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Study of some Mechanical Properties and Erosive Behavior by Taguchi Method for Hybrid Nano Composites

Abstract- *The aim of this research is study the effect Nano TiO_2 powder on impact strength, fracture toughness, hardness shore (D) and erosive wear behavior of polymer composites materials are prepared by simple hand lay-up technique. The specimens was prepared by adding (1%, 2%,3%,4%,5% & 6%) weight fraction of nano powder (TiO_3) has average size of (16 nm) to unsaturated polyester resin reinforcement with (5%) weight fraction of carbon fiber. The value of erosive wear rate for polymer composite materials can be obtaining after (15 hours) and under effect various parameters such as impingement angle (30°, 45°, 60°, 90°), erodent size of sand silica (300, 400 ,500,600 µm) and stand-of distance (17, 19, 21,23 cm). Also in this research study effect of parameters on erosive wear rate by the used of Taguchi orthogonal arrays L16. The results show the maximum value of impact strength , fracture toughness and hardness (shore D) was founded at specimen (89% UP +5% C.F+6% TiO_2) also this specimen has the best resistance to erosive wear rate under parameters (23cm stand- off distance , 300 µm erodent size of sand silica , 60° impact angle) than other specimens. From analysis of variance (ANOVA) the filler content and impingement angle factor have more effect on erosive rate while the stand-off distance and erodent size of sand less effect on erosive wear rate .*

Keywords- *Nano composites, Impact strength, fracture toughness, Hardness, Erosive wear, Taguchi design*.

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1. Introduction

Polymer composites materials have gained great interest as materials for high performance structural defense, automotive, aerospace, civil engineering and marine applications for the past few decades. The reason why polymer composites materials used a more application is stability in dimensions with high strength to rigidity and good thermal properties .[1] Polymer nano composites are commonly defined as the blend of a polymer matrix and extras that have at least one dimension in the nanometer range. The extras it may be one-dimensional (examples include nanotubes) two-dimensional (which include layered minerals like clay), or three-dimensional (including spherical particles) [2]. Commonly nanostructured materials with grain sizes less than 100 nm have been show promotion combinations of mechanical , magnetic and physical properties as comparison to their traditional micro-sized equivalent (>1 µm) because of their very small size of the grains and a large fraction of their atoms located in their grain boundaries. Unsaturated polyester resin is thermosetting polyester that is the cross-linkable by reaction with an unsaturated monomer or prepolymer by virtue of the existence of carbon-to-carbon double bonds in its polymer chain. In generally the unsaturated polyester is dissolved in the reactive monomer. Unsaturated polyesters is widely used in laminates composites such as boat bodies, storage products, tanks and lampposts [3].Titanium dioxide ceramic nanoparticles are one of the most important interesting materials at nowadays. Below the continuous development, they have attracted a growing interest not just to the unique properties, but also the potential for applications in industries like pigments, cosmetics, catalysis, photocatalysis etc [4]. The integration nanoparticles in the polymer can result in a significant improvement of the mechanical properties. Mohan et al. have studied the influence of amalgamation glass fiber–epoxy resin reinforced with tungsten carbide powders on erosive wear behavior. The specimens of composite materials were attended by using vacuum-assisted resin infusion (VARI) method. The influence of impact angles 30° to 90° , erodent size 150-280 µm and impact velocities 40 , 80 m/s on the rendering of the erosion wear resistance of composite materials were measured. The result indicate the all specimens brittle demeanor with a maximum erosion rate at 90° impingement angle. In addition, the tungsten carbide reinforced with glass fiber – epoxy resin show a lower erosion rate than specimen unfilled glass fiber–epoxy resin [5]. Mahesha et al. have studied the influence basalt fiber reinforced with nano clay - epoxy resin on the solid particle erosion wear. The erosion wear is study at various variables such as impingement angles from 30° to 90° at pair types velocities of 23, 42, & 60 m/s and the sand silica is used with the size range 150- 280 μm of irregular shape .The result shows the all samples of composites materials semi-ductile behavior with ultimate erosion rate at 60° impingement angle. Also, indicate the erosion rate increasing with increasing particle velocity and decreases with addition nano clay in Basalt fiber- epoxy resin [6].

