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Erosion Wear Behavior of Natural and Industrial Material for Polymer Matrix Composite by Using Taguchi Analysis

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K E Y W O R D S

Epoxy resin, $CaCO_3$, eggshell, Erosion Wear, Taguchi method.

A B S T R A C T

The behavior of the erosion wear for samples manufactured by hand layup method of epoxy-supported fiberglass, eggshells and calcium carbonate particles were investigated. The test was performed in accordance with the experimental designs Taguchi (L 9) MINITAB (19) to select samples that have the resistance to erosion under the influence of factors. The erosion rate was assessed under the influence of three factors: weight fraction (2% to 8% eggshells and $CaCO_3$ particles), sand size (450, 650, 850 µm) and angles (30º, 60º, 90º) with a fixed face distance of 30 cm, 10 hours and a flow rate of 45 L/min. The results revealed that the rate of erosion is lower for samples consisting of enhanced epoxy resins (eggshell molecules and $CaCO_3$) with chopped fiber glass compared to unfilled samples. Also from these results, it should be noted that the maximum erosion rate was when the weight fraction (2%), the sand size of 850 µm and the angle of 90º, while the minimum rate of erosion was when weight fraction (8%), sand size 650 µm and 30º angle. In this work, the sample of composite materials behaves in a semi- ductile manner.

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1. Introduction

Composite polymeric material reinforced with fiber and particles consists of two or more various constituents, which stay separate at the (micro and macro) level and have various physical and chemical characteristics [1]. Therefore, because of the addition of any reinforced in the matrix resin, the characteristics of these composite polymeric are significantly affected, almost all types of polymers, such as thermoplastics, thermosets, and elastomers have been used to make polymer composites [2]. Composites material work in opposite medium where they are subjected to outside attacks like solid particle erosion during impingement of solid particles occurs on a targeted cover and creates limited destruction connected with material elimination represents erosive [3]. This situation occurs in oil refineries that carry sand slurry in pipe, impeller turbine blades, open engine structures in the desert environment and engine blades in aircraft, etc. The erosive wear occurs because material loss of material on the exposed surface, whilst solid particle beating at a specific speed. Impact angle, velocity, particle size and target material significantly affect the rate of erosion [4]. There are many studies have investigated the erosive behavior and attempted to find the factors more effect on the values of erosive resistances. Mohan et al. [5] researchers studied the tensile strength, shear strength, hardness and erosion wear behavior of epoxy - aramid fiber strengthened by 1%, 2%, 3%, 4% weight fraction ultra-high molecular weight polyethylene. The erosion wear rate was estimated at various factors such as impingement angles from 30º, 60º, 90º, velocities 20, 30, 40 m/s and erodent size 150, 280 µm at a constant standoff distance (10mm). The results detect that erosion wear rate of ultra-high molecular weight polyethylene with aramid fiber-epoxy resin exhibits lower value as compared to samples unfilled, also the ultimate erosion rate was observed at impingement angle 60º. S. Biswas and Aniva Xess [6] this paper study the effect of different weight fraction of short bamboo fiber (0%, 15%, 30% and 45%) reinforced with epoxy resin composite on erosion wear behavior. From the results least erosion rate existing at sample 30% wt. % and 45wt. % composite. Basim et al. [7&8] have studied the effect of rice husk ash coating with epoxy resin for specimens consisting of (3% and 6%) vol% powders of calcium carbonate, potassium carbonate, sodium carbonate, rice husk ash, carrot fiber and wood supported with 6% volume fraction fiber glass in epoxy resin on erosion wear properties. The rate of erosion was calculated after exposure to different factors (standoff distance, angle, size particle sand, temperature, salt content, water content and time). Note from the results that the coating by using rice husk ash with epoxy resin improved the erosion wear rate. Ray et al. [9] investigated the effect of granite powder filled with glass - epoxy on erosion wear. The erosive wear rate studied for specimens under the influence of variables like velocities, erodent sizes and angles and or then the results were analysis using Taguchi experimental design. Results show the minimize erosion wear rate are found in the specimen (epoxy+40%wt glass fiber +10% granite powder). The aim of this current research discusses erosion tests of epoxy filled with 6% wt. glass chopped fiber and $CaCO_3$ and eggshell powder (0%, 2%, 4%, 6%, 8% wt. %). The test was conducted at different sand size 450µm, 650 µm, 850 µm and angles 30°, 60°,90° with constant standoff distance 30 cm, also analysis the results by using Taguchi design L9.

