Journal of Engineering and Sustainable Development
Vol. 22, No. 4, July 2018
ISSN 2520-0917
https://doi.org/10.31272/jeasd.2018.4.6

EFFECT OF CARBON NANO TUBES ON EROSION WEAR OF CARBON FIBER, GLASS FIBER & KEVLAR FIBER REINFORCED UNSATURATED POLYESTER COMPOSITES

*Dr. Aseel Basim Abdul-Hussein[1], Dr. Emad Saadi Abdel Kareem[2], Marwa Subhi Atallah [3]

1) Assist Prof., Materials Engineering Department, University of Technology, Baghdad, Iraq.
2) Assist Prof., Materials Engineering Department, University of Technology, Baghdad, Iraq.
3) Eng., Materials Engineering Department, University of Technology, Baghdad, Iraq.

Abstract: In the present study, nano composites were prepared by Hand lay-up molding. The nano composites component of the unsaturated polyester resin (UP) as a matrix, 3% volume fractions of Carbon Fiber (C.F), Glass Fibers (G.F), Kevlar Fiber (K.F) as reinforcement and (0.5%,1%, 1.5% and 2%) volume fractions of Carbon Nanotubes (CNTs) as filler. The erosion wear behavior of this nano composite at four different impingement angles 30°, 45°, 60° and 90° and four angular silica sand abrasive particle sizes 400, 500 , 600 and 800 µm and density were studied. The results showed that the specimens (UP + 3% (GF, CF, KF) +2% CNTs) have the maximum density when compared with the other volume fractions. The non – reinforced unsaturated polyester have lower erosion resistance than nano composites and the specimen (polyester +3% carbon fiber + 0.5% CNTs) has higher erosion resistance than other nano composites at 15cm, angle 30°, grin size of sand 400µm and 15 hour. Application of this work in protection of aircraft structure, turbine blades and pipes from erosion. The Taguchi experimental design ANOVA shows that the filler content factor has great effect on erosion rate of CNTs filled carbon, glass and Kevlar fibers reinforced unsaturated polyester resin.

Keyword: *Nano Composites, Carbon Nanotubes, Erosion wear, Carbon Fiber, Glass fiber, Kevlar Fiber.*

تاثير انابيب الكاربون النانوية على بلى التعرية لمتراكبات البولي استر الغير مشبع المقوى بالياف الكاربون والياف الزجاج و الياف الكفلر

الخلاصة: تم في هذا البحث تحضير مواد متراكبة نانوية بواسطة طريقة القولبة اليدوية. تتكون المتراكبات النانوية من راتنج البولي استر غير المشبع كماده اساس والياف الكاربون والزجاج والكفلر كمادة تقوية بكسر حجمي 3% و انابيب الكاربون النانوية بكسر حجمي (0.5%, 1%, 1.5%, 2%) كحشوة . سلوك بلى التعرية للمتراكبات النانوية باربعة زوايا مختلفة 30 درجة، 45 درجة و 60 درجة و 90 درجة وثلاث احجام من رمل السيليكا 400 و 500 و 600 و 800 ميكرون و الكثافة قد تمت دراستها. اظهرت النتائج بان العينة [بولي استر + 3% (الياف الكاربون والياف الزجاج و الياف الكفلر + 2% انابيب الكاربون النانوية)] تمتلك اعلى كثافة عندما تقارن مع الكسور الحجمية الاخرى . البولي استر الغير مقوى يمتلك مقاومة للتعرية اقل من المتراكبات النانوية و العينة (بولي استر +3% الياف الكاربون +0.5% انابيب الكاربون النانوية) تمتلك اعلى مقاومة للتعرية من المتراكبات النانوية الاخرى عند15 سم ، زاوية 30°، حجم دقائق تعرية 400 مايكرون و 15 ساعة . تطبيق هذه الدراسة هو حماية هياكل الطائرات و الريش التوربينية و الانابيب من التعرية .

* dr.material @yahoo.com

1. Introduction

Polymer composite materials have generated wide interest in various engineering fields, particularly in aerospace applications, because they exhibit, high specific strength and stiffness as compared to monolithic metal alloys. Polymer composite materials are therefore, finding increased application under conditions in which they may be subjected to solid particle erosion. Examples of such applications are pipe line carrying sand slurries in petroleum refining, helicopter rotor blades [1&2], pump impeller blades, high speed vehicles and aircraft operating in desert environments, water turbines, aircraft engine blades [3].

However, polymer composite materials exhibit poor erosion resistance as compared to metallic materials [4]. It is also known that the erosive wear of polymer composites is usually higher than that of the unreinforced polymer matrix [5]. Erosion is an important wear mode which involves the removal of material from a surface as a result of the impingement of solid particles or liquid droplets. Erosion caused by solid and sharp airborne particles is an especially severe problem in the operation of aircraft structures and of turbine blades over dusty terrains [6]. Erosion rate of the volume loss (v) is defined by the following equation [7]:

$$v = \frac{\varepsilon}{\rho} = \frac{WL}{WS * \rho} \qquad (1)$$

Where

ε: erosion rate of weight loss.

W_L: weight loss of the specimen (gm).

Ws: total weight (gm).

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

There are many studies about composite materials.

Mohammed Ismail et. al., (2012) fabricated epoxy resin reinforced with 20% weight fraction carbon fiber and (0, 2, 4) % weight fraction of fly ash cenosphere (CSP) having particle size 25 to 50 μm by hand lay- up technique followed by compression molding. The solid particle erosion characteristics of the (CSP) filled (C-E) composites were studied and the experimental results were compared with those of unfilled (C-E) composites.

For this, an air jet type erosion test and Taguchi orthogonal arrays (L27) were used. The result showed that the tensile modulus and flexural modulus of fly ash cenosphere filled (C-E) composites are high compared with that of the unfilled (C-E) composites, this enhance is due to higher silica content (60%), therefore a good interfacial adhesion between the cenospheres particles and the matrix occurs. The samples of composite materials (epoxy resin – carbon fiber) and (epoxy resin + carbon fiber+ CSP) shown ductile erosion behavior and the peak erosion rate was found at 30° impingement angle. The erosion rate increased when the impact velocity increased. Also, the filler content had the greater effect factor than impact velocity, particle size impingement angle, and time of erosion during the erosive wear process [8].

Shakuntala Ojha. et.al. (2013) have studied solid particle erosion wear behavior of epoxy resin reinforced by jute-glass fiber and (2%, 4%, 6%) volume fraction of nano alumina .The flexural strength of nano composite is investigated, also the parameter used in the erosion wear test were impact velocity (72 m/s), impact angle (30 °, 45°, 60°, 90°) and silica sand with particle size (200 µm**)** .The results showed that the flexural strength of epoxy resin is lower than jute and glass fiber. After addition of nano alumina, there is an increase in the strength of jute and glass fiber composites. The erosion wear rate of the specimen GF+EP is less than of the net epoxy specimen and also depicted that as the volume fraction of nano alumina increases the erosion resistance increases. The maximum erosion occurs at 90° angle so the material behaves as brittle due to increase in alumina content [9].