Sornakumar et al. have studied the effect of nano TiO_2 powder on tensile strength, flexural strength and shear strength of glass fiber reinforced polyester resin. The samples were fabricate from 33% weight G.F ,(67%,65,63%,61%) weight polyester resin and (0%,2%,4%,6%) weight nano TiO_2 by the hand layup technique . The result shown the flexural strength, shear strength and tensile strength of the glass fiber reinforced polymer increased with 6% weight percentage of nano TiO2 powder content in the polyester resin matrix [7]. The aim of this research study some mechanical properties and erosive wear behavior by use Taguchi orthogonal arrays L16 design to investigation the effects of the weight fraction (1%,2%,3% ,4% ,5% and 6%) TiO_2 nano powder with 3% carbon fiber on erosive wear rate at different variables.

2. Experimental Work

Materials Used for the Preparation of Specimens

References should be cited in numerical order The essential materials required in the preparation of specimens composites material consists of unsaturated polyester resin has density (1.1 gm/cm^3) as the matrix from Saudi company , with strengthened 5% weight fraction (carbon fiber) has density (1.81 gm/cm^3) from Company Tenax and addition (TiO_2) nano powder was equipped from Nano shell Company made in United States of America (USA) has density (4.23 gm/cm^3) and average size according to AFM (16 nm). The typical properties of polyester resin, carbon fiber and (TiO_2) nano filler as shown in Table 1.

Hand lay-up Molding technique is used for the preparation nano composites materials and the mould dimensions (130×130×4) mm. The composition of the prepared specimens was shown in the Table 2.

Table 1: Typical properties of materials used in this research

Unsaturated Polyester Resin		Carbon fiber		Nano TiO_2 Powder	
Density	1.1 – 1.4 gm/cm^3	Density	1.81 gm/cm^3	Density	4.23gm/cm^3
Tensile Strength	34.5 -103.5 (MPa)	Tensile Strength	2.6 GPa	Specific surface area	30 (m^2/g)
Percent Elongation (EL%)	1-5%	Tensile Modulus	240 GPa	Purity	99%
Cure shrinkage	5-12 %	Elongation at break	0.8%	PH value	7-8

Table2: Composition of the specimens

Specimens	Composition
C1	UP
C2	UP+5% C.F
C3	UP+5% C.F+1% Nano TiO_2
C4	UP+5% C.F+2% Nano TiO_2
C5	UP+5% C.F+3% Nano TiO_2
C6	UP+5% C.F+4% Nano TiO_2
C7	UP+5% C.F+5% Nano TiO_2
C8	UP+5% C.F+6% Nano TiO_2

3. Impact strength and Fracture Toughness

ISO- impact test was used to measurement the impact strength and fracture toughness according to ASTM (ISO-180 standard) with dimensions (80 Length *10 Width *4 Thickness) mm [8]. Impact strength and fracture toughness can be calculated by using the following relationship [9].

$$G\mathrm{c} = \frac{\mathrm{Uc}}{\mathrm{A}} \quad (1)$$

Where

G_c= Impact strength of material (KJ/m^2).

U_c=Impact energy (J).

A= cross- sectional area of specimen (m^2)

Fracture toughness can be expressed as.

$$Kc = \sqrt{Gc \ E} \quad (2)$$

Where:

K_c= Fracture toughness of material ($MPa.m^{1/2}$).

E= elastic modulus of material (MPa).

4. Hardness Test (Shore D)

Hardness (shore D) test was used to measurement resistance to permanent indentation according to ASTM-2240 standard [10]. The specimens were cut to a diameter of 50.8 mm and the thickness of 4mm.

5. Erosive Wear and Taguchi Experimental Design

Solid particle erosive wear experiments were carried out based on ASTM G 76 [11]. Specimens have been cut into the dimensions (40*30*4mm). The experimental detail is presented in Table 3. The erosive wear rate determined from the following equation [12] after (15) hour.

$$\text{erosive were rate} = \frac{\Delta \text{Wc}}{\Delta \text{Ws}}$$

Where:

Δ Wc = Weight of the specimen before and after test (gm).

Δ Ws = Weight total of the specimen (gm).

