 1)\mu\text{m}$ and after erosion at (15 hour) the thickness was $(10)\mu\text{m}$. 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.

Keywords: Composites, industrial Materials, Erosion wear, glass fiber, Coating.

سلوك بلى التعرية لمواد الصناعية المدعمة براتنج الايبوكسي وطلائها مع مادة اساسها
طبيعي

الخلاصة

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تم في هذا البحث تحضير المواد المتراكبة بواسطة طريقة القولية اليدوية. تتكون المواد المتراكبة من راتنج الايبوكسي كماده اساس واللياف الزجاج كمادة تقوية بكسر حجمي 6% و مساحيق طبيعية محضرة (كاربونات الكالسيوم , كاربونات الصوديوم او كاربونات البوتاسيوم) بكسر حجمي (3% , 6%) دراسة سلوك بلى التعرية والطلاء بواسطة النفايات الطبيعية (رماد قشور الرز) مع راتنج الايبوكسي بعد التعرية . النتائج اظهرت بان الايبوكسي غير المقوى يمتلك مقاومة للتعرية قليلة من المواد المتراكبة التي اساسها مواد طبيعية والعينة (الايوكسي + 6% الاليف زجاج + 6% كاربونات الكالسيوم) تملك مقاومة للتعرية من المواد المتراكبة المدعمة بمسحوق الجزر وبودرة الخشب عند 25 سم ، زاوية 30°، حجم دقائق تعرية 850 مايكرون ، ودرجة حرارة 20025 C° غم ملح في 3 لتر من ماء 15 ساعة . طلاء العينات براتنج الايبوكسي مع رماد قشور الرز مع حجم حبيبي ضمن المدى (1.4- 2.4) مايكرون لتحسين خواص مقاومة التعرية للعينات التي تم طلاؤها , وسمك الطلاء كان (1 ± 16) مايكرون وبعد التعرية عند 15 ساعة اصبح سمك الطلاء (10) مايكرون. تطبيق هذا الدراسة هو حماية الانابيب من التعرية , وهذه الانابيب تتضمن انابيب الصرف الصحي , انابيب الصرف لمختبرات (الماء الساخن ، المواد الكيماوية والزيت) وانابيب نقل المنتجات النفطية والغازية .

INTRODUCTION

The composite materials were developed during the Second World War [1]. Not only were even more aircraft being developed and, therefore, composites more widely used in tooling, but the use of composites for structural and semi-structural parts was being explored and then adopted. Other early Second World War applications included engine nacelles, which lightened the A-20 airplane and radomes (domes to protect aircraft radar antennas) which gave both structural strength and radar transparency. Ancient Pharaohs made their slaves use bricks with straw to enhance the structural integrity of their buildings, some of which testify to wisdom of the dead civilization even today. Composites results from research and innovation from past few decades have progressed from fibers for automobile bodies to particulate composites for aerospace and a range of other applications [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, etc [3]. 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. A number of studies have been performed to reveal the erosion mechanisms of ductile and brittle materials [4, 5].

Those brittle materials erode by cracking and chipping, while ductile materials erode by a sequence of micro-cutting, forging and fracture, etc [6]. Hence, erosion rate and mechanism are highly dependent on material types.

Erosion rate of the volume loss (v) is defined by the following equation [1]

$$V = \frac{\varepsilon}{\rho} = \frac{W_L}{W_S * \rho} \quad \dots (1)$$

where

ε : erosion rate of weight loss.

W_L : weight loss of the specimen (gm).

W_s : total weight (gm).

ρ : density of the testing material (g/cm^3).

There are many studies about composite materials. Yilmaz M. G. et. al., (2008) have studied the strength and erosive characteristics of CaCO_3 filled unsaturated polyester/glass fiber (UPR/GFR) composite are evaluated. Samples of UPR with 40, 50 and 60 wt% content of CaCO_3 and different CaCO_3 particle sizes of 1, 2, 3, 5 and 10 micron were prepared. The results showed that the higher is the percentage of CaCO_3 in the composite and the smaller is the CaCO_3 particle size, the higher is the strength and the erosive resistance of the glass fiber reinforced/unsaturated polyester composite (UPR-GFR). Furthermore, the highest erosion wear rate is at 90° impingement angle. Finally the results show that the erosive wear of CaCO_3 content UPR/GFR composite in a brittle manner [7]. Amar Patnaik et. al., (2010) have studied the Fiber reinforced polymer composites often have to function in severe erosive environment in which they encounter solid particle erosion. In hybrid composites consisting of reinforcing fibers and particulate filled polymer matrices, the filler material plays a major role in determining the magnitude and mechanism of damage due to erosion. Study of the influence of three different particulate fillers namely fly ash, alumina (Al_2O_3) and silicon carbide (SiC) on the erosion characteristics of glass polyester composites. For this purpose, an air jet type erosion test configuration and the design of experiments approach utilizing Taguchi's orthogonal arrays are used. The wear rates are found to be in good agreement with the theoretical values obtained from an existing prediction model. This study reveals that addition of hard particulate fillers like flyash, Al_2O_3 and SiC improves the erosion resistance of glass polyester composites significantly [8]. Bagci et M. al., (2011) have studied the Materials added to the matrix help improving operating properties of a composite. This experimental study has targeted to investigate this aim where Silicon Oxide particles were added to glass fibre and epoxy resin at an amount of 15% to the main material to obtain a sort of new composite material. In the test results, erosion rates were obtained as functions of impingement angles, impact velocities, particle sizes and fibre orientation. Moreover, materials with addition of Silicon Oxide filler material exhibited lower wear as compared to neat materials with no added filler material [9].

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 Quickmast (105) base as the matrix from the (Don Construction products) Made in Jordan in the form of transparent viscous liquid at room temperature which is a thermally hardened polymers (Thermosets) with a density of ($1.2 \text{ gm} / \text{cm}^3$). All the required moulds for preparing the specimens were made from glass with dimensions of ($150 \times 150 \times 5$) mm. The inner face of the mould was covered with a thin layer of (thermal paper) made from polyvinyl alcohol (PVA) so as to easy removing from the mould after molding.