Sridhar R. et. al (2014) have studied the effect of adding nano clay in percentages (2, 3,and 4)%wt. on erosion wear of vinyl ester – glass fiber composites material by using Taguchi orthogonal array method. Erosion test were perform by used silica sand particle with size 177 to 595 nm. The parameter used in the erosion wear test were impact velocity (33, 45, 66 m/sec), impingement angle ($30^{\circ}, 60^{\circ}, 90^{\circ}$), stand –off distance (120, 180, 240 mm) and erodent size (177, 420, 595 µm). The results showed that the addition of nano clay up to 3% weight fraction decrease the erosion rate of the composite material under the factors (66 m/s velocity, 240mm stand-off distance, 30° impingement angle and 595 µm erodent size) [10].

2. Objectives of the research

1. Prepare nano composites of unsaturated polyester resin reinforced with carbon fiber, glass fiber, and Kevlar fiber and carbon nanotube.
2. Study The erosion wear behavior of this nano composite at four different factors.
3. Study the Taguchi and analysis the result of ANOVA in other to find the most effecting factor on erosion rate.

3. Experimental Work

The materials that used in the manufacturing of specimens consisting of carbon fibers (Carbon UD Stockinette) from Tenax Company, glass fibers (Woven E- Glass Fiber) from the Tenax company, Kevlar fiber (fabric 49) and unsaturated polyester resin base as the matrix from the (faralop0115 company) in the form of transparent viscous liquid at room temperature which is a thermally hardened polymers (Thermosets) with a density of (1.11gm / cm^3). Multi-walled carbon nanotube (Intelligent Materials Pvt. Ltd, NANOSHEL LLC) [11].

All the required moulds for preparing the specimens were made from glass with dimensions of (120×120×5) mm.

The inner face of the mould was covered with a thin layer of (thermal paper) made from polyvinyl alcohol (PVA) to remove easily from the mould after molding. The mean grain size of carbon nanotube was (48) nm, as shown in figure (1).

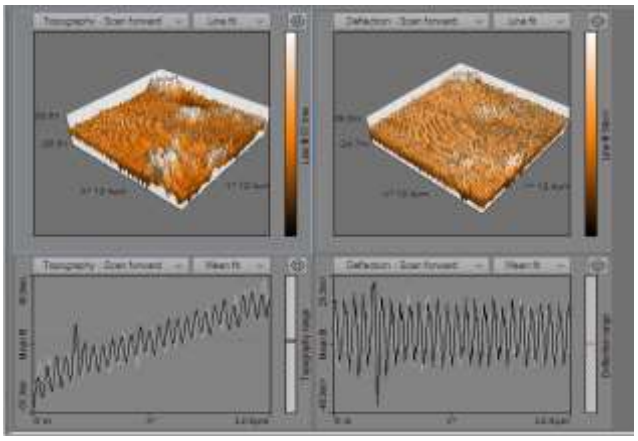


Figure (1): Atomic forcing microscope of nano carbon tubes (CNTs)

3.1. *Raw Materials*

The properties of materials used in preparation of nano composite materials as shown in table (1):

Table (1): Properties of materials

Materials	Density g/ cm^3	Tensile strength	Properties	
Unsaturated Polyester[12]	(1.11)	(65) N/mm^2	Flexural strength (110) N/mm^2	viscosity (1.0) poise
E-glass Fiber [13,14]	(2.58)	(3445) MPa	compressive strength(1080) MPa	young modulus (72.5) Gpa
Carbon Fiber [15]	(1.81)	(5600) MPa	tensile modulus 290 Gpa	elongation 1.9%
Kevlar Fiber [16]	(1.44)	(3750) MPa	young modulus 139 Gpa	poisson's Ratio 0.36
Carbon Nanotube [11]	(1.7)	(150) GPa	particle size (48) nm	young modulus (1200) Gpa

Figure (2) shows that x-ray diffraction pattern confirmed for (CNT) powder. From the results of x-ray diffraction indicating a high crystalline in the synthesized powder. All peaks could be indexed to a hexagonal structure [17].

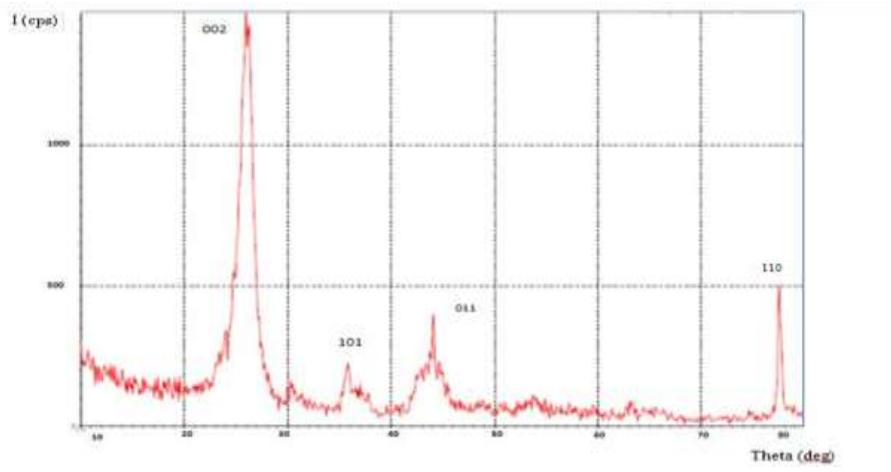


Figure (2): The X- Ray Diffraction pattern of the CNTs powder

3.2 *Preparation of Nano Composites*

Nano composites specimens were prepared from unsaturated polyester reinforced with 3% volume fraction of (Carbon fiber, Glass fiber, Kevlar fiber) and carbon nanotube with volume fraction of (0.5 %, 1%, 1.5%, and 2%). The method used in the preparation of the specimens in this research is the (Hand lay-Up Molding). The nano composites were prepared by cutting fibers into dimensions (120 × 120) mm, according to the dimensions of the mould.

The volume fractions of (C.F, G.F, and K.F) were (3%).Then weighing the reinforcing carbon nanotube to specify volume fraction of (0.5%, 1%, 1.5%, and 2%). Weighing the unsaturated polyester depending on the volume fraction of reinforcement materials (fibers and powder), with taking into consideration the weight of hardener. The unsaturated polyester was mixed with the hardener slowly and continuously by using a glass rod in order to avoid bubbles and then the powder was adding gradually into the mixture and stirring it to obtain homogeneity for a period of (10-15) minutes. While Pouring the mixture into the mould, fibers putting the mat into the mould and continuing of mixture pouring until it covers the entire mat then Pressing the mixture with an appropriate load.

Finally leaving the specimens in the mould for a period of (24) hour at room temperature. Specimens are then extracted from the mould and then heat treated in an oven at (60Ċ) 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 specimens [18].

3.3. *True Density Test*

This test is done according to (ASTM D792) standard at the room temperature [19]. The specimens were cut into a thickness of 5 mm and a diameter of 40 mm that shown in figure (3).

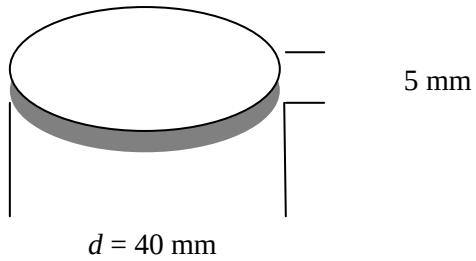


Figure (3): Stander Specimen [19&22]

3.4. *Erosion Wear Test*

This test is performed according to (ASTM G76) at room temperature [20, 21]. Specimens have been cut into disk shape of a diameter of (40mm) and a thickness of (5mm) [22] as represented in figure (3). .The used device for erosion is locally

manufactured; the principal scheme is shown in figure (4) show an illustration of erosion wear device sketch a plastic (Perspex) tank is used as a chamber. The Perspex tank has 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 specimen tube are (15, 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 four angle levels (30°,45°, 60°, 90°), and the operating flow rate (35 L⁄min).The fluid used in the erosion tests are sand water contains solid particles of abrasives with different sizes (400, 500,600, 800) μm. In this work, an orthogonal array of the type (L_{16}) has been chosen since there are four factors (variables) and four levels as shown in table (2), it shows the design used in the work [23]. During the erosion wear test, four test factors for each type of nano composites are considered, these are: (1) Filler Content; (2) Stand-off Distance; (3) Impingement Angle; (4) Sand size as represented in table (2).