In this present, work the study erosive wear rate of the all-composite specimens under four parameters by using Taguchi L16 orthogonal array design twice as shown in Table 4. The experimental observations are further transformed into signal-to-noise (S/N) ratios. The S/N ratio for minimum erosive rate can be expressed as ''lower is better" characteristic, which is calculated as logarithmic transformation of loss function as per the equation shown below smaller is the better [13].

$$\frac{S}{N} = -10 \log \frac{1}{n} \left(\sum y^2\right) \quad (3)$$

Where:

N = is the number of observations.

Y = the erosive wear rate.

Table 3: Erosive test conditions

Test parameters	
Erodent	Silica sand
Erodent size	300 , 400,500,600 µm
Stand –off distance	17 , 19 , 21 , 23 cm
Impingement angle	30º , 45º , 60º , 90º
Filler Content	C1 ,C2 , C3 , C4 , C5, C6 ,C7 ,C8
Flow rat constant	45 L/min
Test temperature	Room temperature
Nozzle diameter	4 mm
Pump diameter	50 mm
Time	15 hours

Table 4: Taguchi orthogonal array design (L16) [14]

Experiment no.	Factor (A) Filler Content	Factor (B) Stand –off Distance	Factor (C) Erodent Size of Sand Silica	Factor (D) Impingement Angle
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	2	4	3
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

6. Results and Discussion

I. Ray Diffraction

Result of x- ray diffraction of nano-titanium dioxide as shows in Figure 1. Height intensities of sharp maximum can be obtained, pointing to a high crystalline in the synthesized powder. All the peaks could be interpreted to the tetragonal structure [15].

II. Atomic Force Microscope of Nano TiO_2

The atomic force microscope was used determine the size of (TiO_2) nano powder, the Figure (2) showed the particle size was in the range of (4-40) nm and indicated the average size was equivalent (16 nm).

III. Impact strength and Fracture Toughness

The results of impact strength and fracture toughness for neat and nano specimens as show in Figures 3 & 4. From the results note the specimen (C2) has high affect strength and fracture toughness value than specimen (C1), due to the strengthen affect positively in the impact strength and increase the impact energy need to break the samples [16]. Also can be seen from the figures specimen (C8) increasing value of impact strength and fracture toughness than other nano specimens because the good bonding strength between nano fillers with matrix and fiber , the flexibility of the interface molecular results in absorbing and dispersing more energy, and prevents the early initiation of cracks more effectively .

