Erosion Wear Response of Pineapple Leaf Fiber (PALF) Reinforced Vinylester Composites Filled with Flyash: A Power plant waste

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Abstract: Natural fiber-based composites are under intensive study due to their eco-friendly nature and peculiar properties. The advantage of natural fibers is their continuous supply, easy and safe handling, and biodegradable nature. Natural fibers exhibit admirable physical and mechanical properties. Pineapple leave fiber (PALF) is one of the natural fiber abundantly available wastes materials in India and has not been studied yet. This research work is carried out a possibility that the incorporation of both particulate filler and fibers in polymer could provide a synergism in terms of improved properties. In view of this, the present research work is undertaken the fabrication of a set of Pineapple leaf fiber (PALF) reinforced Vinylester composites filled with flyash a power plant waste product as the particulate filler. These results are compared with those of a similar set of Glass fiber reinforced Vinylester composites filled with same particulate filler. It also attempts to study the solid particle erosion wear response of these composites under multiple impact condition. The methodology based on Taguchi's experimental design approach is employed to make a parametric analysis of erosion wear process. This systematic experimentation has led to determination of significant process parameters and material variables that predominantly influence the wear rate of the particulate filled composites reinforced with pineapple leaf fiber. The significant control factors predominantly influencing the wear rate are identified. The filler content in the composites, the impingement angle and erodent temperature are found to have substantial influence in determining the rate of material loss from the composite surface due to erosion.

Keyword: - Natural fiber, Pineapple leaf fiber, particulate filler, Taguchi experimental design, erosion wear

I. INTRODUCTION

Over the past few decades, it is found that polymers have replaced many of the conventional metals/materials in various applications. This is possible because of the advantages such as ease of processing, productivity, cost reduction etc. offered by polymers over conventional materials. In most of these applications, the properties of polymers are modified by using fibers to suit the high strength/high modulus requirements. All synthetic polymers (Thermoplastics, Thermoset and Elastomers) can be used as matrices in PMCs. As far as the reinforcement is concerned, extensive use has been made of inorganic man-made fibers such as glass and organic fibers such as carbon and aramid. As all these reinforcing fibers are expensive, various fibers like cellulose, wool, silk etc. abundantly available in natures are also used in composites. Cellulosic fibers like henequen, sisal, coconut fiber (coir), jute, palm, bamboo, Pineapple leaves fiber (PALF) and wood, in their natural conditions and several wastes cellulosic products such as shell flour, wood flour and pulp have also been used as reinforcing agents of different Thermosetting and thermoplastic resins. It is well known that natural fibers impart high specific stiffness, strength and biodegradability to polymer matrix composites. Also, cellulosic fibers are readily available from natural sources and most importantly, they have low cost per unit volume.

There are many natural resources available which has potential to be applied in industries as raw materials such as pineapple, kenaf, coir, abaca, sisal, cotton, jute, bamboo, banana, Palmyra, talipot, hemp, and flex [1,2]. Among them Pineapple leaf fiber (PALF) is one of the waste materials in agriculture sector, which is widely grown in India as well as Asia. After banana and Citrus, Pineapple (Ananas comosus) is one of the most essential tropical fruits in the world [3]. Commercially pineapple leaves are considered as waste materials of fruit which is being used for producing natural

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fibers. The chemical composition of PALF constitute holocellulose (70– 82%), lignin (5–12%), and ash (1.1%).

Major constituents in a natural fiber reinforced composite are the reinforcing fibers and a matrix, which acts as a binder for the fibers. In addition, particulate fillers can also be used with some polymeric matrices primarily to reduce cost and improve their dimensional stability. So, although a judicious selection of matrix and the reinforcing phase can lead to a composite with a combination of strength and modulus comparable to or even better than those of conventional metallic materials [4], the physical and mechanical characteristics can further be modified by adding a solid filler phase to the matrix body during the composite preparation. The fillers play a major role in determining the properties and behavior of particulate reinforced composites. The term 'filler' is very broad and encompasses a very wide range of materials. It is arbitrarily defined as a variety of natural or synthetic solid particulates (inorganic, organic) that may be irregular, circular, fibrous or flakey. The improved performance of polymers and their composites in industrial and structural applications by the addition of particulate fillers has shown a great promise and so has lately been a subject of considerable interest.

