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STUDY THE EROSION WEAR BEHAVIOR FOR UNSATURATED POLYESTER RESIN COMPOSITES MATERIALS REINFORCED BY CARBON FIBERS WITH AL_2O_3 POWDER USING TAGUCHI METHO

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Abstract: this research investigates the erosion wear behavior of polyester resin composites materials reinforced with 4% volume fraction carbon fiber and (2%, 4%, 6% and 8%) volume fraction Al_2O_3 powder. These specimens were fabricated by hand lay-up technique. Erosion wear behavior was studied at different variables, are angles impingement (30°, 60°, 90°), with dry silica sand particles size (350,425,600 µm) at 10 hour, stand-off distance (17 cm) and flow rate (35 L ⁄min). In this research erosion testing were carried out according to ASTM G76 and study effect of parameters on erosion wear rate by using Taguchi orthogonal arrays L9. The results indicate that, the specimen (UP+4%C.F+8% Al_2O_3) has high value of true density than other specimens. Also the specimen (UP+4%C.F+8% Al_2O_3) has (0.00011 cm^3/gm) better erosion rate resistance at variables (425 µm , 30 °) as compare to other composite materials . The ANOVE analysis showed that filler content factor (Al_2O_3) powder more effect on erosion rate than other factors .

Keywords: *Polymer Composite, Unsaturated Polyester Resin, Carbon Fiber, Erosion Wear, True density, Taguchi method, S/N ratio, ANOVE*.

دراسة سلوك بلى التعرية لمواد متراكبة من راتنج البولي استر غير المشبع مقواه بالألياف الكاربون مع مسحوق ألومينا باستخدام طريقة تاكوجي

الخلاصة: في هذا البحث تم التقصي عن سلوك بلى التعرية لمواد متراكبة من راتنج البولي استر غير المشبع المقواة مع كسر حجمي4 % من الالياف الكاربون ومسحوق الالومينا بكسور حجمية (2%، 4%، 6% و 8%)، صنعت هذة العينات بتقنية الصب اليدوي . تم دراسة سلوك بلى التعرية عند متغيرات مختلفة وكانت زاوية التصادم (30°, 60°, 90°) و حجم دقائق رمل السيكا الجافه 350,425,600 (µm) مايكرون عند 10ساعات و مسافة التصادم (17cm) و معدل جريان (35 L⁄min) . في هذا البحث كان اختبار بلى التعرية وفقا (ASTM G76) و دراسة تأثير المتغيرات على معدل بلى التعرية بواسطة استخدام المصفوفات المتعامدة لتاكوجي L9 . اشارت النتائج ان عينة ($UP+4\%CF+8\%Al_2O_3$) تمتلك اعلى قيمة من الكثافة الحقيقية من العينات الاخرى . ايضا من النتائج يمكن ملاحظة ان العينة (UP+4%C.F+8% Al_2O_3) تمتلك (0.00011 cm^3/gm) افضل مقاومة لتعرية عند المتغيرات (425 µm , 30 °) كمقارنة مع المواد المتراكبة الاخرى . تحليل الانوفا اظهر بان عامل محتوى الحشوه لدقائق (Al_2O_3) هو الاكثر تاثيرا على معدل التعرية من العوامل الاخرى.

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1. Introduction

The engineering materials can be classified in to three groups: polymers, metals and ceramics. These materials can be combining from these types or even different materials on every group , In order to get the distinctive characteristics of materials [1]. A composite materials can be defined as a substance consisting of two or more materials no soluble with other material have certain characteristics differ from the properties of the other material [2]. Polymer composites reinforced with particles are widely used in many applications because it is inexpensive and also easy fabricate [3]. Mechanical properties of polymer matrix composite materials reinforced by filler powder rely powerfully on the particle size of filler , adhesion connect between matrix with particle and filler content [4]. Unsaturated polyester resin is one of the types of polymers thermoset and are widely used in many fields Because of the properties owned in addition to ease of use [5].