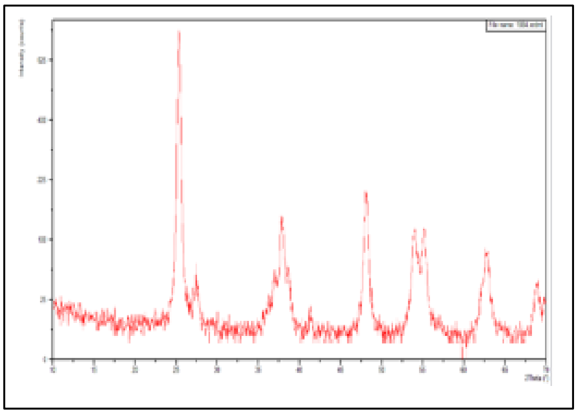


Figure 1: X- Ray diffraction of TiO_2 Nano Powder

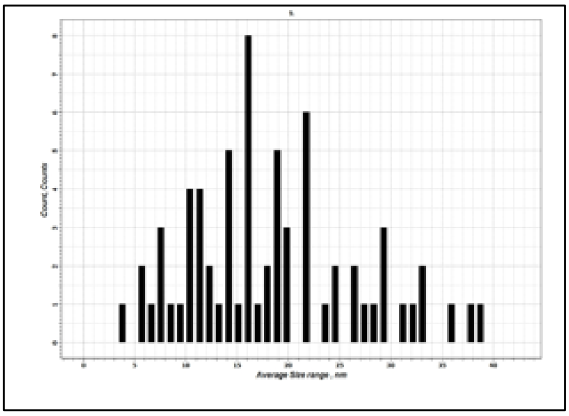


Figure 2: Atomic force microscope of Nano-titanium dioxide powder

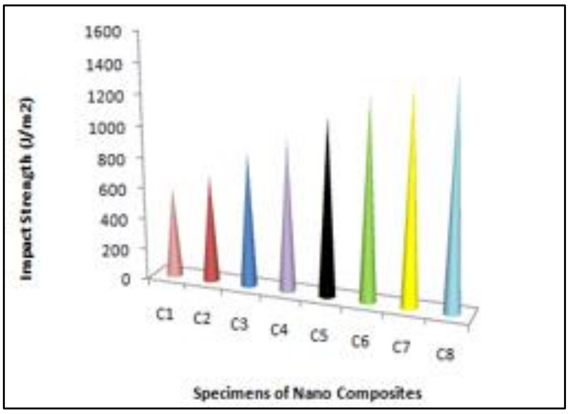


Figure3: Impact strength for nano composites materials

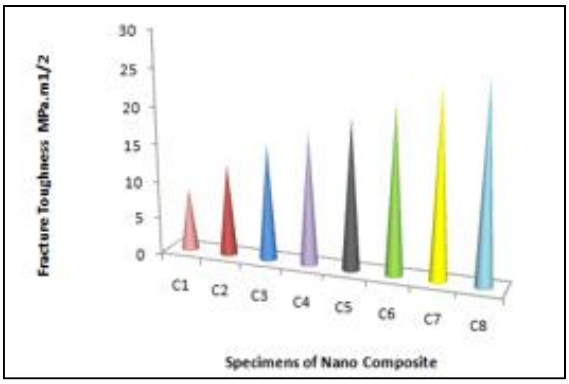


Figure 4: Fracture toughness for nano composites materials

IV. Hardness of Shore D

(D) of unsaturated polyester resin with carbon fiber and (TiO_2) nano powder. Results showed the specimen C2 is better than the specimen C1 due to the carbon fiber content is and the hardness shore (D) is directly proportional to the reinforcement content [17]. The value of the hardness shore D improves with the addition of (TiO_2) nano powder because the TiO_2 nano powder contain an element of its hardness higher than carbon fiber and resin matrix and also the TiO_2 nano powder good distribution with matrix resin and fiber.

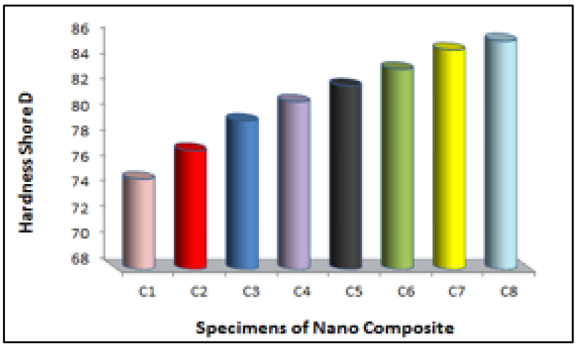


Figure 5: **Shore (D) hardness for nano composites material**

V. Erosive Wear Test and Taguchi Experiments

Tables 5 and 6 indicated results the erosive wear rate tests carried out in accordance with a predetermined design on unsaturated polyester resin with carbon fiber and (TiO_2) nano powder composites materials. The last columns represent *S/N* ratio of the erosive rate, which is in fact the average of four replications. The overall mean for the *S/N* ratio of the erosion rate is found to be (25.2880, 79.1721) of the specimens (C4, C8) gives the minimum erosion rate. The analysis is made using the popular software specifically used for design of experiment applications known as Minitab.

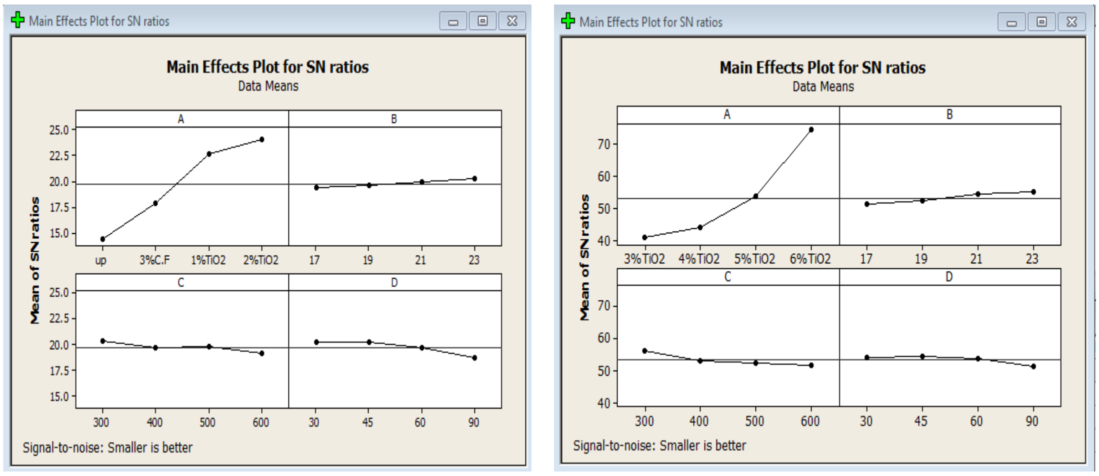
Table 5: Results of erosive wear test with corresponding S/N ratios by using Taguchi method under different test conditions as per L16 ortho gonal array for specimens (C1, C2, C3, and C4) composites materials