Another possibility that the incorporation of both particulates and fibers in polymer could provide a synergism in terms of improved properties and wear performance has not been adequately explored so far. However, some recent reports suggest that by incorporating filler particles into the matrix of fiber reinforced composites, synergistic effects may be achieved in the form of higher modulus and reduced material cost, yet accompanied with decreased strength and impact toughness. Such multi-component composites consisting of a matrix phase reinforced with a fiber and filled with particulates are termed as hybrid composites.

Nowadays much attention is devoted towards the study of solid particle erosion behavior of polymer composites due to the high potential use of these materials in many mechanical and structural applications. Hence, erosion resistance of polymer composites has become an important material property, particularly in selection of alternative materials and therefore the study of solid particle erosion characteristics of the polymeric composites has become highly relevant. Differences in the erosion behaviour of various types of composite materials are caused by the Amount, Type, Orientation and Properties of the reinforcement on one hand and by the type and properties of the matrix and its adhesion to the fibers/fillers on the other hand. A full understanding of the effects of all system variables on the wear rate is necessary in order to undertake appropriate steps in the design of machine or structural component and in the choice of materials to reduce/control wear [5].

II. METHODOLOGY OF THE PRESENT RESEARCH WORK

1. Fabrication of Vinylester based hybrid Composites.
2. Planning of Taguchi Experimental Design (Control parameter: - Erodent size, impact velocity, Erodent Temperature, Filler Content, Stand-off Distance, Impingement edge)
3. Erosion Test Experimentation utilizing Erosion test rig device.
4. Investigate the samples surfaces specifically by using Scanning Electron Microscope (SEM).
5. Comparison of rate of erosion of Pineapple Leaves fiber (PALF) - Vinylester composites with E-glass-Vinylester composites in various experiment conditions.

III. EXPERIMENTAL DETAILS

In this present research work Vinylester is chosen as the matrix material, i.e. grade of FB-701, Density 1.35 gm/cc, Elastic modulus 3.25 Gpa, (Supplied by Zenith Industrial supplies, Bangalore) and the Raw natural Pineapple leaf fiber (PALF) mat is unidirectional horizontal. The width is 17 inch and thickness is 2.8 mm, Density 1.56 gm/cc, Elastic Modulus 62.1 Gpa, (supplied by Go-green products, Chennai) are used as the reinforcing phase in the composites.

Though the present research work is focused mainly on the pineapple leaf fiber reinforced composites, their relative evaluation can only be made on comparing them with a similar set of composites with some conventional synthetic fiber. In the present work, E-glass fibers chopped strand mat density 2.54 gm/cc; modulus 72.4 Gpa, (supplied by Zenith Industrial supplies, Bangalore) has been used as the reinforcing material in the composites. The major constituents of E-glass are silicon oxide (54 wt. %), aluminum oxide (15 wt. %), calcium oxide (17 wt. %), boron oxide (8 wt. %) and magnesium oxide (4.5 wt. %).

A variety of natural or synthetic solid particulates, both organic and inorganic is already being commercially used as reinforcing fillers in polymeric composites. While ceramic powders such as alumina ($Al2O3$), silicon carbide (SiC), silica ($SiO2$), titanium ($TiO2$) etc. are widely used as conventional fillers, the use of industrial wastes for such purpose is hardly found. In view of this, in the present work an industrial waste such as Flyash are chosen as particulate fillers to be used in the composites. The other industrial waste used in this investigation is flyash used here is of Cenosphere type and has been collected from the Captive Power Plant of National Aluminium Co. (NALCO) located at Angul in India.

The chemical compositions and density of Flyash particulate filler materials for this study are mentioned in the Table 1.