2. Materials and Preparation Samples

I. Materials

The epoxy (LEYCO-POX101) used a resin matrix equipped with a company "LEYCOCHEM LEYDE GMBH GERMANY" to production the polymer composite. Chopped E-glass utilized in this work and provided by “Tenax Company, England made” as reinforced materials. Calcium carbonate is used in this work as filler material provided from Sigma Aldrich, made in Germany. The particle size distribution for calcium carbonate was examined using (MASTERSIZER 2000) technique for as illustrated in Figure 1, where the mean particle size was (19.9 µm). The egg shells also are used as filler material with epoxy resin after washed with water and dried by the sun to remove membranes then grinding for 2 hours using a mill. Figure 2 shows the particle size analyzer of egg shell powder, where the mean particle size was (22.1 µm).

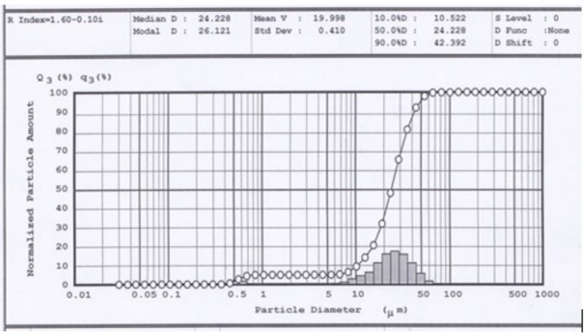


Figure 1: Particle size analyzer of calcium carbonate

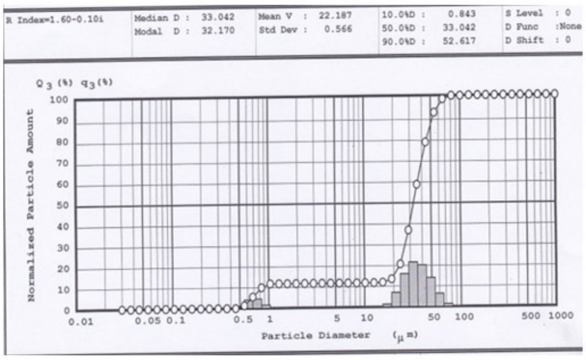


Figure 2: Particle size analyzer of egg shell powder after grinding

II. Specimens Preparation

The dimensions of mold used in this research to prepare samples were (250 mm ×250 mm×5 mm). The mold was made of glass and covered with a layer glass to achieve samples with fine surface and non-roughness. At the beginning, the specific ratio of epoxy resin is placed in a dry and clean glass flask and then adds the specified ratio of the hardener gradually to the epoxy resin. The mixture is mixed continuously and homogeneously at room temperature and then pours the mixture into the middle of the mold. Then cut the chopped glass fibers and weigh from (2% to 8% wt.) for both eggshells and calcium carbonate depending on the dimensions of the mold used in sample preparation and repeat the steps above. Leave the mixture inside the mold for 24 hours at room temperature and removing the samples from the mold, then put them in the oven at a temperature of 60 ºC for 50 minutes in order to get rid of the remaining stresses and increase the strong bond between the base material and the strengthening material. The details of composite specimens are shown in Table 1.

Table 1: Details composition of the specimens

Specimens	Composition
A1	100% Epoxy resin
A2	94% EP+6% G.F
A3	92%EP+ 6%G.F+2% egg shell
A4	90%EP+ 6%G.F+4% egg shell
A5	88%EP+ 6%G.F+6% egg shell
A6	86%EP+ 6%G.F+8% egg shell
B1	92%EP+ 6%G.F+2% $CaCO_3$
B2	90%EP+ 6%G.F+4% $CaCO_3$
B3	88%EP+ 6%G.F+6% $CaCO_3$
B4	86%EP+ 6%G.F+8% $CaCO_3$

3. Erosion Wear Behavior and Experimental Design

The ASTM: G 76 was utilized to study the erosive wear tests of the specimens composites polymeric [10]. Specimens have been cut into the dimensions 30×30×4mm. Three control operators are applied to inspect the erosion wear rate in this work: the weight fraction of ($CaCO_3$, egg shell powder) (2% to 8%), sand size (450µm, 650µm, 850µm) and angle (30º, 60º, 90º). Before and after the erosion test, the specimens composite clean by acetone to remove any sand particles of the surface. Figure (3) illustrates the apparatus used to measure the erosion rate and is a locally manufactured device. Erosion wear rate can be determined from (weight loss of specimens after test (g) divided by total weight of the specimens before the test (g) [11]. The Taguchi experiments were utilized to locate the best operating parameters to analyze erosion behavior. Taguchi technology supplies an effective and systematic methodology for process improvement and is widely utilized for product design and development worldwide [12-13]. Table 2 shows the experimental circumstance for the erosion wear test. Table 3 shows the levels and control factors used to determine the best erosion resistance of the specimens. Table 4 shows the designed experimental runs L9. For a better analysis, the outcomes obtained were transformed into a signal-to-noise ratio. Three types of conversion properties, larger is better, smaller is better and nominal is better. In this research, erosion rate of the polymeric composites is expected to be smaller is better. The signal-to-noise ratio characteristic is given as [14 and 15]:

