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Fabrication & Erosion wear Response of E-Glass-Epoxy Based Hybrid Composites filled with CFA/CFACP

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Abstract*: *In this research work Coal Fly Ash (CFA)/ mixture of Coal Fly Ash (CFA) and Coal Powder (CP) filled E-glass Fiber Epoxy Resin Hybrid composites were fabricated with three weight proportions (0wt%, 5wt% and 10wt %) by manual hand layup technique. Coal Fly Ash and Coal Powder are the solid waste generated from power generation plants (VTPS, VJA). The erosion wear behavior of the composites were determined at different impingement velocities (30, 60 and 90m/sec), impingement angles (45°,60° and 75°), weight proportions (0%, 5%, 10wt %) and S.O.D (25, 35 and 45mm) at constant feed rate of Al_2O_3 of 5grams/min and size of (50μm) following the experiments of erosion by Air Jet erosion Test Rig. It was observed that with the addition of fillers (CFA/CFACP) to E-Glass Fiber Epoxy composites. Hardness and erosion wear resistance were improved and the effect/influence of control factors (Impact velocity, Impingement angle, S.O.D and weight percentage of fillers) on erosion wear rate were determined by ANOVA

Keywords*: *Fiber Reinforced Polymers (FRP's), Coal Fly Ash (CFA), Coal Fly Ash and Coal Powder (CFACP), Erosion wear, Taguchi's, orthogonal array, ANOVA.

I. INTRODUCTION

In various engineering applications such as automobiles, structures, aerospace, mining, sports kits, space ships manufacturing and marine equipment etc., Fiber reinforced polymer composites are used as engineering parts due to their resistance to wear, abrasion, erosion, corrosion, high strength at low weights and low cost [1-8]. Erosion wear resistance and mechanical properties are very poor for polymers [9-10]. Hence to get the desired mechanical properties and erosion wear resistance, fibers are reinforced in polymers (matrix). Here the erosion is the removal of the material from the surface of composite due to the impingement of solid particles [11]. The erosion rate mainly depends on composition of the eroding material (or) target material and the experimental conditions while doing the experiment on Air Jet Erosion Test Rig, some of the experimental conditions which effects the erosion wear rate Are Impingement velocity, Angle of Impingement, Standoff distance, Fiber orientation and content, filler content, feed rate of erodent [12-14]. To bring down the overall cost of the component and to improve the stiffness and wear resistance, inorganic/organic fillers in the form of fillers are used along with Fiber reinforcement in polymers [15-16]. Coming to process parameters of erosion Impingement angle plays important role in material removal (erosion) in composites. The maximum erosion will occur at 15°-20° in the composites which are having ductile behavior and the erosion will be maximum in the composites whaving brittle behavior at 90° impingement angle [17]. With the addition of hard particulate fillers like red mud, coal fly ash, SiO_2, Al_2O_3, $CaCo_3$, marble dust, saw wood dust, SiC to the Fiber reinforced polymers the wear resistance will be improved [18-23]. A good amount of work has been done to improve the erosion wear resistance of fiber reinforced polymers with the addition of coal fly ash as filler which is the industrial waste generated from power plants. About 70% of coal fly ash is wasted every year and it is the potential filler to improve the wear resistance. Coal Powder/Coal dust is also an industrial waste which is produced while delivering it from coal storage yard to boiler through various material handling equipment's. The use of coal fly ash along with coal powder as filler in fiber reinforced polymers has not been reported. Coal powder and Coal Fly Ash usage reduces environmental effects and provides economical benefits. Combination of Coal Fly Ash and Coal Powder give good abrasion and chemical resistance. Keeping all the above things in mind, The objective of the present research work is to develop the low-cost E-glass fiber and CFA/CFACP reinforced hybrid composite with Epoxy resin as matrix material in different weight proportions and erosion wear performance of specimens as per ASTM G76 is studied. The experiments on erosion wear have been conducted as per Taguchi Experimental Design (DOE).