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Table 1. Chemical compositions and density of Flyash filler

Filler	Composition/Chemical formula	Density (gm/cc)
Flyash	SiO_2 (48.3%), Al_2O_3 (20.2%), Fe_2O_3 (6.4%), TiO_2 (1.9%)	1.3

A. Composite Fabrication

The resin used in this research work is Vinylester FB-701 resin (density 1.35 gm/cc, Elastic modulus 3.25Gpa) and reinforcing phase a unidirectional Pineapple Leaves Fiber (PALF) and E-glass fibers are reinforced separately in Vinylester resin to prepare the fiber reinforced composites P_1 and G_1 in which no particulate filler Material is used. The other composite samples P_2 – P_3 and G_2 – G_3 Flyash particulate fillers of varied amount but with fixed fiber loading (30 wt %) are fabricated. The composition and designation of the composites prepare for this study are listed in Table 2.

The Cobalt Naphthenate 2% is mixed thoroughly in Vinylester resin and then 2% methyl ethyl ketone peroxide (MEKP), 2% N- dimethylaniline is mixed in the resins prior to reinforcement. The fiber loading weight fraction of unidirectional Pineapple Leaves Fiber (PALF) or E-glass fiber chopped strand mat in the composite is kept 30 wt% for all the samples. The stacking procedure consists of placing the fabric one above the other with the resin mix well spread between the fabrics on a mould release sheet.

Table 2. Designations and detailed compositions of the composites

Designation	Composition
P_1	Vinylester (70 wt %) + PALF (30 wt %)
P_2	Vinylester (60 wt %) + PALF (30 wt %) + Flyash (10 wt %)
P_3	Vinylester (50 wt %) + PALF (30 wt %) + Flyash (20 wt %)
G_1	Vinylester (70 wt %) + Glass Fiber (30wt %)
G_2	Vinylester (60 wt %) + Glass Fiber (30wt %) + Flyash (10 wt %)
G_3	Vinylester (50 wt %) + Glass Fiber (30wt %) + Flyash (20 wt %)

A porous Teflon film was again used to complete the stack. To ensure uniform thickness of the sample, a 4mm spacer was used. The mould plates were coated with release agent in order to aid the ease of separation on curing. A metal roller was used so that uniform thickness and compactness could obtain the whole assembly is placed in the light compression molding machine at a pressure of 40Kgf/cm2 and allowed to cure at room temperature for 24hrs. The laminate sheets of sizes 210 x 210 x 4mm were prepared. Specimens of suitable dimensions were cut using a diamond cutter for physical and mechanical characterization as per ASTM standard.

B. Erosion Wear test

The set up for the solid particle erosion wear test used in this study is capable of creating reproducible erosive situations for assessing erosion wear resistance of the prepared composite samples.

The pictorial view and the schematic diagram of the erosion test rig are given in Figure 1. The test rig consists of an air compressor, an air-drying unit, a conveyor belt-type particle feeder and an air particle mixing and accelerating chamber. In the present study, dry silica sand (assumed to be square pyramidal shaped) of different particle sizes (300µm, 450µm and 600µm) are used as the erodent. The dried and compressed air is mixed with the erodent which is fed constantly by a conveyor belt feeder into the mixing chamber and then is accelerated by passing the mixture through a convergent brass nozzle of 3 mm internal diameter. The erodent particles impact the specimen which can be held at different angles with respect to the direction of erodent flow using a swivel and an adjustable sample clip. The velocity of the eroding particles is determined using the standard double disc method. The apparatus is equipped with a heater which can regulate and maintain the erodent temperature at any pre-determined fixed value during an erosion trial.