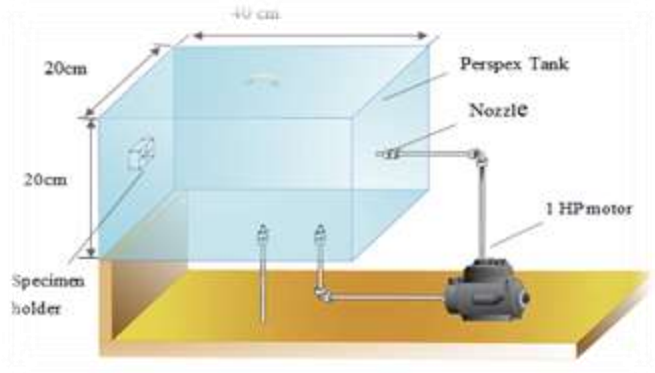


Figure (4): Erosion wear device

Table (2): Design of the orthogonal array (L_{18}) [23]

Test run	Factor A Filler Content (%)	Factor B Stand-off Distance (cm)	Factor C Impingement Angle Degree	Factor D Sand Size μm
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

4. Results and Discussion

4.1. *True Density*

Figure (5) shows the true density for the specimens unsaturated polyester+3% carbon fiber + (0.5%, 1%, 1.5%, 2%) carbon nanotube, unsaturated polyester+3% glass fiber + (0.5%, 1%, 1.5%, 2%) carbon nanotube and unsaturated polyester +3% Kevlar fiber + (0.5%, 1%, 1.5%, 2%) carbon nanotube. From the figure (5) it may be noted in all values of the nano composites density increased with increasing the volume fraction due the more voids are found with the addition of fiber and filler in the nano composites material [24]. In figure (5) can be seen that the specimens UP+ 3%C.F+0.5%-2% CNTs, UP+3% GF+0.5%-2% CNTs,UP+ 3%K.F+0.5-2% CNTs) have density higher than specimen UP, This is due to the fact that these fibers have a high density compared with the density of UP, also can be observed that the higher density has been found for the specimen (UP+ 3% G.F + 2% CNTs) than other specimens at same volume fraction because these CNTs are made to diminish or fill the voids and spaces which were inside the UP matrix. While the lower true density has been found for the specimen (UP + 3% K.F +2% CNTs) than other specimens. The preparation of composites with more than two materials is difficult, and increasing the volume fraction of any constituent can increase the difficulty and defect directly on the shrinkage of the matrix, and may create more voids-preferred sites. Also, the overall density will depend on the good distribution and bonding of all constituent [25].

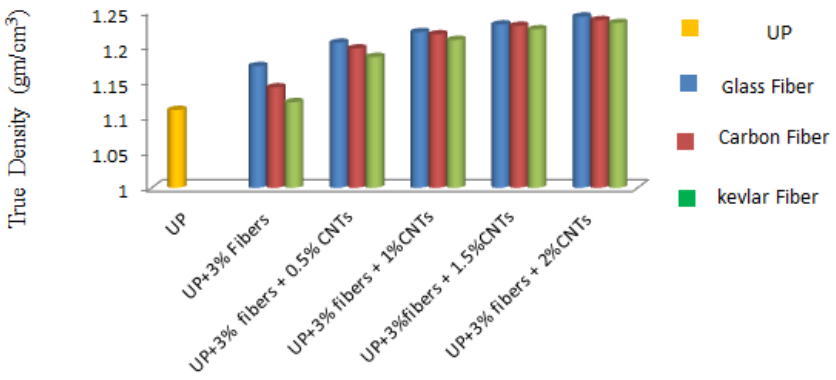


Figure (5): True Density of Nano Composite Materials

4.2. *Erosion Wear Test*

The solid particle erosion wear rates of CNTs filled unsaturated polyester composites under various test conditions are studied. The weight of the Nano composite is taken before the erosion test, later after the erosion test again the weight of the Nano composite under study is taken and the difference in their weight is calculated. The weight of the Nano composite after erosion is always less than that of before erosion. The difference in their weight is called mass or weight loss of the specimen due to solid particle impact. The ratio of this mass loss to the mass of the eroding particles causing the loss is then computed as the erosion rate. The erosion rate is thus defined as the mass loss of the specimen due to erosion divided by total weight of the specimen multi

by true density of the testing materials. Erosion wear rate include many mechanisms which are largely controlled by different factors such as impingement angle, particle size of silica sand, stand –off distance and filler content.

4.2.1. *Effect of impingement angle on erosion rate*

The impingement angle can be defined as the angle between the trajectory of the particle immediately before impact and the eroded surface. In cases when erosion shows a maximum at low impingement angles, it is concluded that the "ductile mode of erosion wear" prevails [26]. Conversely, if the maximum erosion rate is found at high impingement angles, then the "brittle mode" is assumed [27]. It is evident from figure (6) that impingement angle has significant influence on erosion rate and the maximum erosion is occurring at an impingement angle of 90° for all specimens and the minimum at (30°-60°). So the mode of erosion wear is neither a ductile erosion mode nor brittle erosion wear mode, it is behaving like semi ductile modes of erosion wear.