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II. MATERIALS AND METHODS

Composite Fabrication: In the present work, epoxy Resin (LY 556) is utilized as the framework material and its basic name is bisphenol-A-diglycidyl-ether, and it synthetically has a place with 'epoxide' family. The epoxy resin and the relating hardener (HY 951) were provided by kotsan engineering corporation private limited, Guntur. Bi-directional E-glass fiber tangle was utilized as the strengthening material. The densities for E-glass fiber and Epoxy resin are 2590kg/m^3 and 1100kg/m^3 respectively and the modulus for E-glass fiber is 72.5Gpa whereas for Epoxy resin is 3.42Gpa.The filler materials coal powder (CP) & Coal Fly Ash (CFA) were collected from Vijayawada thermal power station, Andhra Pradesh.

The gathered fillers were dried in oven with a temperature of 110^{o}C for evacuation of dampness and were sieved to get a molecule measure in the request of 70– 80 micro meters. Composites of three distinct syntheses (0 wt%, 5 wt % and 10 wt% of coal fly ash/coal fly ash & coal powder) were made and the fiber stacking was kept at 50wt% in every one of the composition (shown in **Table 1**).

Table 1: Designation and Composition of the Composite Samples

Designation	Wt% of Matrix	Wt% of Glass Fiber	Wt% of Filler
E-G	50	50	0
E-G-CFA5	45	50	5
E-G-CFA10	40	50	10
E-G-CFACP5	45	50	5
E-G-CFACP10	40	50	10
E:Epoxy Resin	G:E-Glass Fiber	CFA: Coal Fly Ash	CFACP: Coal Fly Ash & Coal Powder

The ratio of mixing the Epoxy resin (LY556) and the Hardener is 10:1 by weight as suggested. To prepare the composite without filler the blend was mixed in a mechanical stirrer to scatter consistently in the network. The castings were put under heap of about 35 kg for 24 h for appropriate relieving at room temperature. The cast was then post-relieved in air for another 24 h after expulsion from the form. Eight layers of E-Glass fiber mats were utilized to acquire around 3.2 mm thick overlays. To prepare the composites with fillers in composites, fillers (CFA/CFACP) were added with 5wt% and 10wt% to epoxy resin and then hardener (HY951) is added to the mixture of epoxy and filler, a mold of size 300X300X3.2 mm^3 was used for composite fabrication .silicone spray was applied to the mold for the easy removal of cast after curing specimens as per ASTM G 76 were prepared for Erosion wear test.

Test Apparatus: The solid particle erosion wear tests were conveyed out according to ASTM G76 utilizing air jet erosion test rig (TR470) provided by DUCOM Ltd. The air jet erosion test rig is the assembly of a conveyor belt type, erodent feeder, an air-drying unit, an air compressor, an air molecule blending and quickening chamber. The dried and packed air was then blended with the Al_2O_3(erodent) which was encouraged continually by a transport line feeder into the blending chamber and afterward quickened by passing the blend through a concurrent metal spout of 1.5 mm inner diameter. The setup is fit for making erosive circumstances for surveying erosive wear obstruction of the composite samples. At different impingement angles the erodent strikes the target material (specimen) with respect to the direction of flow of erodent utilizing a swivel and a flexible specimen cut. In the present work, a precision electronic balance is used to measure the weights of the specimens before and after the erosion test to an accuracy of 0.1mg to calculate the erosion Wear rate the weight loss of the specimen was recorded. Before test the acetone was used to clean the sample, the procedure was rehashed no less than multiple times till the erosion rate achieves a consistent esteem called steady state erosion rate.

Experimental Design: Taguchi structure of investigation is a basic, effective and deliberate way to deal with advance execution, quality also, cost.[24] This test technique has been utilized prior for parametric examination of erosion behavior of glass fiber-strengthened polyester/epoxy hybrid composites[25– 27] The choice of control factors is the most imperative part in the structure of trial/DOE. Subsequently, countless factors are at first included so that the non significant variables can be identified easily. Erosion wear behavior of polymer composites is highly influenced by the operating parameters like impact velocity, weight percentage of filler, stand-off distance, impingement angle etc., and the effect of these four factors on erosive wear of polymer composites is thusly considered in this work using a L9 Array. In Table 2 the variable and fixed parameters are shown to conduct the erosion wear test and the picked estimations of the four control factors are recorded in **Table 3**. The cost and time for experiments are reduced by Taguchi in which 9 numbers of experiments are conducted instead of 81 runs. For the better analysis of the problem erosion wear rate (mg/kg) is converted in to S/N ratios. The S/N ratio is “Lower is Better (LB)” characteristics for minimum erosion wear rates. The tests were finished by preliminary arrangement seemed **Table 4**, in which each portion addresses a test parameter while a section speaks to a test condition. The arrangement of test is from column (1) to column (5) as Test run, Impingement/Impact velocity (A), weight % of filler (B), stand-off distance (S.O.D) (C) and Impingement angle (D) respectively for both the composites loaded up with Coal fly ash (CFA)/Coal fly ash and coal powder (CFACP)**.**