The polymeric composite materials consisting from polyester resin possesses resistance from environmental conditions and carried of forces to the fiber reinforcement and these composites will be given a wide array of mechanical, thermal , chemical and physical properties depend in to installation of the unsaturated polyester resin [5]. Solid particle erosion is a term commonly used to depict the mechanical endurance (wear) of any material subject to flooding of the suspended particles affecting its surface. Damage created by has been accounted for in a few industries for a wide range of situations. One of them influences erosion, which is a crucial problem in many industrial applications, such as aircraft structures and turbine blades , pipes, boats, sewage ,…etc. due to impingements of solid particles being suspended in the fluids flowing at high velocity. The erosion of solid particles can be defined as the gradual loss of the weight from a solid surface material due to the mechanical erosion between the surface and solid particles. It is widely assumed that the polymer and its compounds have poor dissociation resistance.

Erosion rates (ER) are much higher than metals. Also, the corrosion rate of compound polymer material is higher than that of a neat polymer. Erosive wear is a dynamic procedure that causes material decay and shortens the service life of the parts [6]. Taguchi procedure it includes parameter design, framework design, and toleration design steps to obtain a robust process and result for the best item quality. The basic confidence of the Taguchi method is its use of design parameter which is an engineering method for product or procedure outline that concentrate on select the parameter (element) settings delivering the best levels of a quality properties "execution measure" with least variety [7] .

Patnaik A. et. al., have studied the solid particle erosion wear for composite hybrid materials consisting of unsaturated polyester resin, G.F and Al_2O_3 particles (mean size 50 μm) at three various weight fraction (0%, 10% and 20%) Al_2O_3. The design experiments approach using Taguchi's orthogonal arrays L27 has been used with impingement angle of (45^o, 60^o, and 90^o), speed impact (32, 45, 58 m/sec) erodent size (300,500,800 μm) ,stand - off distance (120,180,240mm) and filler content (0,10,20%) . The result shows the specimen UP – G.F composite without Al_2O_3 particles have greater erosion loss than specimen reinforced with Al_2O_3 particles. Also form result the peak erosion rate is found at 60^o angle under different experimental conditions [8].

Niharika Mohanta and Dr S K Acharya [9] have studied the influence of red mud filler, speed particle and impact angle on the solid particle erosion behavior of composite epoxy resin matrix reinforced with glass fiber. The erosive wear of red mud with glass fiber and EP. Resin composites is estimated at type impact angles from 30º to 90º and at three different speeds of 48, 70, 82 m/s. The user erodent is silica sand with a size range 150–250μm of irregular shapes. The result appears erosion wear behavior with maximum erosion rate at 60º impingement angle. As found the glass fiber reinforced plastic (GFRP) composite with 25%red mud as filler exhibit lower erosive wears . Specimen epoxy + glass fiber without filler has the higher erosion rate due to weak strength of the connections between matrix and strength [9].

Aseel Basim et. al., [10]. have study the effect of 2%,4%,6% volume fraction from micro powder (Al_2O_3, SiO_2, TiO_2) with 3% glass fiber (GF) and epoxy resin as matrix of composites materials on erosion behavior . The results revealed that the neat epoxy has a weak resistance to erosion than micro composites materials also the specimen (Ep+3%GF+6% SiO_2) has great resistance to erosion than 6% $Al_2O_{3,}$ 6% TiO_2 composites materials. The peak erosion is carried out at 60°an impact angle. Erosion wear resistance increase with volume fraction increase [10].

2. Objectives of the Research

The objective of this research:

1. Study true density of the specimens composite materials in other to use the value of true density to find the erosion wear rate .
2. Use Taguchi experiment design method on erosion wear rate at different variables for specific composite materials .
3. Study the ANOVE analysis and indicate the most influence factors on erosion wear rate.

3. Experimental Work

3.1. *Materials Used and Specimen Preparation*

The materials used for the specimens preparation polymer composite materials consisting of unsaturated polyester resin as matrix it is prepared from the (Saudi company) with 4% volume fraction of carbon fibers from the type (Carbon UD Stockinette from Tenax Company, England the advantage of the Carbon UD Stockinette) is that it can be used for shaped models to have high-strength resin laminates and (2%, 4%, 6% and 8%) volume fraction of Al_2O_3 was provided from (Sigma-Aldrich Company, made in Germany) in the form of powder has mean particle size (1.914 μm) . “Table 1” shows typical properties of unsaturated polyester resin, carbon fiber, and Al_2O_3 powder respectively. The mold used for Preparation of specimens composite materials made of glass with dimensions of (120×120×5) mm.