EXP.	Filler Content (W%)	Stand-off Distance (cm)	Erodent Size of Sand Silica (μm)	Impingement Angle (°)	Erosion Wear Rate (g)	S/N
1	UP	17	300	30°	0.1695	15.4166
2	UP	19	400	45°	0.1811	14.8416
3	UP	21	500	60°	0.1979	14.0711
4	UP	23	600	90°	0.2151	13.3472
5	UP+5%C.F	17	400	60°	0.1352	17.3805
6	UP+5%C.F	19	300	90°	0.1470	16.6537
7	UP+5%C.F	21	600	30°	0.1253	18.0410
8	UP+5%C.F	23	500	45°	0.1103	19.1485
9	UP+5%C.F+1%TiO_2	17	500	90°	0.0839	21.5248
10	UP+5%C.F+1%TiO_2	19	600	60°	0.0776	22.2028
11	UP+5%C.F+1%TiO_2	21	300	45°	0.0638	23.9036
12	UP+5%C.F+1%TiO_2	23	400	30°	0.0712	22.9504
13	UP+5%C.F+2%TiO_2	17	600	45°	0.0769	22.9871
14	UP+5%C.F+2%TiO_2	19	500	30°	0.0598	24.4660
15	UP+5%C.F+2%TiO_2	21	400	90°	0.0667	23.5175
16	UP+5%C.F+2%TiO_2	23	300	60°	0.0544	25.2880

Table 6: Results of erosive wear test with corresponding S/N ratios by using Taguchi method under different test conditions as per L16 orthogonal array for specimens (C5, C6, C7, and C8) composites materials

EXP.	Filler Content (W%)	Stand-off Distance (cm)	Erodent Size of Sand Silica (μm)	Impingement Angle (°)	Erosive Wear Rate (g)	S/N
1	UP+5%C.F+3%TiO_2	17	300	30°	0.0080	41.9382
2	UP+5%C.F+3%TiO_2	19	400	45°	0.0089	41.0122
3	UP+5%C.F+3%TiO_2	21	500	60°	0.0093	40.6303
4	UP+5%C.F+3%TiO_2	23	600	90°	0.0098	40.1755
5	UP+5%C.F+4%TiO_2	17	400	60°	0.0067	43.4785
6	UP+5%C.F+4%TiO_2	19	300	90°	0.0073	42.7335
7	UP+5%C.F+4%TiO_2	21	600	30°	0.0061	44.2934
8	UP+5%C.F+4%TiO_2	23	500	45°	0.0051	45.8486
9	UP+5%C.F+5%TiO_2	17	500	90°	0.0036	48.8739
10	UP+5%C.F+5%TiO_2	19	600	60°	0.0027	51.3727
11	UP+5%C.F+5%TiO_2	21	300	45°	0.0010	60.0000
12	UP+5%C.F+5%TiO_2	23	400	30°	0.0018	54.8945
13	UP+5%C.F+6%TiO_2	17	600	45°	0.00030	70.4576
14	UP+5%C.F+6%TiO_2	19	500	30°	0.00019	74.4249
15	UP+5%C.F+6%TiO_2	21	400	90°	0.00023	72.7654
16	UP+3%C.F+6%TiO_2	23	300	60°	0.00011	79.1721

Figures (6-a,b) illustrate the effect of control factors on erosive wear rate of the specimens . Analysis of the results leads to the conclusion that factor combination of A4 filler content (2% TiO_2 , 6% TiO_2) , B4 distance (23 cm) , C1 erodent size of sand silica (300 µm) and D2 Impingement angle (45°) gives the minimum erosive rate for the nano composite materials .