Raw Material:

The properties of material used in preparation of composites material as shown in table : (1)

Table: (1) properties of material

Materials	Properties			
Epoxy (105)	Density (1.2) gm/cm ³	Tensile strength (25) N/mm ²	Flexural strength (60) N/mm ²	Viscosity (1.0)
E-glass	Density (2.58) gm/cm ³	Tensile strength (3445) MPa	Compressive strength(1080) MPa	Young modulus (72.5) Gpa
Sodium Carbonates	Density (2.54) gm/cm ³	Minimum assay (98%)	Particle size (19.99) μm	Melting point (851 c)
Calcium Carbonates	Density (2.71) gm/cm ³	Minimum assay (98%)	Particle size (0.71) μm	Melting point (825 c)
Potassium Carbonates	Density (2.43) gm/cm ³	Minimum assay (98%)	Particle size (22.18) μm	Melting point (891 c)

Preparation of Composites

The composites samples were prepared from epoxy reinforced with glass fiber of (6%) volume fraction, and industrial powder of (calcium carbonate CaCO₃, potassium carbonate K₂CO₃ or Sodium carbonate Na₂CO₃) with volume fraction of (3%, 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. The composites are prepared according to the following steps:

- 1- Preparation of glass fibers woven of dimensions (150 × 150) mm according to the dimensions of the mould. The used volume fractions are (6%).
- 2- Weighing the reinforcing powder to specify a volume fraction of (3% and 6%).
- 3- Weighing the epoxy depending on the volume fraction of reinforcement materials (fiber and powder), while taking into consideration the weight of hardener.
- 4- Mixing the epoxy with the hardener continuously and slowly by using a glass rod so as to avoid bubbles. The mixing is carried out at room temperature.
- 5- Adding the powder intermittently into the mixture and stirring it for a period of (10-15) minutes to obtain homogeneity. A rise in the temperature of the mixture will result as an indication to the beginning of the interaction process. It is very important that the mixture must have a good viscosity for the purpose of protecting the particles from precipitation which may result in the heterogeneity of the mixture that leads to the agglomeration after hardening.
- 6- Pouring the mixture into the mould, then putting the glass fiber mat into the mould and continuing of mixture pouring until it covers the entire mat.
- 7- Pressing the mixture with an appropriate load.
- 8- For the purpose of completing the process of hardening, finally is leaving the sample in the mould for a period of (24) hour at room temperature. Samples are then extracted from the mould and then heat treated in an oven at (60C) for a period of (60) minutes. This process is very important for the purpose of obtaining the best cross linking between polymeric chains, and to remove the stresses generated from the preparation process and complete the full hardening of the samples [10] .

Erosion Wear test

This test is performed according to (ASTM G76) at room temperature [11, 12]. Samples have been cut into disk shape of a diameter of (40mm) and a thickness of (5mm). Figure (1) shows standard specimens for erosion wear [13]. The used device for erosion is locally manufactured; the principal scheme is shown Figure (2), Figure (3) shows illustration of erosion wear device sketch a plastic (Perspex) tank is used as a chamber. 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 angle levels (90° , 60° , 30°), and the 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 as shows in figure (4) shows the design the used in the work [14]. 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) abrasive particle ; (6) Temperature; (7) salt content; and (8) water content each at three levels,

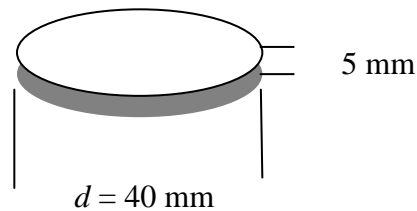


Figure (1): Standard specimens [13]



Figure (2): Erosion wear device

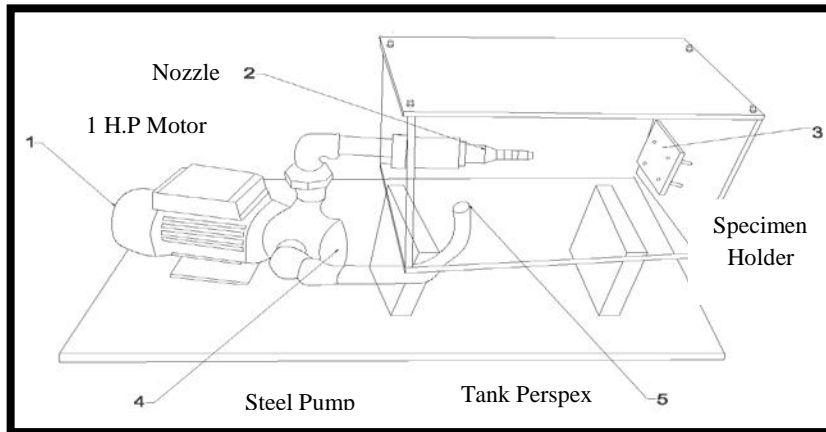


Figure (3): Sketch illustration of erosion wear device

Experiment	P1	P2	P3	P4	P5	P6	P7	P8
1	1	1	1	1	1	1	1	1
2	1	1	2	2	2	2	2	2
3	1	1	3	3	3	3	3	3
4	1	2	1	1	2	2	3	3
5	1	2	2	2	3	3	1	1
6	1	2	3	3	1	1	2	2
7	1	3	1	2	1	3	2	3
8	1	3	2	3	2	1	3	1
9	1	3	3	1	3	2	1	2
10	2	1	1	3	3	2	2	1
11	2	1	2	1	1	3	3	2
12	2	1	3	2	2	1	1	3
13	2	2	1	2	3	1	3	2
14	2	2	2	3	1	2	1	3
15	2	2	3	1	2	3	2	1
16	2	3	1	3	2	3	1	2
17	2	3	2	1	3	1	2	3
18	2	3	3	2	1	2	3	1