The method used in the preparation of the specimens in this research is (Hand lay-Up Molding). “Table 2” indicates percentages of the specimens.

Table 1. Typical properties of materials used

Unsaturated Polyester resin [11]		Carbon fiber [12]		Al_2O_3 Powder	
Density	1.1 gm/cm^3	Density	1.81 gm/cm^3	Density	4.05 gm/cm^3
Tensile Strength	70.3 -103 MPa	Tensile Strength	5600 MPa	Melting point	2050 (C°)
Percent Elongation (EL%)	<2.6	Tensile Modulus	290 GPa	mean particle size	1.914 μm

Table 2. Designation and percentages of specimens

Specimens	Percentages
A1	Unsaturated polyester
A2	Unsaturated Polyester+4% Carbon fiber
A3	Unsaturated Polyester+4% Carbon fiber +2% Al_2O_3
A4	Unsaturated Polyester+4% Carbon fiber +4% Al_2O_3
A5	Unsaturated Polyester+4% Carbon fiber +6% Al_2O_3
A6	Unsaturated Polyester+4% Carbon fiber +8% Al_2O_3

3.2. True Density

This test is performed by (D792) standard at the room temperature [13]. The true density (ρ_t) is calculated from the method of immersion in water at 24 hour (Archimedes base) using the following relationship. Specimens for this test size (30mm×20mm×4mm).

$$\rho t = \frac{Wd}{Ws - Wn} * D \qquad (1)\ [13]$$

Where:

ρ_t : True density (gm/cm^3).

D : Density of distilled water (1 gm/cm3).

W_d : Dry weight of the specimen (gm).

W_n : Weight of the specimen when submerged with water (gm).

W_s : Weight of the specimen after saturation in water at (24 hour) (gm).

3.3. *Erosion Wear Testing and Taguchi Experimental Design:*

Erosion wear test was carried out as per ASTM G76 [14] at room temperature. The dimensions of the specimens for erosion wear test were (3cm length, 2cm width 0.4 mm thickness). "Fig. (1)" shows sketch illustration of erosion wear device draw a plastic (Perspex) tank is used as a chamber. The tank has a measurements of 40 cm long, 20 cm in height, and 20 cm in width. The nozzle diameter 5mm , pump diameter is 40 mm, and flow rate 35 (L/min) . The pump joints and valves linked with the chamber they are produced by using the steel and slurry as well as jet nozzle. Erosion wear tests are execution through changing the brink between the liquid flow and the horizontal pivot of the test example α . Dry silica sand of various particle sizes was used as erodent. Erosion rate of the volume loss (v) after (10 hour) can be obtain form the following equation [15].

$$\mathrm{v} = \frac{\varepsilon}{\rho} = \frac{WL}{WS * \rho} \qquad (2)$$

Where:

V : Volume loss

W_L: (Weight of the specimen before erosion (gm) - Weight of the specimen after erosion (gm))

Ws: weight of the specimen before erosion (gm).

ρ : True density of the testing composites material (gm/cm^3) .

The impacts of these three parameters on erosion wear rate of these composite materials are studied by using L9 orthogonal array design. The levels of variables used in the experiment erosion test are given in "Table 3 (A&B)" where used L9 orthogonal array twice. The erosion wear rate tests are conducted as per the L9 experimental design show in "Table 4". Experimental observations are also converted into signal-to-noise ratios (S / N). The S / N ratio of the lower erosion rate can be expressed as ''less is better" characteristic, which is calculated as logarithmic transformation of loss function as per the equation shown below Smaller is the better [16].

$$\frac{S}{N} = -10\log\frac{1}{n}\left(\sum y2\right) \qquad (3)$$

Where:

S/N = It is the ratio between the desired factors to undesirable factors.