Table 2: Parameter Setting for Erosion Test

S.No	Fixed/Variable Parameter	Value/Type
1	Erodent Material	Aluminum oxide(Al_2O_3)
2	Size of Erodent (micro meters)	50
3	Shape of Erodent	Spherical
4	Velocity of Impact (m/sec)	30,60 and 90
5	Angle of Impingement(Degrees)	45,60 and 75
6	Stand-off Distance(mm)	25,35 and 45
7	Erodent Feed Rate(grams/min)	5
8	Erodent Density(gm/cm^3)	3.97
9	Nozzle Diameter(mm)	1.5
10	Nozzle Length(mm)	50
11	Test Duration(min)	3
12	Test Temperature	Ambient

Table 3: Levels(L) of Control Factors

Control Factors	L-I	L-II	L-III	Units
A: Velocity of Impact(V.O.I)	30	60	90	m/sec
B:wt% of Filler	0	5	10	Wt%
C:Stand-off Distance	25	35	45	mm
D: Angle of Impingement(A.O.I)	45	60	75	Degrees

Table 4: L9 Taguchi Design.

Test Number	A: V.O.I	B:wt% of Filler	C:S.O.D	D:A.O.I
1	30	0	25	45
2	30	5	35	60
3	30	10	45	75
4	60	0	35	75
5	60	5	45	45
6	60	10	25	60
7	90	0	45	60
8	90	5	25	75
9	90	10	35	45

III RESULTS AND DISCUSSION

Analysis of Experimental Results: Taguchi Analysis of Experimental Results& Response optimization: In Tables 5&6, the erosion wear rates of various composites filled with Coal fly ash (CFA) /Coal fly ash & coal powder (CFACP) for every one of the 9 test runs and their relating S/N proportions are given. The erosion wear rates of various composites filled with Coal fly ash (CFA) /Coal fly ash & coal powder (CFACP) for every one of the 9 test runs and their relating S/N proportions are given. Each Esteem is in certainty the mean of three replications. For CFA Filled epoxy composites the average of S/N ratio in proportion to erosion wear is observed to be -61.1912 dB and -55.4333 dB for CFACP Filled Composites. Software called MINITAB 18 is used as a predictor to measure the performance by considering the control factor interactions. Therefore, factorial design fuses basic methods for testing for the nearness of cooperation impacts. There is no effect of control factors on erosion wear rate. In the graph of control factors (or) erosion wear rate, if the line is at close level for a particular factor. These outcomes are displayed in Figure 1&2, where the combinations of factors A_1=30m/sec, B_1=0wt%, C_3=45mm and $D2=60^o$ yields least erosion wear rate in case of CFA Filled Hybrid Composites and the combination of A1=30m/sec, B3=10wt%, C3=45mm and $D2=60^0$ yield least erosion wear rate in case of CFACP Filled Hybrid Composites

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Table 5: Erosion Wear(Er) Results of coal fly ash (CFA) based Hybrid Composites.

Test	A: V.O.I	B:wt% of Filler	C:S.O.D	D:A.O.I	E_r (mg/kg)	S/N Ratio(dB)
1	30	0	25	45	100	-40.0000
2	30	5	35	60	314.666	-49.9568
3	30	10	45	75	389.33	-51.8064
4	60	0	35	75	1813.33	-65.1696
5	60	5	45	45	1428	-63.0946
6	60	10	25	60	2105.33	-66.4664
7	90	0	45	60	1718.66	-64.7038
8	90	5	25	75	5880.66	-75.3885
9	90	10	35	45	5090	-74.1344

Table 6: Erosion Wear Results of coal fly ash & Coal Powder (CFACP) based Hybrid Composites.