A B

Figure 6: Effect of control factor on erosive rate for the specimen

VI. Effect of Control Factor on Erosive Rate

1. Filler Content

Filler content has effect is very strong on erosive wear rate. The specimen unsaturated polyester without any reinforcement exposed to erosive wear more of other specimens. Due the presence of fiber and nano powder improves good bonding between matrix and reinforcement and thereby improves properties of mechanical and reduces from erosive wear rate. Effect filler content on erosive rate are represented in Figures 7 & 8. In figures (7&8) the minimum resistance erosive wear rate found in specimen (UP+5%C.F+6%TiO_2) the reason is that the addition of 6% TiO_2 nano powder with 5% carbon fiber improves mechanical properties and thus improves the resistance of the specimen to the erosive wear at different conditions.

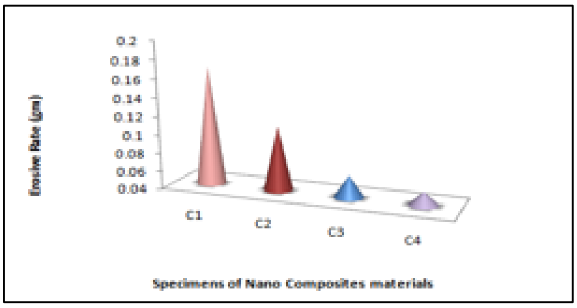


Figure7: Effect of filler content on erosive rate for the specimens (C1, C2, C3, C4)

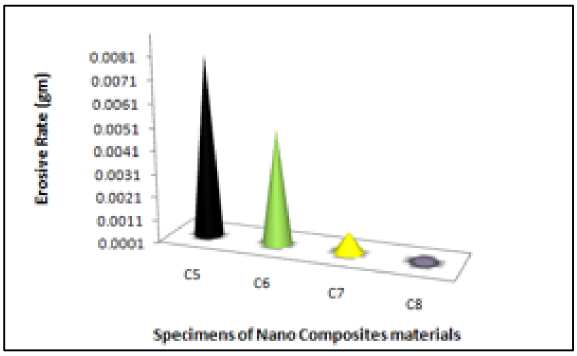


Figure 8: Effect of filler content on erosive rate for the specimens (C5, C6, C7, C8)

2. Stand-off Distance:

Stand - off is the distance between the surface of specimens and slot nozzle responsible to pump water onto the specimen surface. Figures 9 & 10 indicate main effect different stand- off distances (17, 19, 21, and 23) cm on erosive wear rate for the unsaturated polyester reinforced with carbon fiber and TiO_2 nano powder. It is remarkable with a decrease in distance 17-23 cm decrease the specimens resistance to erosive wear rate. In this paper was the highest erosive wear rate at stand-off distances (19 cm) and minimum erosive wear rate at stand- off distances (21 cm, 23 cm) [18].

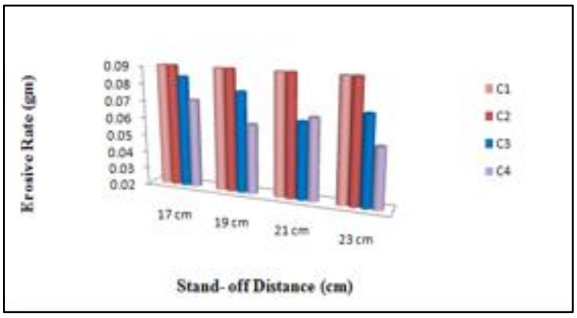


Figure 9: Effect of standoff distance on erosive rate for the specimens (C1, C2, C3, and C4)

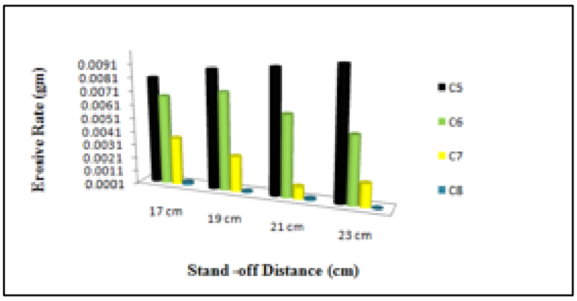


Figure 10: Effect of standoff distance on erosive rate for the specimens (C5, C6, C7, and C8)