$$\frac{S}{N} = -10\log\frac{1}{x}\left(\sum\alpha 2\right) \qquad (1)$$

Where:
α: Erosive wear rate.
x :denotes the number of experiments

Table 2: experimental circumstance for the erosion wear test

Circumstance test	Specifications
Erodent size	Sand silica
Erodent shape	angular
Erodent size	450, 650, 850 µm
Flow rate	45 L8/min
Impingement angle	30º, 60º, 90º
Test temperature	RT
Nozzle diameter	4 mm
Pump diameter	50 mm
Time	10 hours

Table 3: Control factors and levels

Factors	Levels			Unite
	1	2	3	
A: weight fraction of $CaCO_3$, egg shell	A1 A4 B1 B4	A2 A5 B2 B5	A3 A6 B3 B6	%
B: Erodent size of silica sand	450	650	850	µm
C: Impingement angle	30º	60º	90º	Degree

Table 4: orthogonal array of L9 Taguchi design

Experiment no.	Factor (A) Weight fraction %	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

Figure 3: Erosion wear device

4. Results and Discussion

I. Erosion Wear Rate

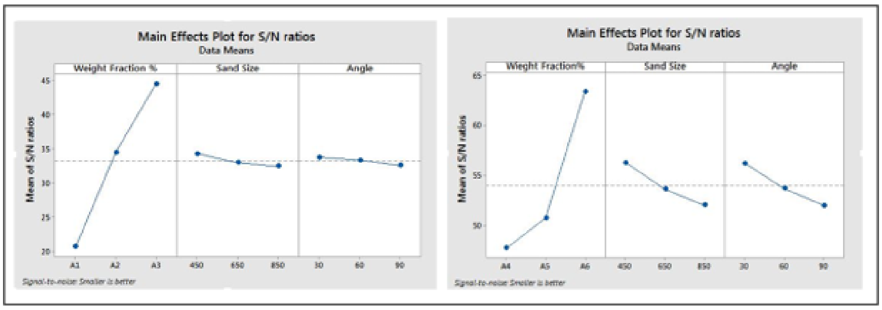
Tables 5 and 6 show the results of erosion wear rates and signal-to-noise ratios analyzed and tabulated using the MINITAB 18 program for samples (chopped glass fiber reinforced epoxy resin with eggshell and $CaCO_3$ particles). We noted from the results of the tables that the high value (S/N) gives the lowest erosion wear rate, so the best resistance to erosion wear rate was present in the samples (Ep+6% CH. GF+8% eggshell and $CaCO_3$) (0.0005g, 0.0001 g) respectively under the variables (8% wt. eggshell and $CaCO_3$, 650µm, 30°). Due to the chopped glass fiber and filler materials gives a good interface with the resin matrix during the erosive wear conditions, this result agrees with [8]. Figure (4) presents, the main effect plot of control factors on erosion wear, where the S/N ratio was not stable for the entire range, suggesting that these factors have the highly consequence on the erosion rate. From the analysis of the results we summarize that 8%wt.eggshell and $CaCO_3$, sand size of 450 µm and an angle of 30º give the minimum erosion rate, so all the factors have an impact on the S/N ratio rate. Figure (5) illustrates the interaction between all factors for all samples. It is clear that the weight fraction of (eggshell and $CaCO_3$), size sand particles and angle is highly interactive and highly effect on erosion wear behavior, because the polymer reinforced with filler (ceramic) tends to be more brittle when the weight fraction increases from 2 to 8%, due to the elongation at break decreases when the reinforcement ratio increases [16].