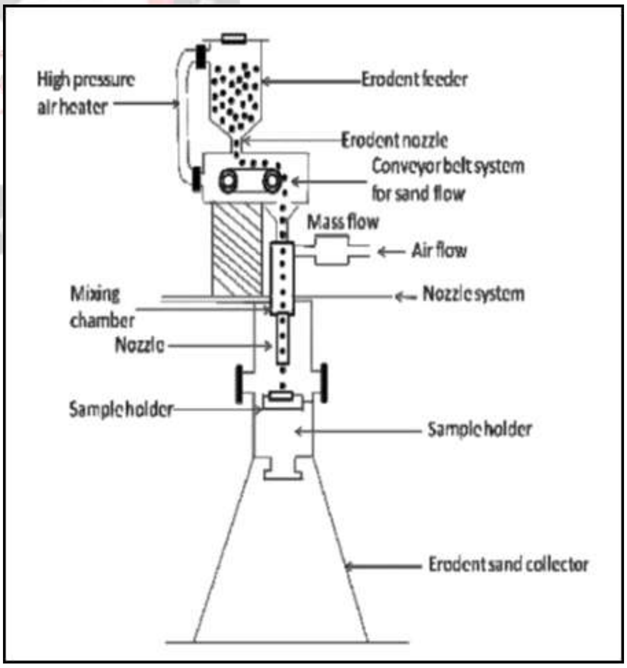

Figure 1. A Schematic diagram of the erosion test rig

The samples are cleaned in acetone, dried and weighed before and after the erosion trials using a precision electronic balance to an accuracy of ± 0.1 mg. The weight loss is recorded for subsequent calculation of erosion rate. The process is repeated till the erosion rate attains a constant value called steady state erosion rate. The erosion

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rate is defined as the ratio of this weight loss to the weight of the eroding particles causing the loss.

C. *Taguchi Method*

In any experimental research, since test procedures are generally expensive and time consuming, the need to satisfy the design objectives with the least number of tests is clearly an important requirement. In this context, Taguchi method provides the designer with a systematic and efficient approach for experimentation to determine near optimum settings of design parameters for performance and cost. This method involves laying out the experimental conditions using specially constructed tables known as 'orthogonal arrays. Use of orthogonal arrays significantly reduces the number of experimental configurations to be studied. The conclusions drawn from small scale experiments are valid over the entire experimental region spanned by the control factors and their settings. The most important stage in the design of experiment lies in the selection of the control factors.

Therefore, initially a large number of factors are included so that non-significant variables can be excluded at the earliest opportunity. Exhaustive literature review reveals that parameters i.e. impact velocity, impingement angle; fiber loading, filler content, erodent size, stand-off distance etc. largely influences the erosion rate of polymer composites [6, 7].

However, the author has not come across any report on the influence of a factor like erodent temperature on wear performance of polymer composites. Therefore, the present work, to explore the possible effect of erodent temperature, it is also considered as a control factor in addition to impact velocity, impingement angle, filler content, erodent size and stand-off distance. Thus, the impact of six parameters are studied using L_{27} (3^{13}) orthogonal design. The control factors and the parameter settings for erosion test are given in Table 3. and Table 4. Presents the selected levels for various control factors.

The standard linear graph as shown in Figure 2 is used to assign the factors and interactions to various columns of the orthogonal array [9,10.14]. The selected parameters viz., impact velocity, filler content, erodent temperature, stand-off distance, impingement angle and erodent size, each at three levels, are considered in this study. These six parameters each at three levels would require 3^6 = 729 runs in a full factorial experiment whereas Taguchi's experimental approach reduces it to 27 runs only offering a great advantage.

Table 3. Parameter settings for erosion test

Control Factors	Symbols	Fixed parameters	
Impact velocity	Factor A	Erodent	Silica sand
Filler content	Factor B	Erodent feed rate (g/min)	10.0 +1.0
Erodent Temperature	Factor C	Nozzle diameter (mm)	3
Impingement angle	Factor D	Length of nozzle (mm)	80
Standoff distance	Factor E		
Erodent size	Factor F		

The plan of the experiments as shown in Table 5. is as follows: the first, second, fifth, ninth, tenth and twelfth columns are assigned to impact velocity (A), filler content (B), erodent temperature (C), impingement angle (D), stand-off distance (E) and erodent size (F) respectively. The third and fourth column are assigned to $(A\times B)_1$ and $(A\times B)_2$ respectively to estimate interaction between impact velocity (A) and filler content (B), the sixth and seventh column are assigned to $(B\times C)_1$ and $(B\times C)_2$ respectively to estimate interaction between filler content (B) and erodent temperature (C), the eighth and eleventh column are assigned to $(A\times C)_1$ and $(A\times C)_2$ respectively to estimate interaction between the impact velocity (A) and erodent temperature (C) and the remaining columns are used to estimate experimental errors.