3. Erodent Size of Sand Silica (µm)

The erosive wear rate of (TiO_2) nano powder reinforced unsaturated polyester with carbon fiber composites materials have been studied by varying erodent size of sand silica from 300, 400, 500 and 600 µm at constant flow rate 45 (L/min) as shown in figures (11&12). From Figures 11 & 12 it is notes the erosive wear rate increase with increase erodent size of sand silica portable in a flowing liquid lead to the loss of weight form the specimen surface, due the erosive wear is a mechanical corrosion that occurs between the center of water-bearing particles sand silica and the surface of the specimens. In this paper was the maximum erosive wear rate are found at (600 µm) ,while least erosive wear rate at
(300 µm).

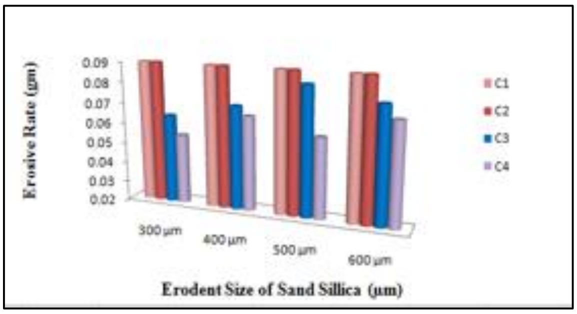


Figure11: Effect of erodent size of sand sillica on erosive rate for the specimens (C1, C2, C3, C4)

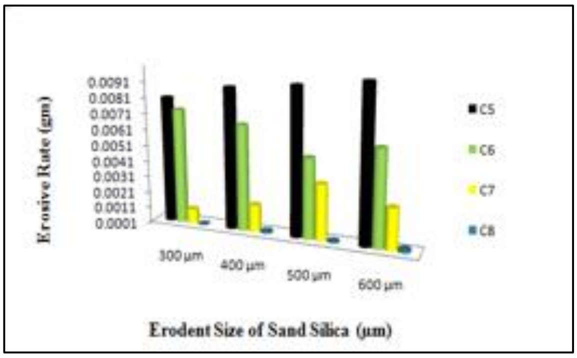


Figure 12: Effect of erodent size of sand sillica on erosive rate for the specimens (C5, C6, C7, and C8)

4. Impingement Angle

Impingement angle is one of the most influential variables on erosive wear behavior for polymer nano composites materials.The erosive wear behavior of materials is overall classified in the brittle occurs at (90º) and ductile occurs at (15º-30º) based on the variation of erosive wear rate with impingement angle [19]. Figures (13&14) show main effect of different impingement angle 30º, 45º, 60º, 90º on erosive wear rate for the unsaturated polyester reinforced with (TiO_2) nano powder and carbon fiber at. From Figure 13, it is observed the erosive wear rate starts increasing appreciably with the increasing impingement angle from 30° to 90°. From Figures 13 & 14 it is notes that the peak erosive rates are observed at an impingement angle of 90° for all nano composite specimens. This shows semi-ductile erosive wear response for the unsaturated polyester reinforced with (TiO_2) nano powder and carbon fiber composites materials. Minimum erosive rate was observed at an impingement angle of 45◦.

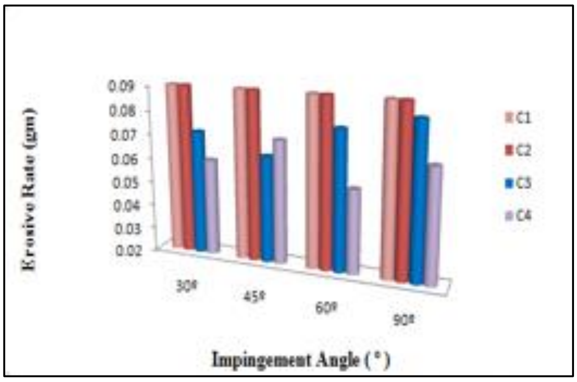


Figure13: Effect of impingement angle on erosive rate for the specimens (C1, C2, C3, C4)