Table 5: Results erosion wear rate and S/N of samples reinforced with eggshell particles

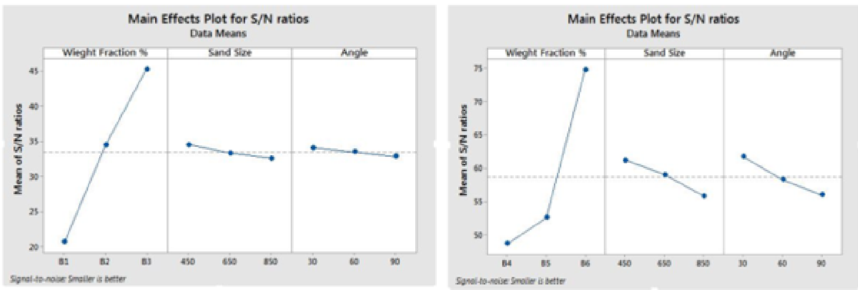
Exp. no	Weight Fraction%	Sand Size(µm)	Angle	Erosion Rate	S/N
1	EP	450	30°	0.08490	21.4218
2	EP	650	60°	0.09350	20.5838
3	EP	850	90°	0.10130	19.8878
4	EP+6%G.F	450	60°	0.01520	36.3631
5	EP+6%G.F	650	90°	0.02290	32.8033
6	EP+6%G.F	850	30°	0.01930	34.2889
7	EP+6%G.F+2%ES	450	90°	0.00567	44.9283
8	EP+6%G.F+2%ES	650	30°	0.00530	45.5145
9	EP+6%G.F+2%ES	850	60°	0.00701	43.0856
10	EP+6%G.F+4%ES	450	30°	0.0025	52.0412
11	EP+6%G.F+4%ES	650	60°	0.0047	46.5580
12	EP+6%G.F+4%ES	850	90°	0.0059	44.5830
13	EP+6%G.F+6%ES	450	60°	0.0021	53.5556
14	EP+6%G.F+6%ES	650	90°	0.0039	48.1787
15	EP+6%G.F+6%ES	850	30°	0.0030	50.4576
16	EP+6%G.F+8%ES	450	90°	0.0007	63.0980
17	EP+6%G.F+8%ES	650	30°	0.0005	66.0206
18	EP+6%G.F+8%ES	850	60°	0.0009	60.9151

Table 6 : Results erosion wear rate and S/N of samples reinforced with $CaCO_3$ particles

Exp.no	Weight Fraction%	Sand Size(µm)	Angle	Erosion Rate	S/N
1	EP	450	30°	0.0849	21.4218
2	EP	650	60°	0.0935	20.5838
3	EP	850	90°	0.1013	19.8878
4	EP+6%G.F	450	60°	0.0152	36.3631
5	EP+6%G.F	650	90°	0.0229	32.8033
6	EP+6%G.F	850	30°	0.0193	34.2889
7	EP+6%G.F+2%$CaCO_3$	450	90°	0.0051	45.8486
8	EP+6%G.F+2%$CaCO_3$	650	30°	0.0047	46.5580
9	EP+6%G.F+2%$CaCO_3$	850	60°	0.0066	43.6091
10	EP+6%G.F+4%$CaCO_3$	450	30°	0.0022	53.1515
11	EP+6%G.F+4%$CaCO_3$	650	60°	0.0040	47.9588
12	EP+6%G.F+4%$CaCO_3$	850	90°	0.0057	44.8825
13	EP+6%G.F+6%$CaCO_3$	450	60°	0.0015	56.4782
14	EP+6%G.F+6%$CaCO_3$	650	90°	0.0035	49.1186
15	EP+6%G.F+6%$CaCO_3$	850	30°	0.0025	52.0412
16	EP+6%G.F+8%$CaCO_3$	450	90°	0.0002	73.9794
17	EP+6%G.F+8%$CaCO_3$	650	30°	0.0001	80.0000
18	EP+6%G.F+8%$CaCO_3$	850	60°	0.0003	70.4576