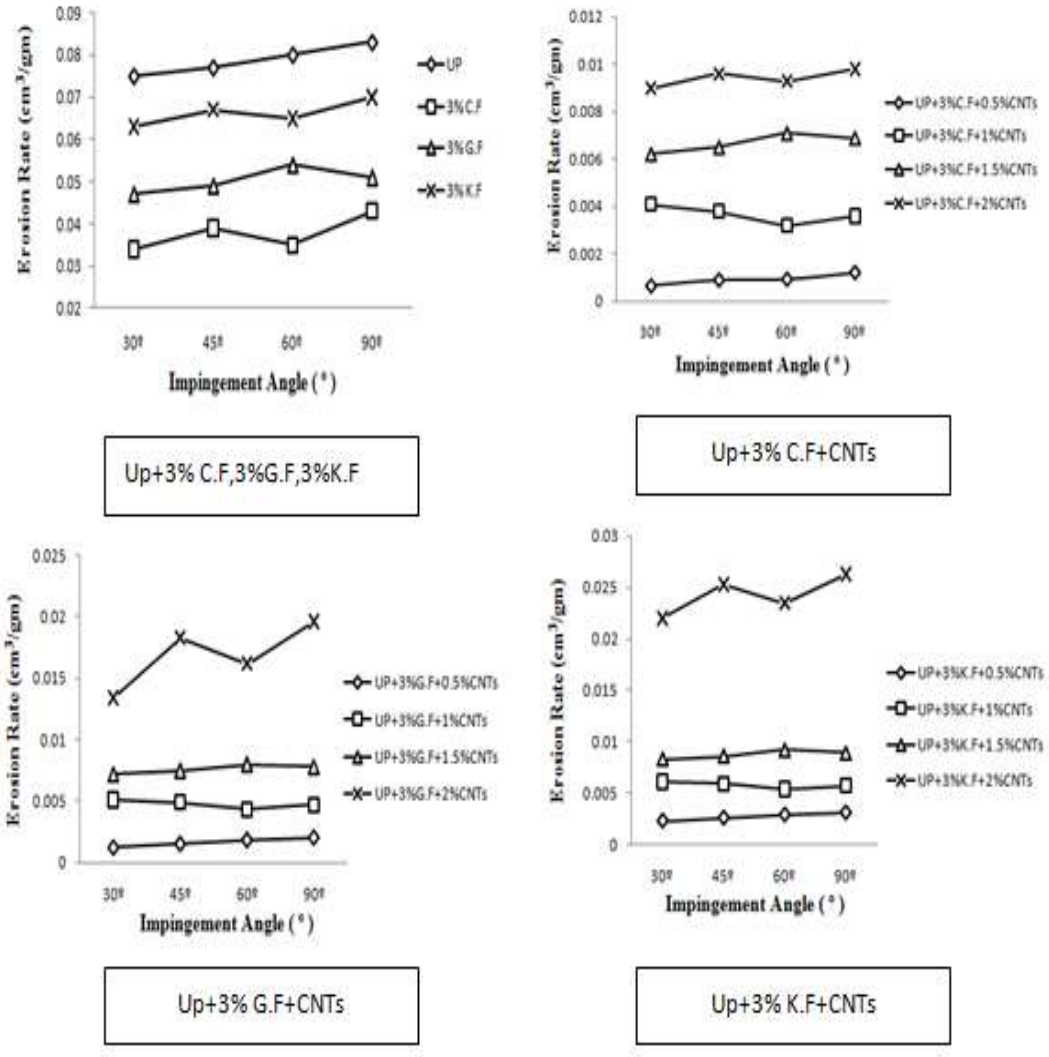


Figure (6): Effect of Impingement Angle on Erosion Wear Rate of Nano Composites

4.2.2. *Effect of particle size of silica sand on erosion rate*

The erosion rate of nano filler reinforced the unsaturated polyester resin has been studied by different size of silica sand (400, 500, 600, and 800) μm at constant flow rate (35 L⁄min) as shown in figure (7). It is observed, that with the increase in erodent size from (400 μm to 800 μm) the erosion rate increase.

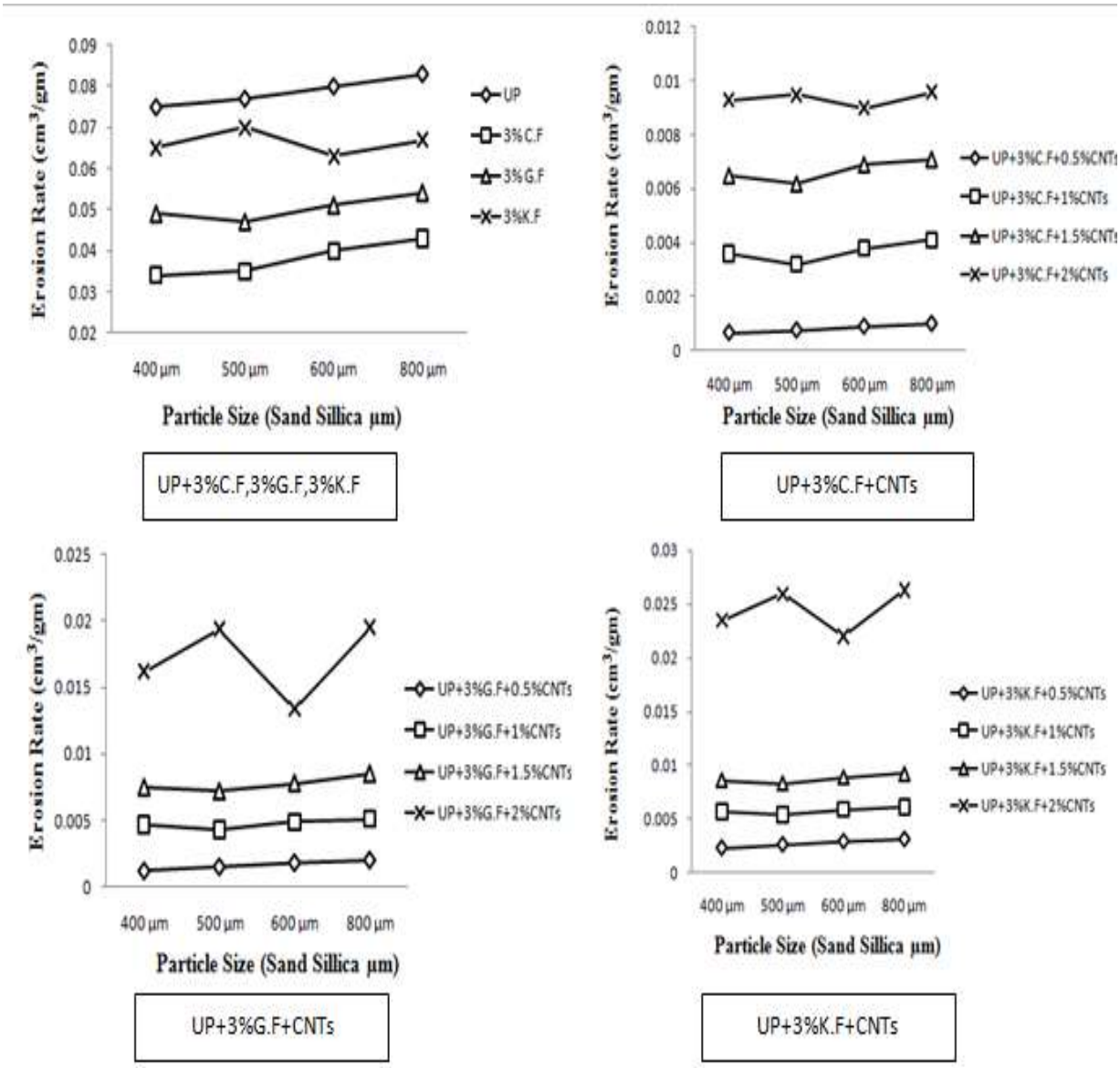


Figure (7): Effect of Particle Size of Silica Sand on Erosion Wear Rate of Nano Composites

4.2.3. *Effect of stand- off distance on erosion rate*

The stand–off is the distance between the eroded surface and the nozzle. The figure (8) shows the erosion rate of nano composites have been studied by different stand-off distance (15, 20, 25, and 30) cm. it is observed, that with the decrease in distance from (30 cm to 15 cm) the erosion rate increase.