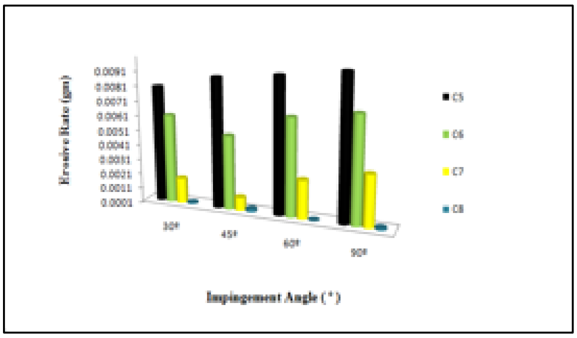


Figure 14: Effect of impingement angle on erosive rate for the specimens (C5, C6, C7, C8)

VII. Analysis of Variance (ANOVA)

In order to understand the concrete perception of the effect various factors on the erosive wear behavior, it is recommended analysis of variance (ANOVA) to determine the most influence factors on the erosive rate. Tables 7, 8 It illustrates the results of the (ANOVA) with the erosive wear rate. The last column of the tables refers to the essential effect are very important (all have very p small value). In the table 7 can be noted that the filler content % (p= 0.003) and impingement angle (p=0.0278) have great effect on erosive wear rate , while the stand – off distance (cm) (p =0.0982) and erodent size of sand (μm) (p=0.039) have less effect on erosive wear rate .From table 8 can be noted that the filler content % (p= 0.001) and impingement angle (p=0.0135) have great effect on erosive wear rate , while the stand – off distance (cm) (p =0.0509) and erodent size of sand (μm) (0.0614) have less effect on erosive wear rate. Where the Df (degree freedom) , Seq SS (sum of squar) , Adj SS (adjusted sum of squares) , Adj MS (adjusted mean square) , F (value random) and P (level of confidence) .

Table 7: ANOVA results for the specimens (C1, C2, C3, C4) nano composite materials

Source	Df	Seq SS	Adj SS	Adj MS	F	P
A	3	0.0413917	0.0413917	0.0137972	68.46	0.003
B	3	0.0000312	0.0000312	0.0000104	0.05	0.0982
C	3	0.0003870	0.0003870	0.0001290	0.64	0.0639
D	3	0.0012739	0.0012739	0.0004246	2.11	0.0278
Error	3	0.0006046	0.0006046	0.0002015		
Total	15	0.0436884				

Table 8: ANOVA results for the specimens (C5, C6, C7, and C8) nano composite materials

Source	Df	Seq SS	Adj SS	Adj MS	F	P
A	3	0.0001874	0.0001874	0.000625	156.77	0.001
B	3	0.0000012	0.0000012	0.0000004	0.97	0.0509
C	3	0.0000008	0.0000008	0.0000003	0.69	0.0614
D	3	0.0000050	0.0000050	0.0000017	4.18	0.0135
Error	3	0.0000012	0.0000012	0.0000004		
Total	15	0.0001956				

7. Conclusions

The most important conclusions of results were:-

1-This work shows that successful preparation of unsaturated polyester resin reinforced with 5% carbon fiber and 1%-6% nano TiO_2 by simple hand lay-up technique and note that there is a clear improvement in the mechanical properties and resistance to erosive wear rate with increased volume fraction of nano TiO_2.

2-Composite with (UP + 5% CF+6% nano TiO_2) has the maximum impact strength, fracture toughness and hardness shore D when compared with weight fraction (1%, - 6%) TiO_2 nano powder.

3-The specimen (UP +5% CF +6% nano TiO_2) has (0.00011gm) erosive rate resistance at (23 cm) , (300 μm) and (60 while the higher erosive wear rate found in specimen (UP) at (17 cm) , (600 μm) and (90 at constant (15hours) time , and flow rate (45 L ⁄min).

4-The response for all nano composites materials is found semi-ductile and the maximum erosive rate takes place at the impingement of 90º.

5-From analysis of variance (ANOVA) the filler content and impingement angle factor have more effect on erosive rate while the stand-off distance and erodent size of sand less effect on erosive wear rate for hybrid polymer nano composite.

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