Test	A: V.O.I	B:wt% of Filler	C:S.O.D	D:A.O.I	E_r (mg/kg)	S/N Ratio(dB)
1	30	0	25	45	100	-40.0000
2	30	5	35	60	66.66	-36.4773
3	30	10	45	75	53.33	-34.5394
4	60	0	35	75	1813.33	-65.1695
5	60	5	45	45	1408	-62.9721
6	60	10	25	60	368.66	-51.3325
7	90	0	45	60	1718.66	-64.7038
8	90	5	25	75	3499.3	-70.8797
9	90	10	35	45	4378	-72.8255

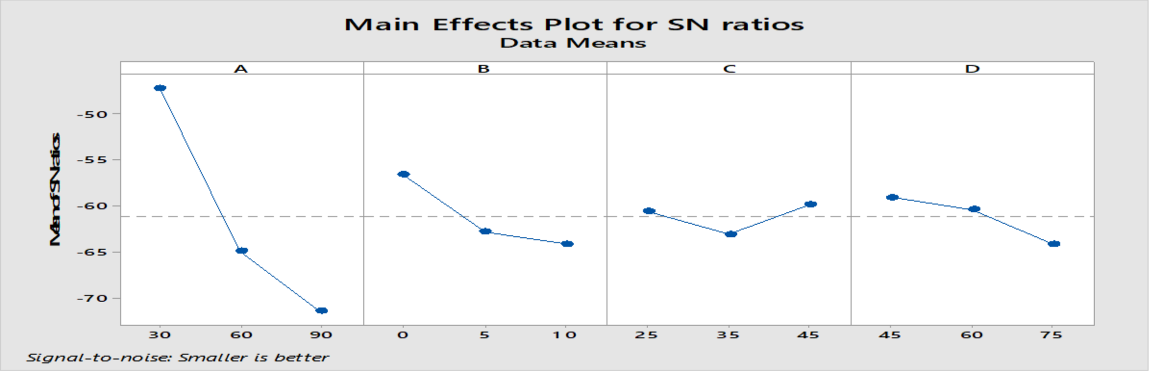

Figure 1: Effect of Control Factors on S/N Ratio of Epoxy based hybrid composites filled with coal fly ash (CFA) (Means)

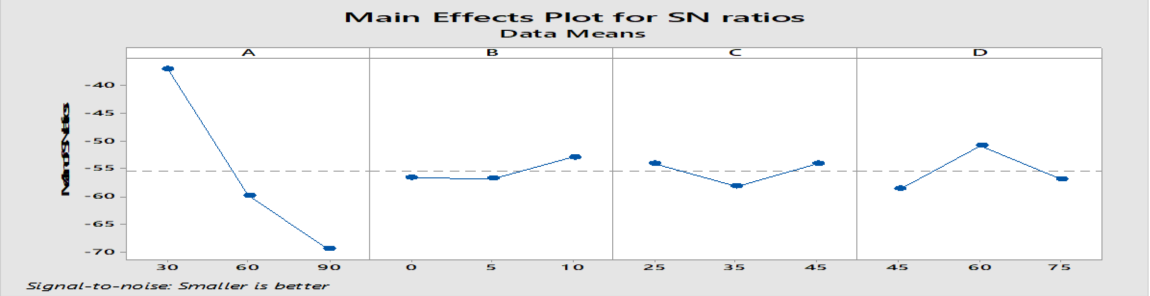

Figure 2: Effect of Control Factors on S/N Ratio of Epoxy based hybrid composites filled with coal fly ash and Coal Powder (CFACP) (Means)

ANOVA and the impact of Factors: So as to discover factual importance of different variables like Impact velocity (A), weight percentage of filler (B), stand-off distance (C) and impingement angle (D) on erosive wear rate, examination of fluctuation/Analysis of variance (ANOVA) are performed on the exploratory information. The results of the Analysis of variance with the rate of erosion are demonstrated in Table 7&8, and the level of confidence of significance of 5% was considered in analysis. The P-values in the last columns of Table: 7&8 indicates the main effect of control factors on erosion wear rate. From **Table 7**, unmistakably impact velocity (p = 0.009), wt% of filler (p =0.185) and stand-off distance (p =0.139) have extraordinary impact on erosive wear rate. Interestingly, impingement angle (p=0.585) has less significant commitment on the erosion rate where as from **Table 8** impact velocity (p = 0.025), wt% of filler (p =0.686) and stand-off distance (p =0.0783) have extraordinary impact on erosive wear rate. Interestingly, impingement angle (p=0.856) has less significant commitment on the erosion wear rate.