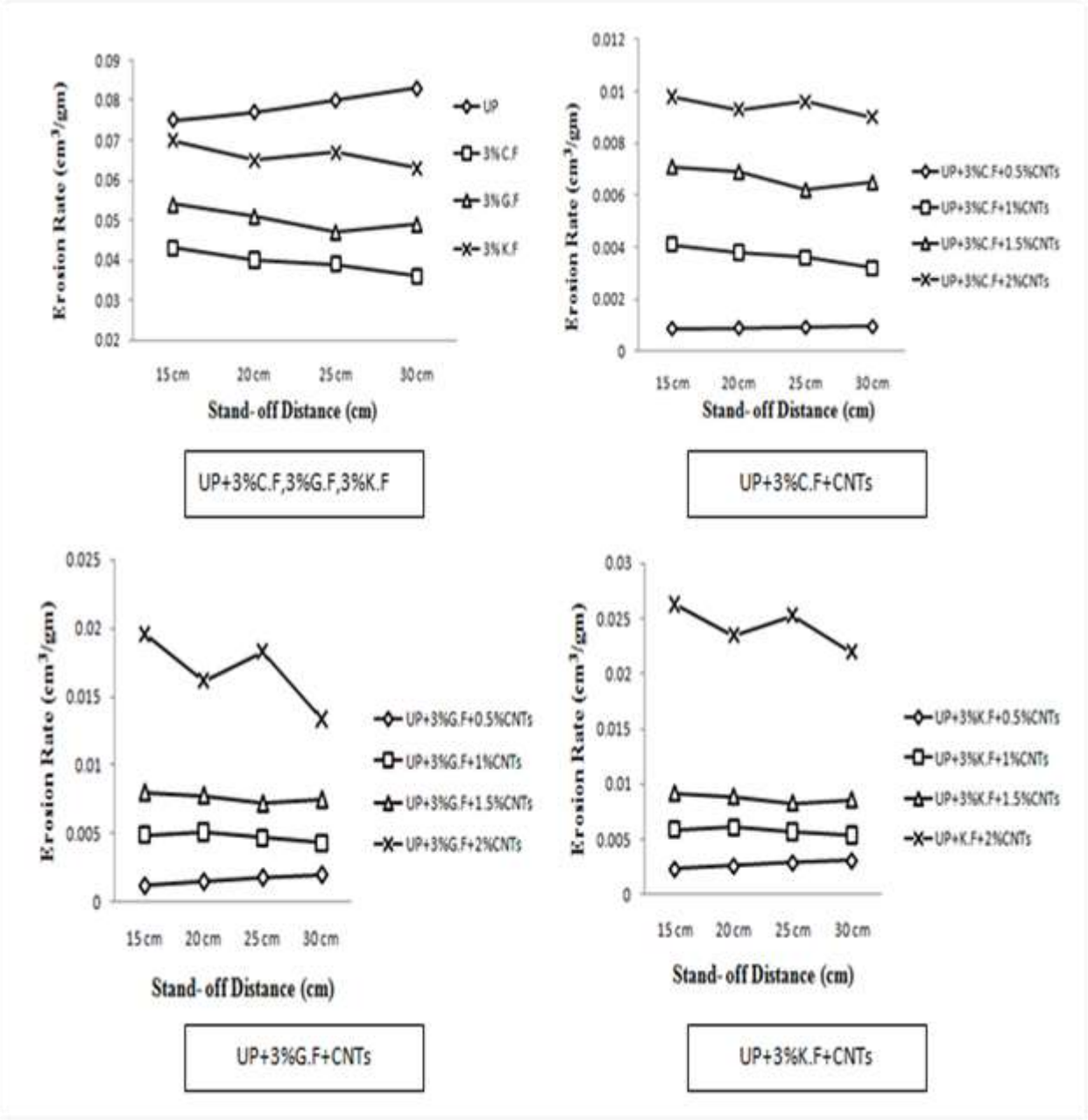


Figure (8): Effect of Stand-off Distance on Erosion Wear Rate of Nano Composites

4.2.4. *Effect of filler content on erosion rate*

The erosion rate of nano filler reinforced the unsaturated polyester resin has been measured for(UP+3%C.F,3% G.F,3% K.F+0.5%, 1%, 1.5%, and 2%) volume fraction of CNTs.

Figure (9) shows that the specimens (UP +3%C.F, 3%G.F, 3% K.F + 0.5% MWCNTs) have the maximum erosion rate resistant than other (UP +3%C.F, 3%G.F, 3%K.F + 1%, 1.5%, 2% MWCNTs).

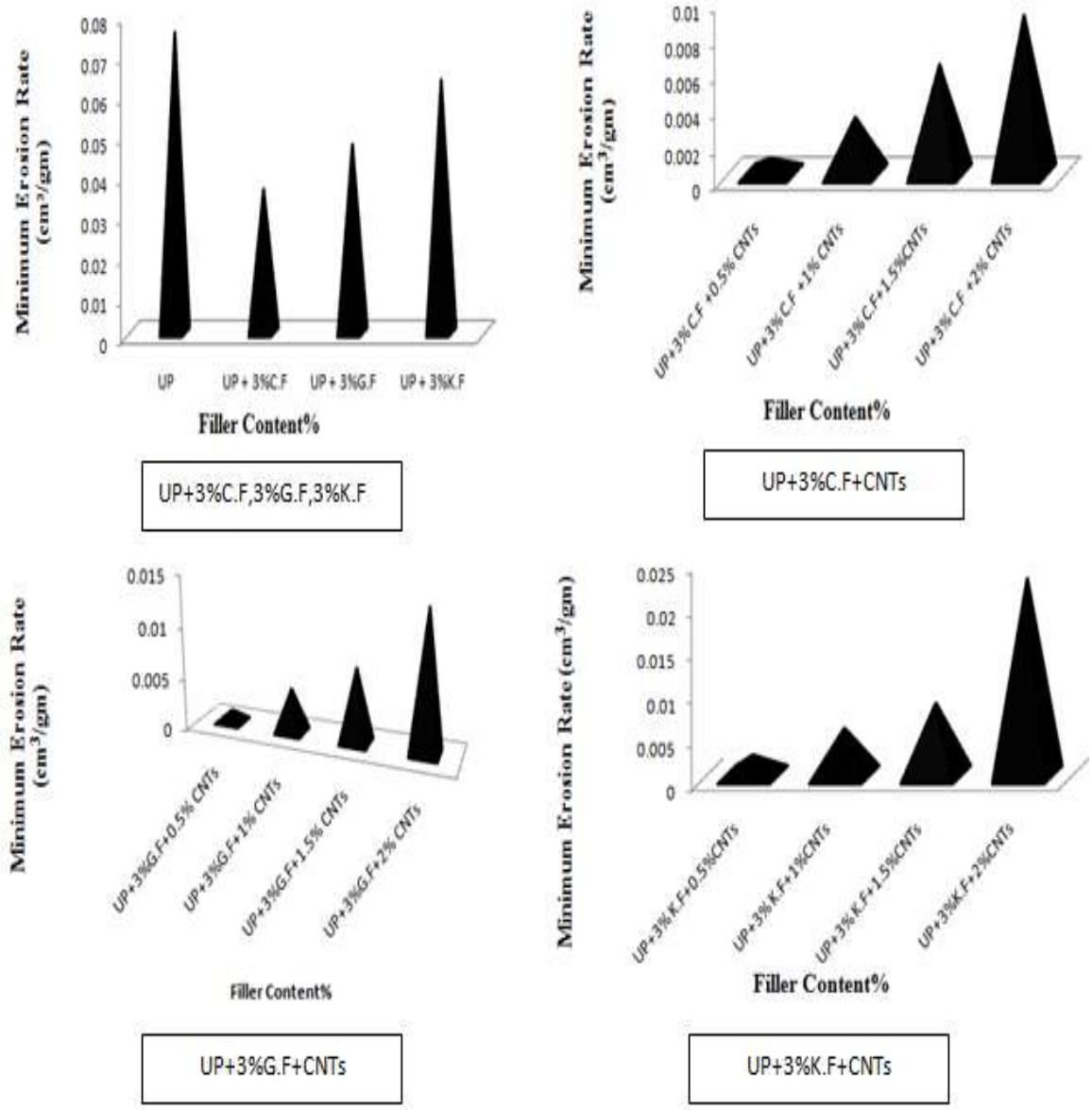


Figure (9): Effect of Filler Content on Erosion Wear Rate of Nano Composites

5. Taguchi Analysis

Tables (3) to (6) show the erosion rate of nano composites type for all 16 test runs and their corresponding S/N ratios.