Figure (4): Design of the orthogonal array (L₁₈) [14]

Coating

Spin coating is a procedure used to deposit uniform thin films to flat substrates. Usually a small amount of coating material is applied on the center of the substrate, which is either spinning at low speed or not spinning at all. The substrate is then rotated at high speed in order to spread the coating material by centrifugal force. A machine used for spin coating is called a spin coater, or simply spinner. Rotation is continued while the fluid spins off the edges of the substrate, until the desired thickness of the film is achieved. During spin coating, a polymer solution (epoxy resin with rice husk ash) in a solvent is applied to the center of a flat substrate. The spin coater rotates the substrate at high speed in order to spread the fluid by the centrifugal force. Because the solvent is volatile, a thin layer of polymer will be left at the substrate. The thickness and uniformity of such film are greatly affected by the polymer solution and spin speed. The thickness of the film also depends on the viscosity and concentration of the solution and the solvent [15]. Figure (5) shows spin coater device (mode 410, origin Taiwan) located in (Corrosion) Laboratory, Material Engineering Department, University of Technology. In this research was the preparation steps for the purpose of coating mixing are the following :

1. Weight 10 gm from epoxy.

2. Weight 7 gm from hardener.
3. Weight 10 gm from rice husk ash
4. Mixing the epoxy with the hardener continuously and slowly by using a glass rod so as to avoid bubbles. The mixing is carried out at room temperature.
5. Adding the powder (Rice Husk Ash) with (particle size 1.4-4.2 μm) natural waste in industry as additive to epoxy resin as coating of thermosetting pipes. Intermittently in to the mixture and stirring it for a period of (10-15) minutes to obtain homogeneity.
6. Pouring the mixture to the sample (which does not have the resistance of the erosion ware to improve the resistance to wear erosion) is installed in the device (spin coater) slowly, after proving parameter device which is (**time ;3000 sec ,speed ;1000 RPM " revolutions per minute" ;& Accelerate ;8 sec**) the spin coater distribute the mixing evenly on the sample. Figure (6) shows the specimens after coating by used spin coating.



Figure (5): Spin coater device



Figure (6): (Some of specimens after coating)

Results and discussion

Erosion wear

The results of erosion wear for the pure Epoxy and industrial-based materials composites are illustrated in Tables (2) to (7).The results show, the industrial-based materials composites give the lower erosion wear when they are compared with the other (Pure Epoxy and Epoxy +6%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 [16]. 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 [17]. On impact the erodent particle kinetic energy is transferred to the composite body that leads to crater formation and subsequently material loss [16]. 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),(4),(6) and Figures (7) ,(9), (11) it is clear that there is a pronounced effect of the addition of 6% glass fiber with 3% volume fraction from (industrial powder) percents on the erosion wear ,it can be seen the specimen (Epoxy +6% Glass Fiber +3% CaCO_3) give better erosion resistance than the composites filled with (3% K_2CO_3 and 3% Na_2CO_3) at (15 hour) time , (30 cm) stand-off distance, (60°) angle, ($425\mu\text{m}$) grain size of sand ,(30°C) temperature,(300 gm) salt content in (2 liter) water content. From the Tables (3),(5),(7) and Figures (8) ,(10), (12) it is clear that there is a pronounced effect of the addition of 6% glass fiber with 6% volume fraction from (industrial powder) percents on the erosion wear ,it can be seen the specimens (Epoxy +6% Glass Fiber +6% CaCO_3) give better erosion resistance than the composites filled with (6% K_2CO_3 and 6% Na_2CO_3) at (15 hour) time , (30 cm) stand-off distance, (60°) angle, ($425\mu\text{m}$) grain size of sand ,(30°C) temperature,(300 gm) salt content in (2 liter) water content because CaCO_3 has high value hardness with small particle size. 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 [16].The angle of impingement is usually defined as the angle between the eroded surface and the trajectory of the particle immediately before impact [18]. 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 [16]. In the present study the results show the peak erosion taking place at an impact angle of 30° and 90° .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 (CaCO_3) 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 (K_2CO_3) in industrial-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 +6% glass fiber and epoxy +6% glass fiber +3% Na₂CO₃

Experiment	Time (hour)	Filler content	Stand-off distance (cm)	angle	grin size (μ m)	Temperature (C°)	Salt content (gm)	Water content (ml)	Total weight (WS) (gm)	Weight after erosion (WL) (gm)	Erosion rate (€) $W_1/W_s * \rho_1$ (cm ³ /gm)
1	10	Pure epoxy	20	30°	425 μ m	25	100	2	7.7006	7.6800	0.0022
2	10	Pure epoxy	25	60°	600 μ m	30	200	2.5	7.7006	7.6752	0.0027
3	10	Pure epoxy	30	90°	850 μ m	35	300	3	7.7006	7.6600	0.0043
4	10	Epoxy+6% GF	20	30°	600 μ m	30	300	3	8.3645	8.3534	0.0011
5	10	Epoxy+6% GF	25	60°	850 μ m	35	100	2	8.3645	8.3524	0.0017
6	10	Epoxy+6% GF	30	90°	425 μ m	25	200	2.5	8.3645	8.3540	0.0010
7	10	Epoxy+6% GF+ 3% Na ₂ CO ₃	20	60°	425 μ m	35	200	3	9.8683	9.7900	0.0063
8	10	Epoxy +6%GF+ 3% Na ₂ CO ₃	25	90°	600 μ m	25	300	2	9.8683	9.7800	0.0071
9	10	Epoxy +6%GF+ 3% Na ₂ CO ₃	30	30°	850 μ m	30	100	2.5	9.8683	9.7750	0.0075
10	15	Pure epoxy	20	90°	850 μ m	30	200	2	7.7006	7.5743	0.0136
11	15	Pure epoxy	25	30°	425 μ m	35	300	2.5	7.7006	7.5863	0.0123
12	15	Pure epoxy	30	60°	600 μ m	25	100	3	7.7006	7.5753	0.0135
13	15	Epoxy+6% GF	20	60°	850 μ m	25	300	2.5	8.3645	8.3234	0.0040
14	15	Epoxy+6% GF	25	90°	425 μ m	30	100	3	8.3645	8.3320	0.0032
15	15	Epoxy+6% GF	30	30°	600 μ m	35	200	2	8.3645	8.3300	0.0033
16	15	Epoxy +6%GF+ 3%Na ₂ CO ₃	20	90°	600 μ m	35	100	2.5	9.8683	9.7700	0.0079
17	15	Epoxy +6%GF+ 3% Na ₂ CO ₃	25	30°	850 μ m	25	200	3	9.8683	9.7650	0.0083
18	15	Epoxy +6%GF+ 3% Na ₂ CO ₃	30	60°	425 μ m	30	300	2	9.8683	9.7730	0.0076