Table 7: Analysis of Variance table for erosion wear rate of CFA filled Epoxy Based Hybrid Composites

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regression	4	29955720	88.04%	29955720	7488930	7.36	0.040
A	1	23543512	69.19%	23543512	23543512	23.14	0.009
B	1	2603929	7.65%	2603929	2603929	2.56	0.185
C	1	3450417	10.14%	3450417	3450417	3.39	0.139
D	1	357862	1.05%	357862	357862	0.35	0.585
Error	4	4070411	11.96%	4070411	1017603		
Total	8	34026131	100.00%				

Table 8: Analysis of Variance table for erosion wear rate of CFACP filled Epoxy Based Hybrid Composites

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regression	4	15027396	75.82%	15027396	3756849	3.14	0.147
A	1	14651469	73.92%	14651469	14651469	12.23	0.025
B	1	227371	1.15%	227371	227371	0.19	0.686
C	1	103483	0.52%	103483	103483	0.09	0.783
D	1	45074	0.23%	45074	45074	0.04	0.856
Error	4	4793405	24.18%	4793405	1198351		
Total	8	19820801	100.00%				

Effect of operating Parameters on Erosion wear Response of Epoxy Based Hybrid Composites: Parameters like impact velocity, weight percentage of filler, Stand-off Distance and Impingement angle plays a vital role in erosion wear response of composites as shown in **figures 3&4**.

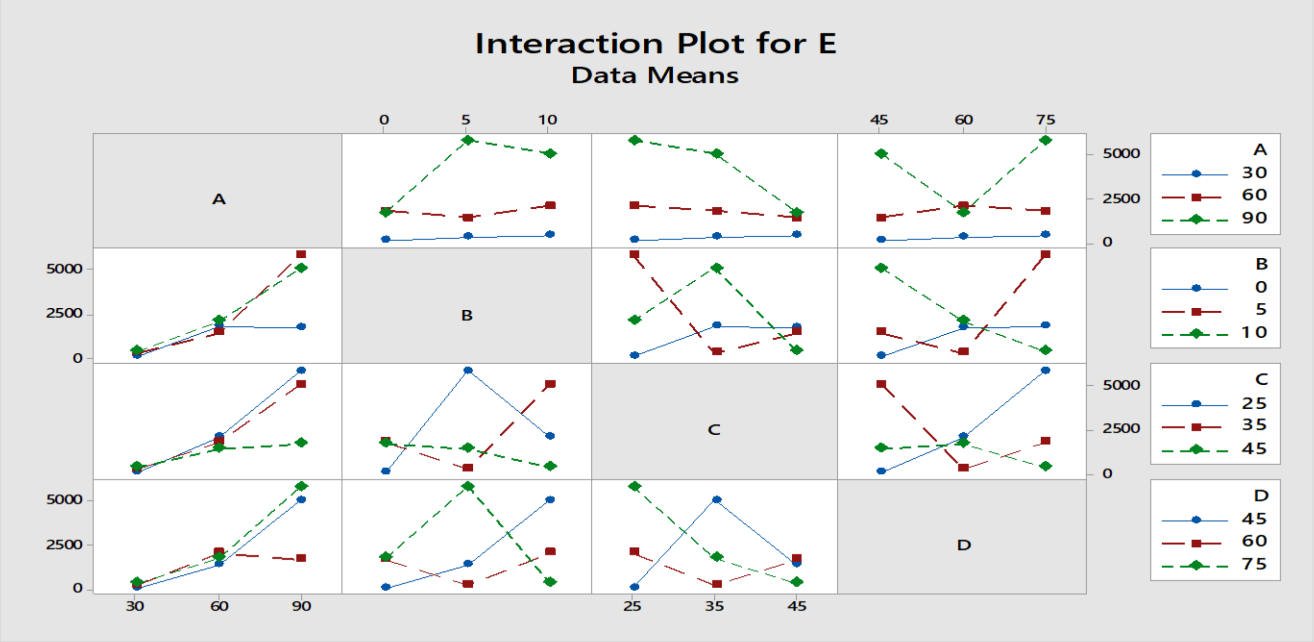

Figure 3: Interaction Plots for Wear Rate of CFA Filled Epoxy Based Hybrid Composites