N = is the number of observations.

Y = the erosion wear rate.

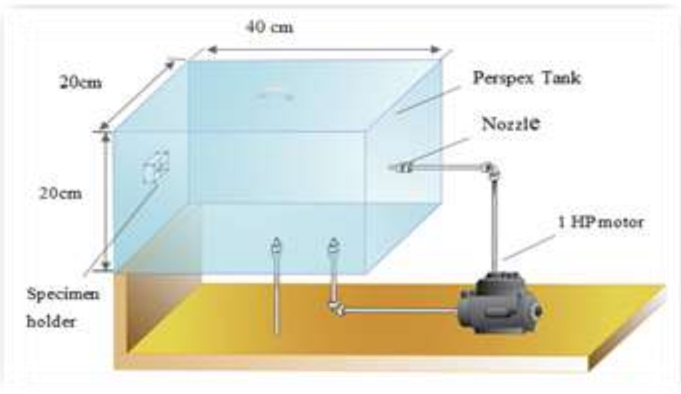


Figure 1. Sketch illustration of erosion wear device

Table 3. Variables used in the experiment erosion wear test

(A)

Factors	Levels			Unite
	1	2	3	
A: Filler Content (Al_2O_3)	A1	A2	A3	%
B: Erodent size of silica sand	350	425	600	µm
C: Impingement angle	30º	60º	90º	degree

(B)

Factors	Levels			Unite
	1	2	3	
A: Filler Content (Al_2O_3)	A4	A5	A6	%
B: Erodent size of silica sand	350	425	600	µm
C: Impingement angle	30º	60º	90º	degree

Table 4. Taguchi orthogonal array design (L9) [17]

Experiment no.	Factor (A) Filler Content	Factor (B) Erodent size of silica sand	Factor (C) Impingement angle
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

4. Results and Discussion

4.1. *True Density*

"Fig.2" shows the result of true density for the composites materials specimens compared with unsaturated polyester resin . From the "Fig. 2" it may be noted that the true density of composites increased when the volume fraction of reinforcement increased due the density of carbon fiber and Al_2O_3 powder higher than the density of unsaturated polyester resin. The specimen (UP+ 4% CF+8% Al_2O_3) have the highest true density than other specimens , While the lower true density has been found for the specimen (UP + 4% C.F +2% Al_2O_3). In preparation of the composites materials from the resin reinforced with fiber and filler content it is difficult and cause weakness directly on the shrinkage of the matrix. The presence of fiber and filler content creates more voids-prefer sites and this negatively effect on mechanical and physical properties.