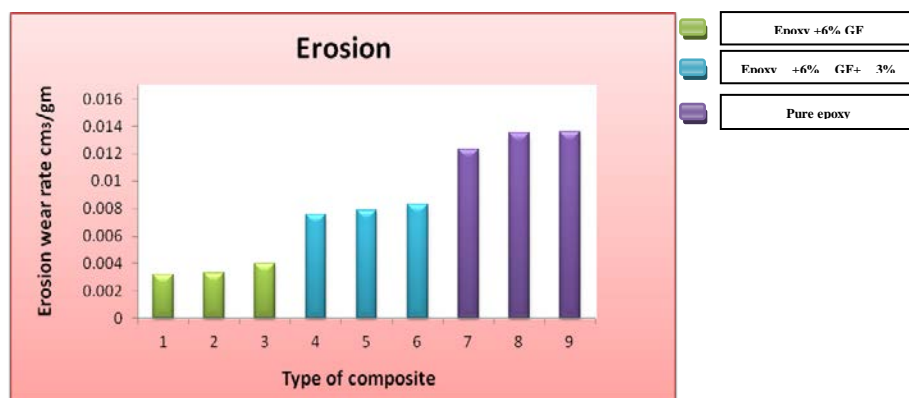


Figure (7) Erosion wear of pure epoxy, epoxy +6% glass fiber and epoxy +6% glass fiber +3% Na₂CO₃ for (15) hours

Table (3) Erosion wear of pure epoxy, epoxy +6% glass fiber and epoxy +6%glass fiber +6% Na₂CO₃

Experiment	Time (hour)	Filler content	Stand-off distance (cm)	angle	grin size (sand) (μ m)	Temperature (C°)	Salt content (gm)	Water content (ml)	Total weight (WS) (gm)	Weight after erosion (WL) (gm)	Erosion rate (€) $W_L/W_S \cdot \rho_s$ (cm ³ /gm)
1	10	Pure epoxy	20	30°	425 μ m	25	100	2	7.7006	7.6800	0.0022
2	10	Pure epoxy	25	60°	600 μ m	30	200	2.5	7.7006	7.6752	0.0027
3	10	Pure epoxy	30	90°	850 μ m	35	300	3	7.7006	7.6600	0.0043
4	10	Epoxy+6% GF	20	30°	600 μ m	30	300	3	8.3645	8.3534	0.0011
5	10	Epoxy+6% GF	25	60°	850 μ m	35	100	2	8.3645	8.3524	0.0017
6	10	Epoxy+6% GF	30	90°	425 μ m	25	200	2.5	8.3645	8.3540	0.0010
7	10	Epoxy+6%GF+ 6%Na ₂ CO ₃	20	60°	425 μ m	35	200	3	10.3664	10.2980	0.0050
8	10	Epoxy +6%GF+ 6% Na ₂ CO ₃	25	90°	600 μ m	25	300	2	10.3664	10.2800	0.0064
9	10	Epoxy +6%GF+ 6% Na ₂ CO ₃	30	30°	850 μ m	30	100	2.5	10.3664	10.2780	0.0065
10	15	Pure epoxy	20	90°	850 μ m	30	200	2	7.7006	7.5743	0.0136
11	15	Pure epoxy	25	30°	425 μ m	35	300	2.5	7.7006	7.5863	0.0123
12	15	Pure epoxy	30	60°	600 μ m	25	100	3	7.7006	7.5753	0.0135
13	15	Epoxy+6% GF	20	60°	850 μ m	25	300	2.5	8.3645	8.3234	0.0040
14	15	Epoxy+6% GF	25	90°	425 μ m	30	100	3	8.3645	8.3320	0.0032
15	15	Epoxy+6% GF	30	30°	600 μ m	35	200	2	8.3645	8.3300	0.0033
16	15	Epoxy +6%GF+ 6%Na ₂ CO ₃	20	90°	600 μ m	35	100	2.5	10.3664	10.2720	0.0070
17	15	Epoxy +6%GF+ 6% Na ₂ CO ₃	25	30°	850 μ m	25	200	3	10.3664	10.2600	0.0079
18	15	Epoxy +6%GF+ 6% Na ₂ CO ₃	30	60°	425 μ m	30	300	2	10.3664	10.2750	0.0067

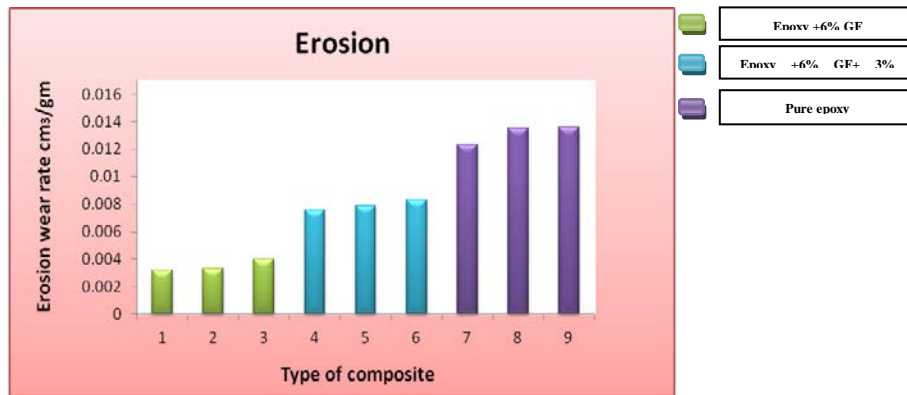


Figure (8) Erosion wear of pure epoxy, epoxy +6% glass fiber and epoxy +6% glass fiber +6% Na₂CO₃ for (15) hours