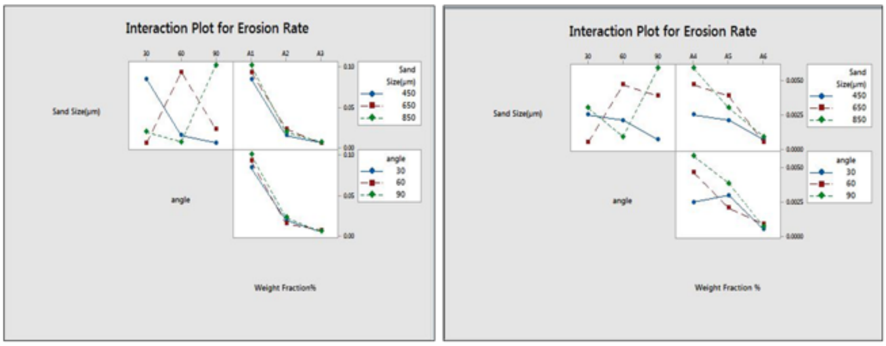


a) Samples reinforced with eggshell particles

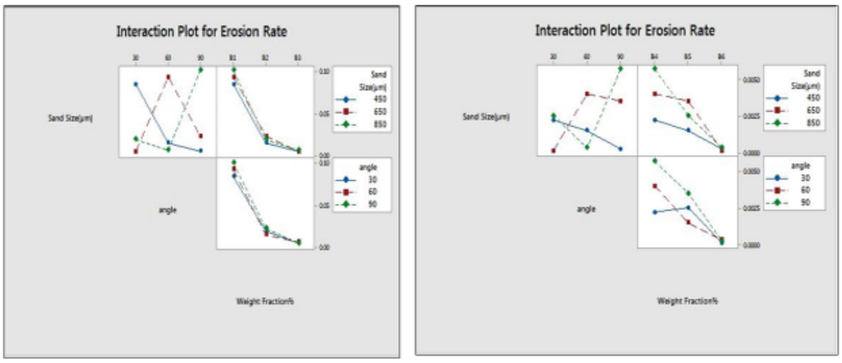


b) Samples reinforced with $CaCO_3$ particles

Figure 4 : Main influence plot of S/N ratios for samples reinforced with a) eggshell particles and b) for $CaCO_3$ particles



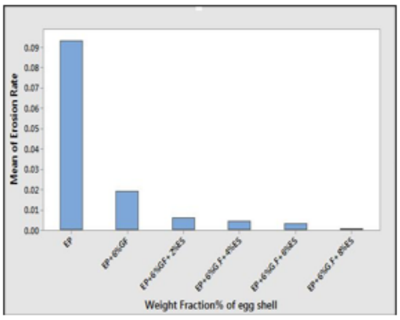
a) Samples reinforced with eggshell particles



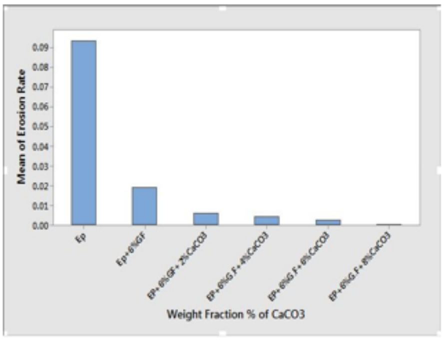
b) Samples reinforced with $CaCO_3$ particles

Figure 5: Interaction plot for erosion wear of Samples reinforced with a) eggshell particles and b) $CaCO_3$particles

Figure 6 displays the consequence of the weight fraction on the erosion wear rate. It is clear that the erosion resistance increasing with the increasing weight fraction of (eggshell and $CaCO_3$). Because that the addition of particles, improves the hardness of the polymer composites. The filler and fibers soak up a good section of kinetic energy during erosion wear operation this result in a limited quantity energy existence prepared to be soaked up through the matrix resin material and reinforce material [17].



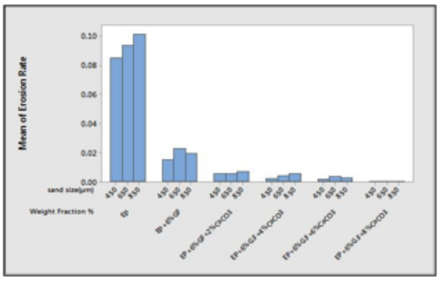
a) Samples reinforced with eggshell particles



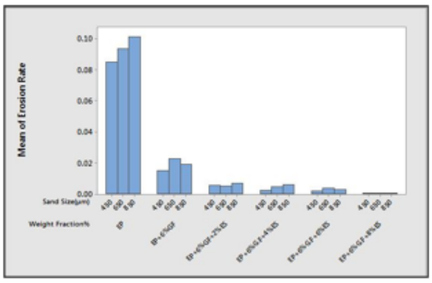
b) Samples reinforced with $CaCO_3$ particles

Figure 6 : Influence weight fraction of a) eggshell and erosion rate, and b) $CaCO_3$ and erosion rate

The relationship between the sand size and erosion rate is shown in Figure 7. Observed from Figure that with increasing sand sizes from (450µm to 850 µm) lead up to decrease erosion wear resistance. The samples (EP+6%G.F+8%ES and EP+6%G.F+8% $CaCO_3$) give less erosion rate at sand size (650µm). The cause is that the existence of filler material increases the bond between the resin matrix and reinforcing material, therefore the weight loss becomes less, this result agrees with [18 and 19].