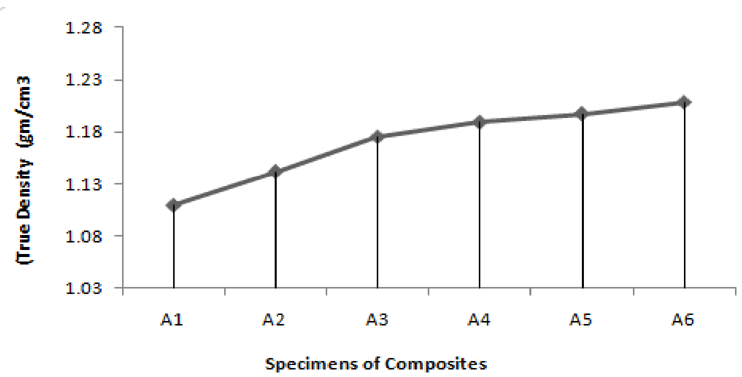


Figure 2. True density of composite materials

4.2. *Taguchi Experiments and Erosion Wear Test*

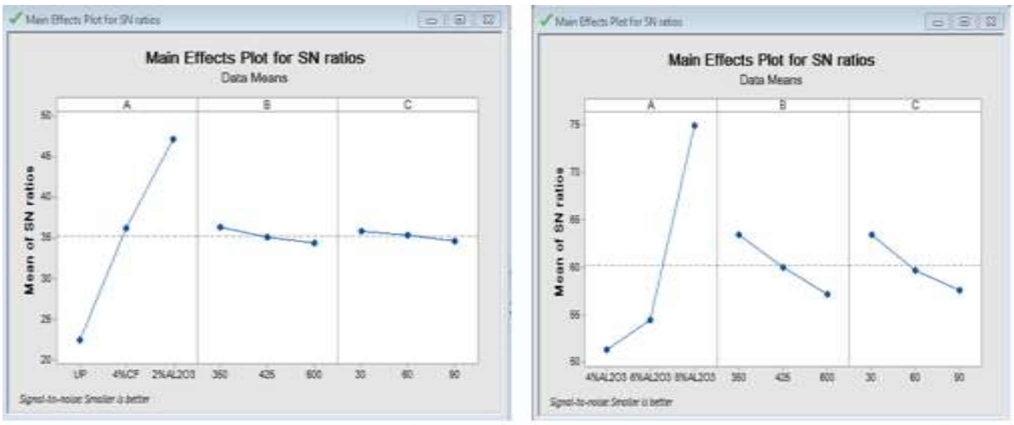
The “Table 5 and 6” show the erosion rate of composites materials for (L9) test runs results. The weight of the specimens composite after erosion is always less than before erosion. The difference in their weight is called mass or weight loss of the specimens due to solid particle impact. The calculated of erosion rate from the "equation (1)". The values of S/N can be obtained from the "equation (2)". The analysis is performed using the common software especially used for design of experiment MINITAB 17. The effects of three factors on erosion rate for different composites are shown in "Fig. 3 (a) and 3(b)". It can be seen that these factors combinations that give minimum erosion rate are (A3, B1 and C1), (A3, B1 and C1) respectively.

Table 5. Results of erosion wears rate of pure unsaturated polyester, UP +4% carbon fiber and UP+4%C.F+2%Al_2O_3

Exp.	Filler Content (A)	Erodent Size of Silica Sand (µm) (B)	Impingement Angle (°) (C)	Weight Before Erosion (gm)	Weight After Erosion (gm)	Erosion Rate (cm^3/gm)	S/N
1	UP	350	30°	1.4342	1.3241	0.0691	23.2104
2	UP	425	60°	1.4342	1.3130	0.0761	22.3723
3	UP	600	90°	1.4342	1.3029	0.0824	21.6815
4	UP+4%C.F	350	60°	1.5462	1.5351	0.0125	38.0618
5	UP+4%C.F	425	90°	1.5462	1.5037	0.0189	34.4708
6	UP+4%C.F	600	30°	1.5462	1.5240	0.0159	35.9721
7	UP+4%C.F+2% Al_2O_3	350	90°	1.7672	1.7585	0.0041	47.7443
8	UP+4%C.F+2% Al_2O_3	425	30°	1.7672	1.7592	0.0038	48.4043
9	UP+4%C.F+2% Al_2O_3	600	60°	1.7672	1.7561	0.0053	45.5145

Table 6. Results of erosion wears rate of UP +4% C.F (4% , 6% and 8% Al_2O_3)

Exp.	Filler Content (A)	erodent size of Silica Sand (µm) (B)	impinge ment angle (°) (C)	Weight before erosion (gm)	Weight after erosion (gm)	Erosion rate (cm^3/gm)	S/N
1	UP+4%C.F+4% Al_2O_3	350	30°	1.9567	1.9534	0.0014	57.0774
2	UP+4%C.F+4% Al_2O_3	425	60°	1.9567	1.9492	0.0032	49.8970
3	UP+4%C.F+4% Al_2O_3	600	90°	1.9567	1.9461	0.0045	46.9357
4	UP+4%C.F+6% Al_2O_3	350	60°	2.1382	2.1350	0.0012	58.4164
5	UP+4%C.F+6% Al_2O_3	425	90°	2.1382	2.1308	0.0028	51.0568
6	UP+4%C.F+6% Al_2O_3	600	30°	2.1382	2.1329	0.0020	53.9794
7	UP+4%C.F+8% Al_2O_3	350	90°	2.2239	2.2234	0.00018	74.8945
8	UP+4%C.F+8% Al_2O_3	425	30°	2.2239	2.2236	0.00011	79.1721
9	UP+4%C.F+8% Al_2O_3	600	60°	2.2239	2.2231	0.00029	70.7520



a - Specimens (A1, A2, A3)   b - Specimens (A4, A5, A6)