Table (4) Erosion wear of pure epoxy ,epoxy+6% glass fiber and epoxy +6%glass fiber+3%CaCO₃

Experiment	Time (hour)	Filler content	Stand-off distance (cm)	angle	grin size (sand) (μ m)	Temperature (C°)	Salt content (gm)	Water content (ml)	Total weight (WS) (gm)	Weight after erosion (WL) (gm)	Erosion rate (€) $W_L/W_S \cdot \rho_1$ (cm ³ /gm)
5	10	Pure epoxy	20	30°	425 μ m	25	100	2	7.7006	7.6800	0.0022
2	10	Pure epoxy	25	60°	600 μ m	30	200	2.5	7.7006	7.6752	0.0027
3	10	Pure epoxy	30	90°	850 μ m	35	300	3	7.7006	7.6600	0.0043
4	10	Epoxy+6% GF	20	30°	600 μ m	30	300	3	8.3645	8.3534	0.0011
5	10	Epoxy+6% GF	25	60°	850 μ m	35	100	2	8.3645	8.3524	0.0017
6	10	Epoxy+6% GF	30	90°	425 μ m	25	200	2.5	8.3645	8.3540	0.0010
7	10	Epoxy+6%GF + 3%CaCO ₃	20	60°	425 μ m	35	200	3	7.6703	7.6586	0.0011
8	10	Epoxy+6%GF + 3%CaCO ₃	25	90°	600 μ m	25	300	2	7.6703	7.6550	0.0015
9	10	Epoxy+6%GF + 3%CaCO ₃	30	30°	850 μ m	30	100	2.5	7.6703	7.6500	0.0020
10	15	Pure epoxy	20	90°	850 μ m	30	200	2	7.7006	7.5743	0.0136
11	15	Pure epoxy	25	30°	425 μ m	35	300	2.5	7.7006	7.5863	0.0123
12	15	Pure epoxy	30	60°	600 μ m	25	100	3	7.7006	7.5753	0.0135
13	15	Epoxy+6% GF	20	60°	850 μ m	25	300	2.5	8.3645	8.3234	0.0040
14	15	Epoxy+6% GF	25	90°	425 μ m	30	100	3	8.3645	8.3320	0.0032
15	15	Epoxy+6% GF	30	30°	600 μ m	35	200	2	8.3645	8.3300	0.0033
16	15	Epoxy+6%GF + 3%CaCO ₃	20	90°	600 μ m	35	100	2.5	7.6703	7.6430	0.0027
17	15	Epoxy+6%GF + 3%CaCO ₃	25	30°	850 μ m	25	200	3	7.6703	7.6400	0.0031
18	15	Epoxy+6%GF + 3%CaCO ₃	30	60°	425 μ m	30	300	2	7.6703	7.6450	0.0025

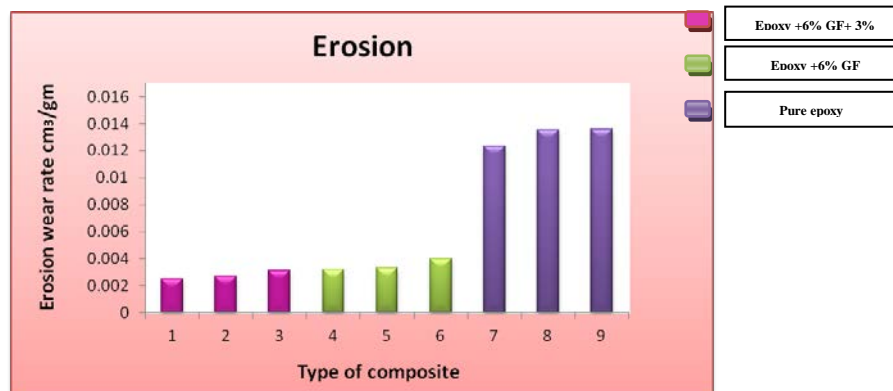


Figure (9) Erosion wear of pure epoxy, epoxy +6% glass fiber and epoxy +6% glass fiber +3% CaCO₃ for (15) hours

Table (5) Erosion wear of pure epoxy, epoxy +6% glass fiber and epoxy +6%glass fiber +6% CaCO₃