The analysis is performed using the common software specially used for design of experiment MINITAB 17. The effect of the four factors on erosion rate for different nano composites are shown in figure (10 a, b, c, d).

From figure can be seen these factors combinations that give minimum erosion rate are (A2 , B4 ,C1 and D2) , (A1 , B4 ,C3 and D2) , (A1 , B4 ,C1 and D1), (A1 , B1 ,C1 and D1) respectively.

Table (3) Erosion wears rate of pure unsaturated polyester, UP +3% C.F, 3% G.F and 3% K.F

Exp.	Filler Content (A)	Stand- off Distance (cm)	Impingement Angle (°) (C)	Particle Size (sand) (µm)	Total Weight (Ws) (gm)	Weight After Erosion (gm)	Erosion Rate (cm^3/gm)	S/N
1	UP	15	30°	400	7.5132	6.8849	0.0753	22.4641
2	UP	20	45°	500	7.5132	6.8670	0.0774	22.2252
3	UP	25	60°	600	7.5132	6.8409	0.0806	21.8733
4	UP	30	90°	800	7.5132	6.8143	0.0838	21.5351
5	UP+3%C.F	15	45°	600	7.5893	7.2346	0.0404	27.8724
6	UP+3%C.F	20	30°	800	7.5893	7.2150	0.0431	27.3105
7	UP+3%C.F	25	90°	400	7.5893	7.2510	0.0390	28.1787
8	UP+3%C.F	30	60°	500	7.5893	7.2759	0.0361	28.8499
9	UP+3%G.F	15	60	800	7.6479	7.1625	0.0541	25.3361
10	UP+3%G.F	20	90	600	7.6479	7.1847	0.0516	25.7470
11	UP+3%G.F	25	30	500	7.6479	7.2231	0.0473	26.5028
12	UP+3%G.F	30	45	400	7.6479	7.2056	0.0493	26. 1431
13	UP+3%K.F	15	90	500	7.5597	6.9632	0.0703	23.0609
14	UP+3%K.F	20	60	400	7.5597	7.0062	0.0653	23.7017
15	UP+3%K.F	25	45	800	7.5597	6.9862	0.0676	23.4011
16	UP+3%K.F	30	30	600	7.5597	7.0215	0.0635	23.9445

Table (4) Erosion wears rate of pure unsaturated polyester, UP +3% C.F, (0.5%, 1%, 1.5%, 2%) CNTs

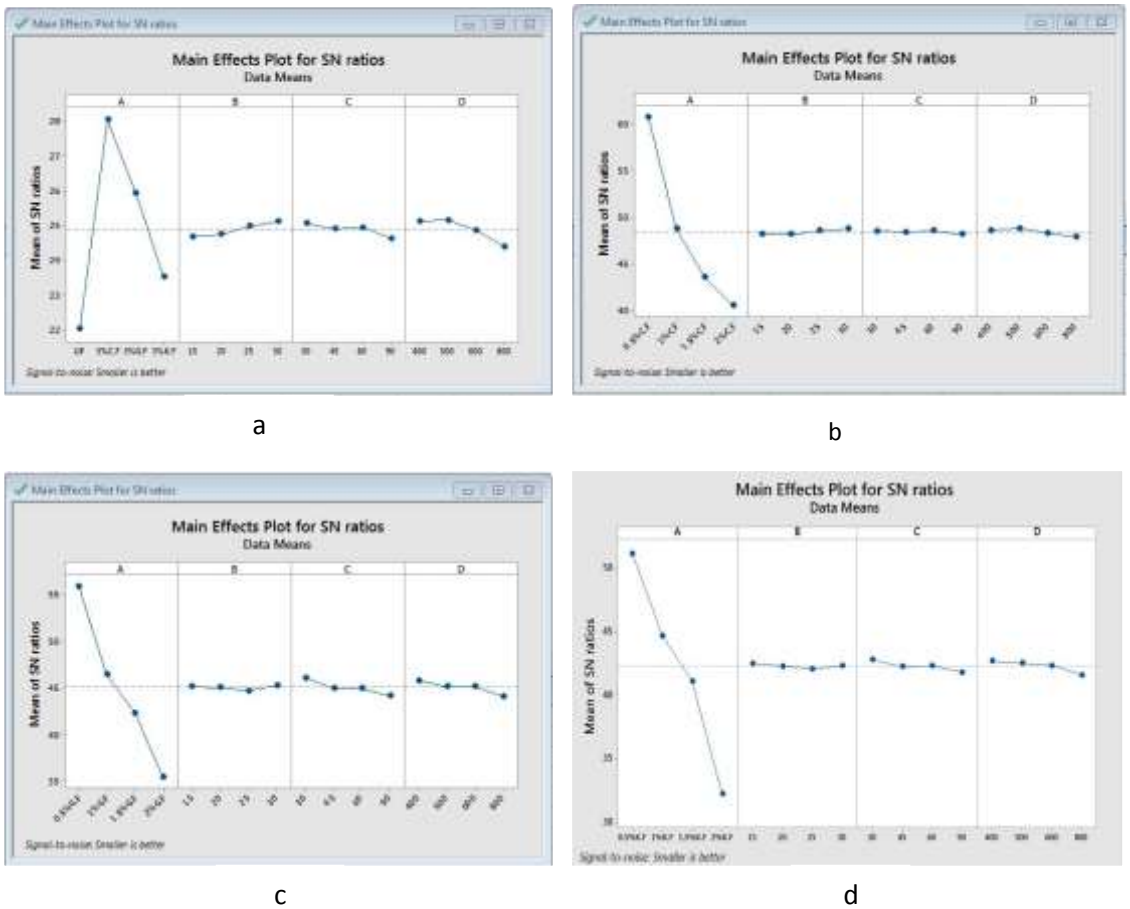
Exp.	Filler Content (A)	Stand- off Distance (cm))	impingement angle (°) (C)	Particle Size (sand) (µm	Total Weight (Ws) (gm)	Weight After Erosion (gm)	Erosion Rate (cm^3/gm)	S/N
1	UP+3%C.F+0.5% CNTs	15	30°	400	7.7475	7.7394	0.00087	61.2096
2	UP+3%C.F+0.5% CNTs	20	45°	500	7.7475	7.7392	0.00089	61.0122
3	UP+3%C.F+0.5% CNTs	25	60°	600	7.7475	7.7389	0.00092	60.7242
4	UP+3%C.F+0.5% CNTs	30	90°	800	7.7475	7.7386	0.00095	60.4455
5	UP+3%C.F+1% CNTs	15	45°	600	7.8576	7.8211	0.0038	48.4043
6	UP+3%C.F+1% CNTs	20	30°	800	7.8576	7.8183	0.0041	47.7443
7	UP+3%C.F+1% CNTs	25	90°	400	7.8576	7.8231	0.00036	48.8739
8	UP+3%C.F+1% CNTs	30	60°	500	7.8576	7.8262	0.00032	49.8970
9	UP+3%C.F+1.5% CNTs	15	60°	800	7.9693	7.8996	0.0071	42.9748
10	UP+3%C.F+1.5% CNTs	20	90	600	7.9693	7.9017	0.0069	43.2230
11	UP+3%C.F+1.5% CNTs	25	30	500	7.9693	7.9078	0.0062	44.1522
12	UP+3%C.F+1.5% CNTs	30	45	400	7.9693	7.9049	0.0065	43.7417
13	UP+3%C.F+2% CNTs	15	90	500	8.1563	8.0565	0.0098	40.1755
14	UP+3%C.F+2% CNTs	20	60	400	8.1563	8.0617	0.0093	40.6303
15	UP+3%C.F+2% CNTs	25	45	800	8.1563	8.0591	0.0096	40.3546
16	UP+3%C.F+2% CNTs	30	30	600	8.1563	8.0649	0.0090	40.9151