Figure 3. (a, b) Effect of control factors on erosion rate

4.3. *ANOVA and Effect of factors on erosion rate*

The ANOVA analysis can be performed from the experimental data for composites materials on erosion rate. "Table (7, 8)" Results are appears of ANOVA for composites materials specimens. This analysis is pledge for a level of confidence importance 5%. The last column of the table appears that the essential influences are very highly significant (all have very small P-values).

Table 7. ANOVA for the specimens (A1,A2,A3) composite materials results

Source	Df	Seq SS	Adj SS	Adj MS	F	P
A	2	0.0088487	0.0088487	0.0044243	1819.89	0.001
B	2	0.0000572	0.0000572	0.0000286	11.77	0.078
C	2	0.0000482	0.0000482	0.0000241	9.91	0.092
Error	2	0.0000049	0.0000049	0.0000024		
Total	8	0.0089590				

Table 8. ANOVA for the specimens (A4,A5,A6) composite materials results

Source	Df	Seq SS	Adj SS	Adj MS	F	P
A	2	0.0000124	0.0000124	0.0000062	41.03	0.024
B	2	0.0000031	0.0000031	0.0000015	10.16	0.090
C	2	0.0000028	0.0000028	0.0000014	9.17	0.098
Error	2	0.0000003	0.0000003	0.0000002		
Total	8	0.0000185				

Erosion wear behavior contains many of mechanisms which are the largely dominated by type factors such as filler content, erodent size of silica sand and impingement angle. From the "Fig. (4,5and 6)" it can be observed the filler content factor more effect on the erosion rate than other factors.

4.3.1. *Influence of filler content on erosion wear rate*

The erosion wear rate of filler strengthened with unsaturated polyester resin has been measured for (UP+4%C.F+ 2%, 4%, 6%, and 8%) volume fraction of Al_2O_3 at different factors as shown in "Fig. (4)". The specimen (UP +4%C.F + 8% Al_2O_3) have the maximum erosion rate resistant than other specimens due to the interconnection between unsaturated polyester resin and carbon fiber with Al_2O_3 powder would be mechanically strong.

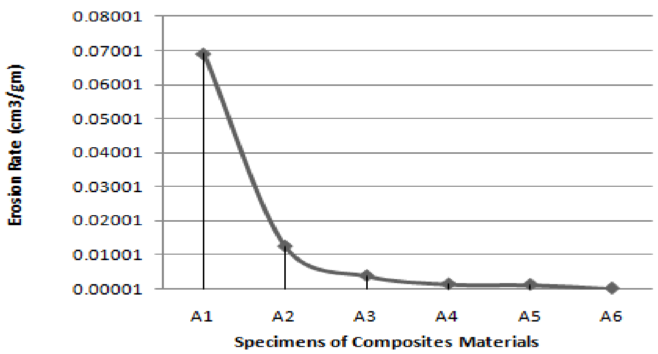
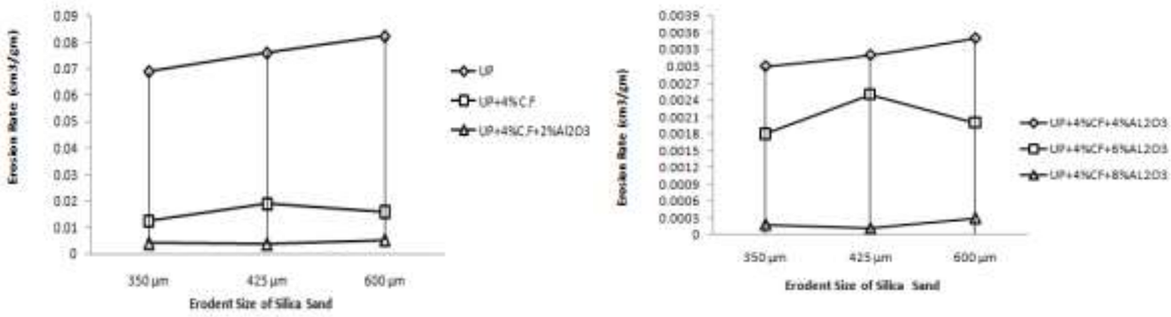