Experiment	Time (hour)	Filler content	Stand-off distance (cm)	angle	grin size (sand) (μ m)	Temperature (C°)	Salt content (gm)	Water content (ml)	Total weight (Ws) (gm)	Weight after erosion (WL) (gm)	Erosion rate (€) $\frac{W_L}{W_S} \cdot \rho_t$ (cm ³ /gm)
1	10	Pure epoxy	20	30°	425 μ m	25	100	2	7.7006	7.6800	0.0022
2	10	Pure epoxy	25	60°	600 μ m	30	200	2.5	7.7006	7.6752	0.0027
3	10	Pure epoxy	30	90°	850 μ m	35	300	3	7.7006	7.6600	0.0043
4	10	Epoxy+6% GF	20	30°	600 μ m	30	300	3	8.3645	8.3534	0.0011
5	10	Epoxy+6% GF	25	60°	850 μ m	35	100	2	8.3645	8.3524	0.0017
6	10	Epoxy+6% GF	30	90°	425 μ m	25	200	2.5	8.3645	8.3540	0.0010
7	10	Epoxy+6%GF + 6%CaCO ₃	20	60°	425 μ m	35	200	3	8.2050	8.2000	0.00046
8	10	Epoxy+6%GF + 6%CaCO ₃	25	90°	600 μ m	25	300	2	8.2050	8.1900	0.0013
9	10	Epoxy+6%GF + 6%CaCO ₃	30	30°	850 μ m	30	100	2.5	8.2050	8.1850	0.0018
10	15	Pure epoxy	20	90°	850 μ m	30	200	2	7.7006	7.5743	0.0136
11	15	Pure epoxy	25	30°	425 μ m	35	300	2.5	7.7006	7.5863	0.0123
12	15	Pure epoxy	30	60°	600 μ m	25	100	3	7.7006	7.5753	0.0135
13	15	Epoxy+6% GF	20	60°	850 μ m	25	300	2.5	8.3645	8.3234	0.0040
14	15	Epoxy+6% GF	25	90°	425 μ m	30	100	3	8.3645	8.3320	0.0032
15	15	Epoxy+6% GF	30	30°	600 μ m	35	200	2	8.3645	8.3300	0.0033
16	15	Epoxy+6%GF + 6%CaCO ₃	20	90°	600 μ m	35	100	2.5	8.2050	8.1775	0.0025
17	15	Epoxy+6%GF + 6%CaCO ₃	25	30°	850 μ m	25	200	3	8.2050	8.1760	0.0026
18	15	Epoxy+6%GF + 6%CaCO ₃	30	60°	425 μ m	30	300	2	8.2050	8.1800	0.0023

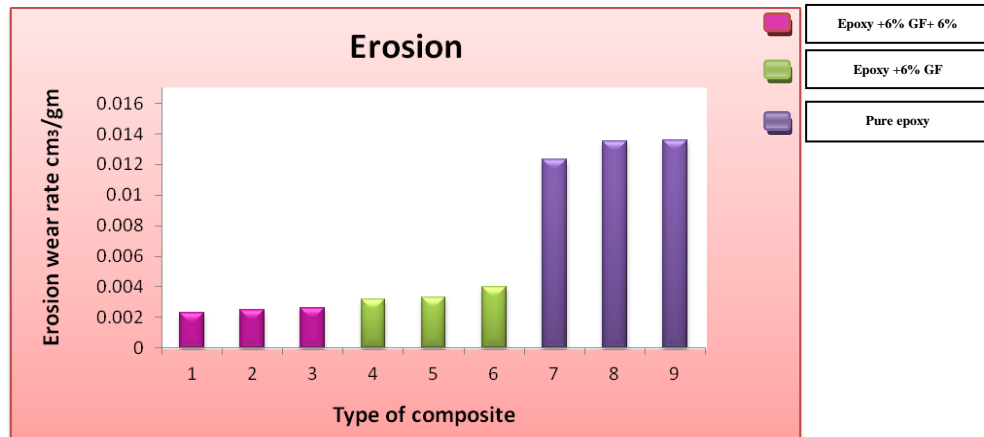


Figure (10) Erosion wear of pure epoxy, epoxy +6% glass fibers and epoxy +6% glass fiber +6% CaCO₃ for (15) hours

Table (6) Erosion wear of pure epoxy, epoxy +6% glass fiber and epoxy +6% glass fiber +3% K₂CO₃

Experiment	Time (hour)	Filler content	Stand-off distance (cm)	angle	grin size (sand) (μ m)	Temperature (C°)	Salt content (gm)	Water content (ml)	Total weight (WS) (gm)	Weight after erosion (WL) (gm)	Erosion rate (€) $\frac{W_L}{W_S} \cdot \rho_t$ (cm ³ /gm)
1	10	Pure epoxy	20	30°	425 μ m	25	100	2	7.7006	7.6800	0.0022
2	10	Pure epoxy	25	60°	600 μ m	30	200	2.5	7.7006	7.6752	0.0027
3	10	Pure epoxy	30	90°	850 μ m	35	300	3	7.7006	7.6600	0.0043
4	10	Epoxy+6% GF	20	30°	600 μ m	30	300	3	8.3645	8.3534	0.0011
5	10	Epoxy+6% GF	25	60°	850 μ m	35	100	2	8.3645	8.3524	0.0017
6	10	Epoxy+6% GF	30	90°	425 μ m	25	200	2.5	8.3645	8.3540	0.0010
7	10	Epoxy+6%GF + 3%K ₂ CO ₃	20	60°	425 μ m	35	200	3	8.2664	8.1681	0.0096
8	10	Epoxy+6%GF + 3%K ₂ CO ₃	25	90°	600 μ m	25	300	2	8.2664	8.1651	0.0099
9	10	Epoxy+6%GF + 3%K ₂ CO ₃	30	30°	850 μ m	30	100	2.5	8.2664	8.1630	0.0101
10	15	Pure epoxy	20	90°	850 μ m	30	200	2	7.7006	7.5743	0.0136
11	15	Pure epoxy	25	30°	425 μ m	35	300	2.5	7.7006	7.5863	0.0123
12	15	Pure epoxy	30	60°	600 μ m	25	100	3	7.7006	7.5753	0.0135
13	15	Epoxy+6% GF	20	60°	850 μ m	25	300	2.5	8.3645	8.3234	0.0040
14	15	Epoxy+6% GF	25	90°	425 μ m	30	100	3	8.3645	8.3320	0.0032
15	15	Epoxy+6% GF	30	30°	600 μ m	35	200	2	8.3645	8.3300	0.0033
16	15	Epoxy+6%GF + 3%K ₂ CO ₃	20	90°	600 μ m	35	100	2.5	8.2664	8.1500	0.0114
17	15	Epoxy+6%GF + 3%K ₂ CO ₃	25	30°	850 μ m	25	200	3	8.2664	8.1450	0.0119
18	15	Epoxy+6%GF + 3%K ₂ CO ₃	30	60°	425 μ m	30	300	2	8.2664	8.1553	0.0109