Table (5) Erosion wears rate of pure unsaturated polyester, UP +3% G.F, (0.5%, 1%, 1.5%, 2%) CNTs

Exp.	Filler Content (A)	Stand- off Distance (cm))	impingement angle (°) (C)	Particle Size (sand) (µm	Total Weight (Ws) (gm)	Weight After Erosion (gm)	Erosion Rate (cm^3/gm)	S/N
1	UP+3%G.F+0.5% CNTs	15	30°	400	7.7686	7.7571	0.0012	58.4164
2	UP+3%G.F+0.5% CNTs	20	45°	500	7.7686	7.7541	0.0015	56.4782
3	UP+3%G.F+0.5% CNTs	25	60°	600	7.7686	7.7511	0.0018	54.8945
4	UP+3%G.F+0.5% CNTs	30	90°	800	7.7686	7.7493	0.0020	53.9794
5	UP+3%G.F+1% CNTs	15	45°	600	7.8785	7.8310	0.0049	46.1961
6	UP+3%G.F+1% CNTs	20	30°	800	7.8785	7.8290	0.0051	45.8486
7	UP+3%G.F+1% CNTs	25	90°	400	7.8785	7.8333	0.0047	46.5580
8	UP+3%G.F+1% CNTs	30	60°	500	7.8785	7.8370	0.0043	47.3306
9	UP+3%G.F+1.5% CNTs	15	60°	800	7.9830	7.9035	0.0080	41.9382
10	UP+3%G.F+1.5% CNTs	20	90	600	7.9830	7.9058	0.0078	42.1581
11	UP+3%G.F+1.5% CNTs	25	30	500	7.9830	7.9116	0.0072	42.8534
12	UP+3%G.F+1.5% CNTs	30	45	400	7.9830	7.9085	0.0075	42.4988
13	UP+3%G.F+2% CNTs	15	90	500	8.1623	7.9636	0.0196	34.1549
14	UP+3%G.F+2% CNTs	20	60	400	8.1623	7.9976	0.0162	35.8097
15	UP+3%G.F+2% CNTs	25	45	800	8.1623	7.9761	0.0183	34.7510
16	UP+3%G.F+2% CNTs	30	30	600	8.1623	8.0261	0.0134	37.4579

Table (6) Erosion wears rate of pure unsaturated polyester, UP +3% K.F, (0.5%, 1%, 1.5%, 2%) CNT

Exp.	Filler Content (A)	Stand- off Distance (cm))	impingement angle (°) (C)	Particle Size (sand) (µm	Total Weight (Ws) (gm)	Weight After Erosion (gm)	Erosion Rate (cm^3/gm)	S/N
1	UP+3%K.F+0.5% CNTs	15	30°	400	7.7282	7.7067	0.0023	52.7654
2	UP+3%K.F+0.5% CNTs	20	45°	500	7.7282	7.7036	0.0026	51.7005
3	UP+3%K.F+0.5% CNTs	25	60°	600	7.7282	7.7016	0.0029	50.7520
4	UP+3%K.F+0.5% CNTs	30	90°	800	7.7282	7.6989	0.0031	50.1728
5	UP+3%K.F+1% CNTs	15	45°	600	7.8353	7.7786	0.0059	44.5830
6	UP+3%K.F+1% CNTs	20	30°	800	7.8353	7.7768	0.0061	44.2934
7	UP+3%K.F+1% CNTs	25	90°	400	7.8353	7.7808	0.0057	44.8825
8	UP+3%K.F+1% CNTs	30	60°	500	7.8353	7.7839	0.0054	45.3521
9	UP+3%K.F+1.5% CNTs	15	60°	800	7.9465	7.8569	0.0092	40.7242
10	UP+3%K.F+1.5% CNTs	20	90	600	7.9465	7.8598	0.0089	41.0122
11	UP+3%K.F+1.5% CNTs	25	30	500	7.9465	7.8652	0.0083	41.6184
12	UP+3%K.F+1.5% CNTs	30	45	400	7.9465	7.8622	0.0086	41.3100
13	UP+3%K.F+2% CNTs	15	90	500	8.1387	7.8741	0.0263	31.6009
14	UP+3%K.F+2% CNTs	20	60	400	8.1387	7.9020	0.0235	32.5786
15	UP+3%K.F+2% CNTs	25	45	800	8.1387	7.8839	0.0253	31.9376
16	UP+3%K.F+2% CNTs	30	30	600	8.1387	7.9105	0.0227	32.8795



a b

c d

Figure (10): Effect of factors on erosion rate: [(a) Filler Content, (b) Stand- off Distance, (c) Impingement Angle Degree, (d) Sand Size.

5.1. Analysis of ANOVA

Analysis of ANOVA has been carried out from the experimental data for nano composites on erosion rate. Tables (7) to (10) shows the ANOVA result for the erosion rate of nano composites under solid particle erosion. This analysis is undertaken for a level of confidence of significance of 5%. The laste column of the table indicates that

the main effects are highly significant (all have very small P-values). From the tables it can be observed the factor have effect on the erosion rate.

Table (7): ANOVA for erosion rate pure unsaturated polyester, UP +3% C.F, 3% G.F and 3% K.F

Source	Df	Seq SS)	Adj SS	Adj MS	F	P
A	3	0.0036615	0.0036615	0.0012205	168.41	0.001
B	3	0.0000079	0.0000079	0.0000026	0.37	0.785
C	3	0.0000309	0.0000309	0.0000103	1.42	0.390
D	3	0.0000583	0.0000583	0.0000194	2.68	0.220
Error	3	0.0000217	0.0000217	0.0000072		
Total	15	0.0037803				

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 (8): ANOVA for erosion rate UP +3% C.F + (0.5%, 1%, 1.5%, 2%) CNTs

Source	Df	Seq SS)	Adj SS	Adj MS	F	P
A	3	0.0001631	0.0001631	0.0000544	1061.35	0.002
B	3	0.0000006	0.0000006	0.0000002	3.65	0.158
C	3	0.0000002	0.0000002	0.0000001	1.01	0.496
D	3	0.0000004	0.0000004	0.0000001	2.71	0.217
Error	3	0.0000002	0.0000002	0.0000001		
Total	15	0.0001644				

Table (9): ANOVA for erosion rate UP +3% G.F + (0.5%, 1%, 1.5%, 2%) CNTs

Source	Df	Seq SS)	Adj SS	Adj MS	F	P
A	3	0.0005192	0.0005192	0.0001731	97.28	0.002
B	3	0.0000057	0.0000057	0.0000019	1.07	0.479
C	3	0.0000071	0.0000071	0.0000024	1.33	0.411
D	3	0.0000050	0.0000050	0.0000017	0.93	0.523
Error	3	0.0000053	0.0000053	0.0000018		
Total	15	0.0005422				