Figure 4. Influence of filler content on erosion wear for all composites specimens

4.3.2. *Influence of erodent size of silica sand erosion wear rate*

The erosion wear rate of filler enhanced with polyester resin has been studied by different size of silica sand (350, 425, and 600) μm at constant flow rate (35 L/min) with 10 hours as shown in "Fig.5". It has been noted from figure that increase in erodent size from 350 to 600 μm the erosion rate increase. From the "Table (5,6)" the specimens

(UP+4% CF+8%Al_2O_3) had better erosion resistance at 425 µm erodent size of silica sand .

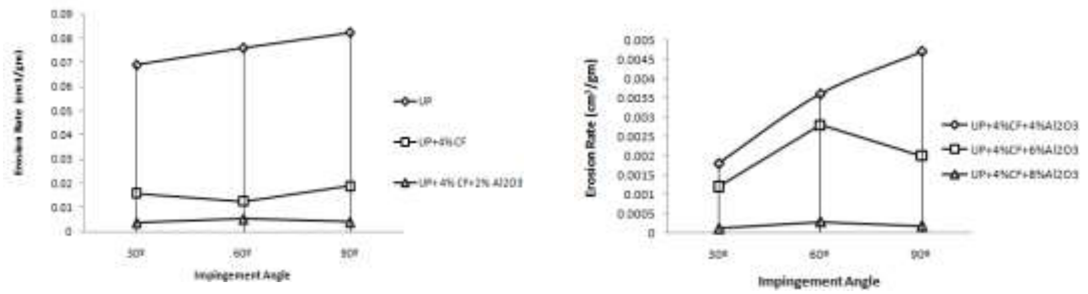


a- Specimens (A1,A2,A3) b- Specimens (A4, A5, A6)

Figure 5. Influence of erodent size of silica sand on erosion rate for all composites specimens

4.3.2 *Effect of impingement angle on erosion rate .*

The influence of different impingement angle (30°, 60°, and 90°) on erosion rate of filler reinforced with polyester resin at 10 hours as shown in "Fig. 6". The erosion of materials is widely classified as either ductile or brittle based on the dependence of their erosion rate on impingement angle .The behavior of the ductile materials is characterized by maximum erosion rate at low impingement angle (15°-30°) , on the other hand the brittle materials show maximum erosion under impingement angle (90) [18,19]. It is observed from figure the increase in impingement angle from (30° to 90° µm) erosion rate increase. From the "Table (5,6)" the specimen (UP + 4%CF+ 8%Al_2O_3) give the maximum erosion rate found at 60° while the minimum erosion rate at impingement angle (30°) . This indicate semi-ductile erosion response for the all composite materials specimens .



a- Specimens (A1, A2, A3) b- Specimens (A4, A5, A6)

Figure 6. Effect of impingement angle on erosion wear rate for all composites materials specimens

5. Conclusions

The main conclusions of results were:-

1. Composite with (UP + 4% CF+8% Al_2O_3) has the maximum density of (1.208 gm/cm^3) when compared with (2%,4%,6%) volume fraction.

2. The specimen (UP +4% CF +8% Al_2O_3) has ($0.00011 cm^3/gm$) erosion rate resistance at (30^0) impingement angle , (424µm) particle size sand , at (10hours) time , Stand-off distance (17 cm) and flow rate (35 L ⁄min) while the higher erosion wear found in specimen (UP) .
3. From the Taguchi experimental design (ANOVE) filler content factor has great effect on erosion rate of Al_2O_3 filled carbon fibers reinforced unsaturated polyester resin. The response for all specimens' composites materials is found semi-ductile and the maximum erosion wear rate takes place at the impingement of 60º.

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