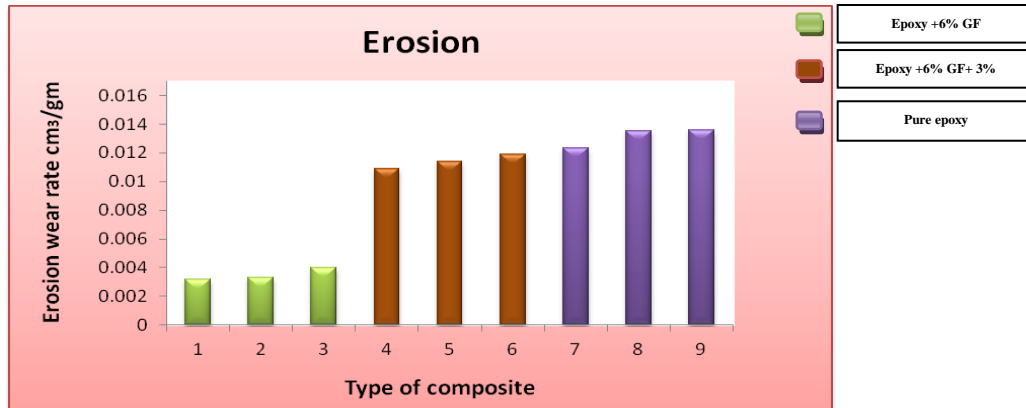


Figure (11) Erosion wear of pure epoxy, epoxy +6% glass fiber and epoxy +6% glass fiber +3% K₂CO₃ for (15) hours

Table (7) Erosion wear of pure epoxy, epoxy +6% glass fiber and epoxy +6% glass fiber +6% K₂CO₃

Experiment	Time (hour)	Filler content	Stand-off distance (cm)	angle	grin size (sand) (μ m)	Temperature (C°)	Salt content (gm)	Water content (ml)	Total weight (WS) (gm)	Weight after erosion (WL) (gm)	Erosion rate (€) $\frac{W_L - W_S}{\rho \cdot t}$ (cm ³ /gm)
1	10	Pure epoxy	20	30°	425 μ m	25	100	2	7.7006	7.6800	0.0022
2	10	Pure epoxy	25	60°	600 μ m	30	200	2.5	7.7006	7.6752	0.0027
3	10	Pure epoxy	30	90°	850 μ m	35	300	3	7.7006	7.6600	0.0043
4	10	Epoxy+6% GF	20	30°	600 μ m	30	300	3	8.3645	8.3534	0.0011
5	10	Epoxy+6% GF	25	60°	850 μ m	35	100	2	8.3645	8.3524	0.0017
6	10	Epoxy+6% GF	30	90°	425 μ m	25	200	2.5	8.3645	8.3540	0.0010
7	10	Epoxy+6%GF+6%K ₂ CO ₃	20	60°	425 μ m	35	200	3	8.5949	8.4990	0.0086
8	10	Epoxy+6%GF+6%K ₂ CO ₃	25	90°	600 μ m	25	300	2	8.5949	8.4940	0.0091
9	10	Epoxy+6%GF+6%K ₂ CO ₃	30	30°	850 μ m	30	100	2.5	8.5949	8.4900	0.0095
10	15	Pure epoxy	20	90°	850 μ m	30	200	2	7.7006	7.5743	0.0136
11	15	Pure epoxy	25	30°	425 μ m	35	300	2.5	7.7006	7.5863	0.0123
12	15	Pure epoxy	30	60°	600 μ m	25	100	3	7.7006	7.5753	0.0135
13	15	Epoxy+6% GF	20	60°	850 μ m	25	300	2.5	8.3645	8.3234	0.0040
14	15	Epoxy+6% GF	25	90°	425 μ m	30	100	3	8.3645	8.3320	0.0032
15	15	Epoxy+6% GF	30	30°	600 μ m	35	200	2	8.3645	8.3300	0.0033
16	15	Epoxy+6%GF+6%K ₂ CO ₃	20	90°	600 μ m	35	100	2.5	8.5949	8.4700	0.0113
17	15	Epoxy+6%GF+6%K ₂ CO ₃	25	30°	850 μ m	25	200	3	8.5949	8.4650	0.0117
18	15	Epoxy+6%GF+6%K ₂ CO ₃	30	60°	425 μ m	30	300	2	8.5949	8.4800	0.0104

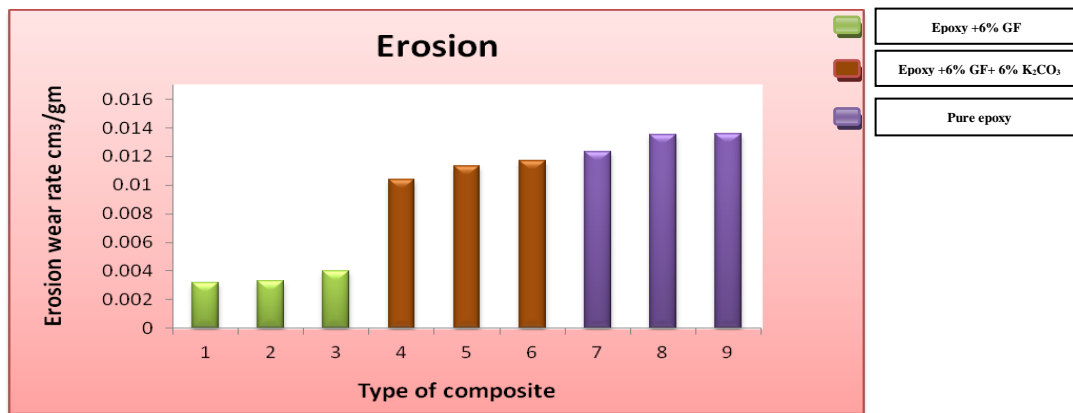


Figure (12) Erosion wear of pure epoxy, epoxy +6% glass fiber and Epoxy +6% glass fiber +6% K₂CO₃ for (15) hours