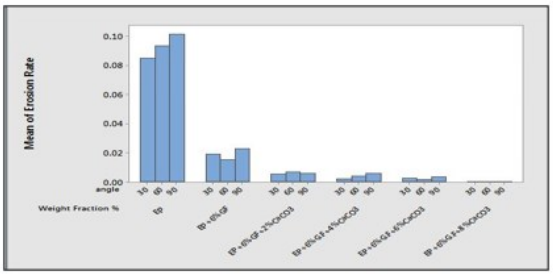


a) Samples reinforced with eggshell particles

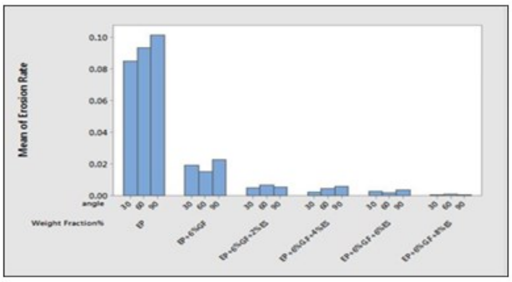


b) Samples reinforced with $CaCO_3$ particles

Figure 7 : Relationship between sand size and erosion rate for samples reinforced with a) eggshell and b) $CaCO_3$.



(a) Samples reinforced with eggshell particles



b)Samples reinforced with $CaCO_3$ particles

Figure 8: Relationship between the angle and erosion rate for samples reinforced with a) eggshell and (b) $CaCO_3$

Figure 8 clarifies the influence of the angle on the erosion rate for all samples. The maximum erosion rate appears at 90º angle, whilst minimum erosion rate appears at angle 30º of specimens reinforced with (eggshell and $CaCO_3$). It is found that some polymers erode in a ductile manner and some erode in brittle this depends on the variance of the erosion rate behavior together with angle. Ductile behavior occurs at a low angle erode in the range of (10º-30°), while the brittle behavior occurs at a higher angle 90° and semi-ductile behavior occurs at medium angles in the range of (45º-60°) [20 and 21]. In the present work, these specimens exhibit (semi-ductile) behavior; these results are consistent with [8].

II. Analysis of ANOVA

Table 7 and 8 shows the Analysis ANOVA results for the erosion wear rate of samples composites reinforced (eggshell and $CaCO_3$ with chopped glass fiber) under effect factors erosion wear. The analysis is undertaken for a level of confidence of significance of 5 %, the last column of the table (p-values) indicates the main effects highly significant on erosion wear. From Table 7 it can be observed the specimens reinforced with eggshell particles that weight fraction (p=0.003) and sand size (p= 0.042) have great influence on erosion rate, while angle has less influence on erosion behavior. Table 8 indicate the samples reinforced with $CaCO_3$ particles that weight fraction (p=0.001), sand size (p= 0.049) and angle (p= 0.055) have great influence on erosion rate.

Table 7: Analysis ANOVA of samples reinforced with eggshell particles

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Weight fraction %	5	0.019377	0.003875	542.75	0.003
Sand size	2	0.000063	0.000031	4.38	0.042
Angle	2	0.000054	0.000027	3.77	0.070
Error	8	0.000057	0.000007		
Total	17	0.019551			

Table 8 Analysis ANOVA of samples reinforced with $CaCO_3$ particles

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Weight fraction %	5	0.019581	0.003916	558.67	0.001
Sand size	2	0.000063	0.000032	4.52	0.049
Angle	2	0.000055	0.000027	3.92	0.055
Error	8	0.000056	0.000007		
Total	17	0.019756			

5. Conclusions

This analysis and experimental design MINITAB (19) of the erosion of specimens prepared by using hand lay-up technique from eggshells and $CaCO_3$ particles filled with epoxy- chopped glass fiber leads to the following conclusions:

1. The addition of 8% wt. of eggshells and CaCO3 - glass fiber into epoxy resin enhanced the erosion wear resistance of polymer composite compared with specimens without any filler.
2. The results reference that weight fraction of filler, sand size and angle are the significant factors affecting the erosion wear rate. Although the effect of angle is less in the specimens filled with eggshell, it cannot be ignored because it shows significant interaction with other factors.
3. These specimens exhibit (semi-ductile) behavior, where peak erosion wear occurring at 30º.

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