Table (10): ANOVA for erosion rate UP +3% K.F + (0.5%, 1%, 1.5%, 2%) CNTs

Source	Df	Seq SS)	Adj SS	Adj MS	F	P
A	3	0.0011217	0.0011217	0.0003739	565.08	0.003
B	3	0.0000021	0.0000021	0.0000007	1.04	0.489
C	3	0.0000029	0.0000029	0.0000010	1.46	0.382
D	3	0.0000023	0.0000023	0.0000008	1.14	0.458
Error	3	0.0000020	0.0000020	0.0000007		
Total	15	0.0011309				

6. Conclusions

1. The results indicate that specimens (UP + 3% (GF, CF, KF) +2% CNTs) has the maximum density of (1.242, 1.237, 1.233 gm/cm^3) respectively when compared with other specimens.
2. The specimens reinforced with carbon , Kevlar , glass and CNTs give better erosion resistance at (15 cm) stand – off distance , (30^0) impingement angle , (400µm) particle size sand , at (15hours) time .

3. From the Taguchi experimental design (ANOVA) filler content factor has great effect on erosion rate of CNTs filled carbon, glass and Kevlar fibers reinforced unsaturated polyester resin. The response for all nano composites is found semi-ductile and the maximum erosion rate takes place at the impingement of 90º.

7. References

1. K.V. Pool, C.K.H. Dharan, and I. Finnie, (1986),"*Erosive wear of composite materials*", Wear, Vol.107, PP.1-12.
2. S.M. Kulkarni, Kishore, (2001) , "*Influence of matrix modification on the solid particle erosion of glass/epoxy composites*", Polym. Polym. Composites,Vol. 9, PP.25-30 .
3. H.A. Aglan, and T.A. Chenock Jr., (1993), "*Erosion damage features of polyimide thermoset composites*", SAMPEQ, PP.41-47.
4. M. Roy, B. Vishwanathan, and G. Sundararajan, (1994), " *The solid particle erosion of polymer matrix composites*", Wear, Vol. 171, PP.149-161.
5. A. Häger, K. Friedrich, Y.A. Dzenis, and S.A. Paipetis, (1995),"*Study of erosion wear of advanced polymer composites*", in: K. Street, B.C. Whistler (Eds.), Proceedings of the ICCM-10, Canada Woodhead Publishing Ltd., Cambridge, PP. 155-162.
6. Finnie I. (1960)," *Erosion of surfaces by solid particles*", Wear, No.2, Vol.3, PP.87-103. .
7. D. N. Qian, L. M.Bao, M. Y. Takatera and A. H.Yamanaka, (2010)," *Development of FRP composites with excellent erosion resistance by solid particles*", Dep. of Bioscience and Textile Tech., Interdisciplinary Graduate School of Science and Tech. Shinshu University,PP. 1-6.
8. M. Ismail, S. Bheemappa and Rajendra N, (2012)**,"***Investigations on Mechanical and Erosive Wear Behaviour of Cenosphere Filled Carbon-Epoxy Composites* **"**, International Conference on Mechanical, Automotive and Materials Engineering, PP. 208-212.
9. O. Shakuntala, R.Gujjala, S. K. Acharya and S. K. Pal , (2013), **"***Mechanical & Tribological Behavior of Alumina Nano Filler Reinforced Epoxy Hybrid Composite***"**, Proceedings of the ASME 2013 International Mechanical Engineering Congress and Exposition, No.15-21, PP.1-6.
10. R. Sridhar, H. N. Narasimha Murthy, G. Angadi, N. Raghavendra, S. Firdosh, and M .Krishna,(2014),"*Effect of Nano clay Addition on the Erosion Wear of Glass/vinylester Composites Using Taguchi's Orthogonal Array Technique*", Elsevier, Vol. 5, PP.1174-1181.
11. Intelligent Materials Pvt. Ltd, nanoshel2@gmail.com, web: www.nanoshel.in, 3422OldCapitolTrailSuit 1305, Wilmington DE-19808US.
12. www.Farapol.com.

13. Abilash N., and Sivapragash M., (2013) **,"***Environmental Benefits of Ecofriendly Natural Fiber Reinforced Polymeric Composite Materials"***,** International Journal of Application or Innovation in Engineering and Management , Issue 1, Vol. 2, PP. 54.
14. Paul A., Frederick T. Wallenberger, Bingham, (2011), **"** *Fiberglass and Glass Technology: Energy-Friendly Compositions and Applications"* ,Springer, PP. 32-211, (ISBN 978-1-4419-0735-6)
15. WW W.otobock.com.
16. Www. Hexcel. Com.
17. L. Shterenberg, and S. Bogdanova, Inorg.Mater. (Engl.Transl.), (1979) , JCPDS-International Center for Diffraction Dat. All rights reserved PCPDFWIN v. 1.30, 15, 632.
18. k. Felix, A. Sylvester and A. Edmund, (2012),"*Storage and handling techniques of maize and groundnut***",** Senra Academic Publishers, Burnaby, British Columbia, No. 3, Vol. 6, PP.2122.
19. Annual Book of ASTM Standard, (2008), "*Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement* **"** D 792-08.
20. A. Gupta, A. Kumar, A. Patnaik, and S. Biswas , (2012) ,"*Effect of Filler Content and Alkalization on Mechanical and Erosion Wear Behavior of CBPD Filled Bamboo Fiber Composites***"**, Journal of Surface Engineered Materials and Advanced Technology, No.2 ,PP.149-157, (doi.org/10.4236/jsemat.2012.23024) .
21. S. Biswas,(2012), "*Erosion Wear Behaviour of Copper Slag Filled Short BambooFiber Reinforced Epoxy Composites"*, Mechanical Engineering Department, National Institute of Technology, Rourkela, India.
22. Annual Book of ASTM Standard, (1988), *"Standard Practice for Conducting Erosion Tests by Solid Particle Impingement Using Gas Jet, G 76-83",* Vol. 03.02.
23. M. Verma, R. K.Malviya, and G. Sahu,(2014) , *" Taguchi Analysis of Erosion Wear Maize Husk Based Polymer Composite"*, International Journal of Modern Engineering Research (IJMER), Vol.4, Iss.3.
24. P. Tapas, R. Swain, and S. Biswas,(2014) , *" Physical and Mechanical Behavior of Al_2O_3 Filled Jute Fiber Reinforced Epoxy Composites",* International Journal of Current Engineering and Technology, Issue 2, PP.67-71, (doi/10.14741/ijcet/spl.2.2014.13).
25. O. S. Muhammed, A. K. Hussein, and R. H. Abdel-Rahim,(2013), *"Effect of Filler Type on some Physical and Mechanical Properties of Carbon Fibers / Polyester Composites",* Engineering &Technology Journal, No.15, Vol.31, PP.2911.
26. J.C. Arnola and I.M. Hutchings, (1993) ,*"Erosive wear of rubber by solid particles at normal incidence "*, wear , No.1-2 , Vol.161 , PP.213-221
27. J.C. Arnola and I.M. Hutchings, (1992) , *"Model for the erosive wear of rubber at oblique impact angles ",* Journal of Physics D , No.1A , Vol.25, PP.A222-A229 .