Coating

The results of coating and erosion wear after coating for the pure epoxy and industrial-based materials composites are illustrated in Tables (8). Erosions characteristics of uncoated samples are depicted in tables (2) to (7) and figures (7) to (12). The (Epoxy+6% Glass Fiber +6% CaCO₃) experiment showed the best resistance to erosion among the industrial-based materials. The (pure epoxy) experiment (10) has been characterized by the following parameters; erosion time of (15 hours), distance of (20 cm), (90°) of impingement angle, (850 μm) grain size, (30 °C) temperature, (200 gm) salt in (2 liters) of water. The weight of the investigated sample of experiment (10) before coating has been equal to (7.5743 gm), after coating the total weight amounted to (7.9042 gm) which corresponds to a coating thickness of (16 ± 1) μm. After erosion, the sample weight has been found equal to (7.9030 gm) with a loss of (0.0012 gm) from the coating layer only. This has been verified under the optical microscope where the coating layer after erosion was measured equal to 10 μm as shown in figure (13). The (epoxy+6% glass fiber) experiment (13) has been characterized by the following parameters; erosion time of (15 hours), distance of (20 cm), (60°) of impingement angle, (850 μm) grain size, (25 °C) temperature, (300 gm) salt in (2.5 liters) of water. The weight of the investigated sample of experiment (13) before coating has been equal to (8.3234 gm), after coating the total weight amounted to (8.6623 gm). After erosion, the sample weight has been found equal to (8.6614 gm) with a loss of (0.0009 gm) from the coating layer only. The (epoxy+6% glass fiber +3% Na₂CO₃) experiment (17) has been characterized by the following parameters; erosion time of (15 hours), distance of (25 cm), (30°) of impingement angle, (850 μm) grain size, (25 °C) temperature, (200 gm) salt in (3 liters) of water. The weight of the investigated sample of experiment (17) before coating has been equal to (9.7650 gm), after coating the total weight amounted to (10.1031 gm). After erosion, the sample weight has been found equal to (10.1026 gm) with a loss of (0.0005 gm) from the coating layer only. The weight of the (epoxy+6% glass fiber +6% Na₂CO₃) sample before coating has been equal to (10.2600 gm), after coating the total weight amounted to (10.5981 gm). After erosion, the sample weight has been found equal to (10.5977 gm) with a loss of (0.0004 gm) from the coating layer only. The weight of the (epoxy+6% glass fiber + 3% CaCO₃) sample before coating has been equal to (7.6400 gm), after coating the total weight amounted to (7.9599 gm). After erosion, the sample weight has been found equal to (7.9596 gm) with a loss of (0.0003 gm) from the coating layer only. The weight of the (epoxy+6% glass fiber +6% CaCO₃) sample before coating has been equal to (8.1760 gm), after coating the total weight amounted to (8.5139 gm). After erosion, the sample weight has been found equal to (8.5137 gm) with a loss of (0.0002 gm) from the coating layer only. The weight of the (epoxy+6% glass fiber +3% K₂CO₃) sample before coating has been equal to (8.1450 gm), after coating the total weight amounted to (8.4746 gm). After erosion, the sample weight has been found equal to (8.4739 gm) with a loss of (0.0007 gm) from the coating layer only. The weight of the (epoxy+6% glass fiber +6 %K₂CO₃) sample before coating has been equal to (8.4650 gm), after coating the total weight amounted to (8.8025 gm). After erosion, the sample weight has been found equal to (8.8019 gm) with a loss of (0.0006 gm) from the coating layer only.

Table (8) (coating and erosion wear after coating for the pure epoxy and industrial based material composites)

Composites	Weight before erosion (gm)	Weight after erosion at 15 hour (gm)	Weight after coating (gm)	Weight after erosion at 15 hour (gm)
Pure epoxy	7.7006	7.5743	7.9042	7.9030
Epoxy+6% glass fiber	8.3645	8.3234	8.6623	8.6614
Epoxy+6%GF+3% Na ₂ CO ₃	9.8683	9.7650	10.1031	10.1026
Epoxy+6%GF+6% Na ₂ CO ₃	10.3664	10.2600	10.5981	10.5977
Epoxy+6% GF+3% CaCO ₃	7.6703	7.6400	7.9599	7.9596
Epoxy+6% GF+6% CaCO ₃	8.2050	8.1760	8.5139	8.5137
Epoxy+6% GF+3% K ₂ CO ₃	8.2664	8.1450	8.4746	8.4739
Epoxy+6% GF+6% K ₂ CO ₃	8.5949	8.4650	8.8025	8.8019

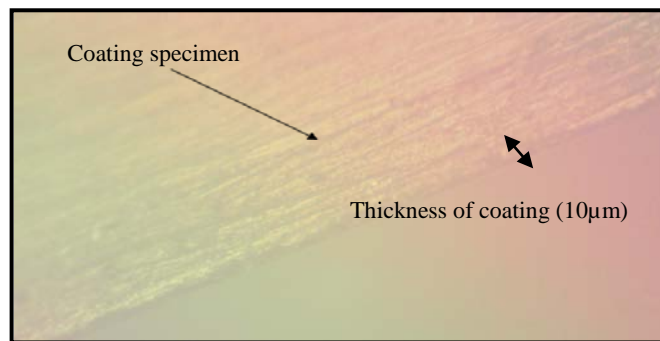


Figure (13) Specimen after Coating for pure epoxy at (100x)

Conclusions

The industrial composites give the lower erosion wear than (pure epoxy and epoxy +6% glass fiber) composite material. Composites with (epoxy +6% glass fiber +6%CaCO₃) give better erosion resistance at (30 cm) stand – off distance , (60°) angle , (425µm) grin size of sand , (30C) temperature , (300 gm) salt content in (2liter) of water and (15hours) time , while the higher erosion wear is for the (epoxy +6% glass fiber+6% K₂CO₃) .The loss of weight of pure epoxy (0.1%) for (epoxy+6%glass fiber) (0.04%) for (epoxy+6%glass fiber+6% CaCO₃) (0.013%). Results that coating specimens with RHA-mixed epoxy resin improve erosion wear resistance characteristics of the coated specimens.

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