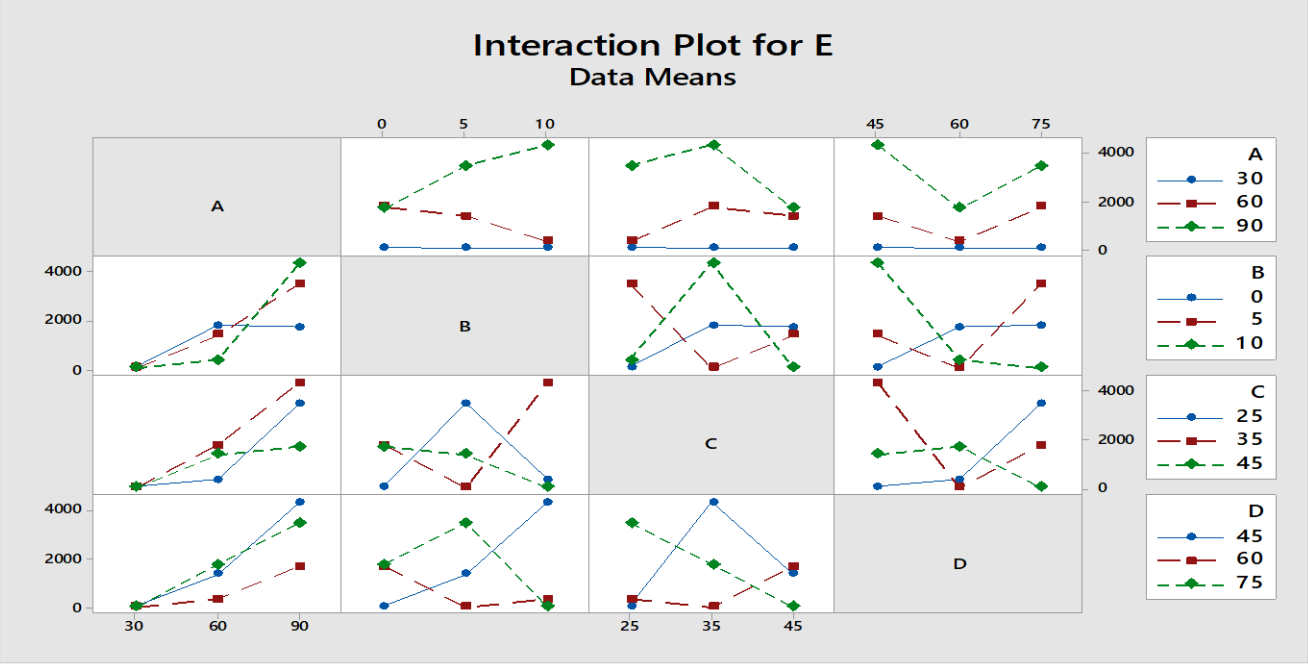

Figure 4: Interaction Plots for Wear Rate of CFACP Filled Epoxy Based Hybrid Composites

IV CONCLUSIONS

The Erosive wear rate examination on CFA/CFACP filled glass-epoxy composites prompts the accompanying ends:

1. Manufacture of another class of minimal effort epoxy based crossover composites comprising of glass– fiber and particulate fillers like CFA/CFACP is conceivable in straightforward hand layup procedure.
2. The Taguchi Design of experiments is used for the successful analysis of the wear response of the composites. The investigation uncovers that the velocity of impact, weight percentage of filler, angle of Impingement and standoff distance are observed to be the huge control factors in diminishing request influencing erosion rate.
3. In CFA filled epoxy based hybrid composites Erosion wear rate is very much less at 60 degrees angle ,at 45 mm S.O.D, at 5wt% filler content and 30 m/sec Impact Velocity.
4. In CFACP Filled Epoxy based hybrid composites minimum erosion occurred at 75 degrees angle, at 45mm S.O.D, at 10wt% of filler and at 30 m/sec Impact velocity.
5. By ANOVA minimum wear rate can be predicted at the combination of A1B1C3D2 for CFA Filled Composites and at the combination of A1B3C3D2 for CFACP Filled composites.

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