The experimental observations are transformed into signal-to-noise (S/N) ratios. There are several S/N ratios available depending on the type of characteristics such as:

$'\text{Smaller} - \text{the} - \text{better}'\ \text{characterstic}:$

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

Table 4. Levels for various control factors

Control factor	LEVEL I	LEVEL II	LEVEL III	Unit
A: Impact velocity	45	55	65	m/sec
B: Filler content	0	10	20	%
C: Erodent Temperature	40	50	60	°C
D: Impingement angle	30	60	90	degree
E: Stand-off distance	65	75	85	mm
F: Erodent size	300	450	600	µm

Where **n** is the number of observations, **y** is the observed data, **Y** the mean and **S** the variance. The S/N ratio for minimum erosion rate comes under 'smaller-the-better' characteristic, which can be calculated as logarithmic transformation of the loss function by using Eq. (1).

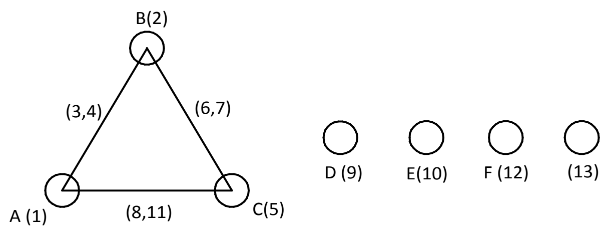

Figure 2. Linear graphs for L_{27} orthogonal array

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Table 5. Orthogonal array for L_{27} (3^{13}) Taguchi Design

L_{27} (3^{13})	1 A	2 B	3 $(AxB)_1$	4 $(AxB)_2$	5 C	6 $(BxC)_1$	7 $(BxC)_2$	8 $(AxC)_1$	9 D	10 E	11 $(AxC)_2$	12 F	13
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2	2	2	2	2	2
3	1	1	1	1	3	3	3	3	3	3	3	3	3
4	1	2	2	2	1	1	1	2	2	2	3	3	3
5	1	2	2	2	2	2	2	3	3	3	1	1	1
6	1	2	2	2	3	3	3	1	1	1	2	2	2
7	1	3	3	3	1	1	1	3	3	3	2	2	2
8	1	3	3	3	2	2	2	1	1	1	3	3	3
9	1	3	3	3	3	3	3	2	2	2	1	1	1
10	2	1	2	3	1	2	3	1	2	3	1	2	3
11	2	1	2	3	2	3	1	2	3	1	2	3	1
12	2	1	2	3	3	1	2	3	1	2	3	1	2
13	2	2	3	1	1	2	3	2	3	1	3	1	2
14	2	2	3	1	2	3	1	3	1	2	1	2	3
15	2	2	3	1	3	1	2	1	2	3	2	3	1
16	2	3	1	2	1	2	3	3	1	2	2	3	1
17	2	3	1	2	2	3	1	1	2	3	3	1	2
18	2	3	1	2	3	1	2	2	3	1	1	3	2
19	3	1	3	2	1	3	2	1	3	2	1	3	2
20	3	1	3	2	2	1	3	2	1	3	2	1	3
21	3	1	3	2	3	2	1	3	2	1	3	2	1
22	3	2	1	3	1	3	2	2	1	3	3	2	1
23	3	2	1	3	2	1	3	3	2	1	1	3	2
24	3	2	1	3	3	2	1	1	3	2	2	1	3
25	3	3	2	1	1	3	2	3	2	1	2	1	3
26	3	3	2	1	2	1	3	1	3	2	3	2	1
27	3	3	2	1	3	2	1	2	1	3	1	3	2

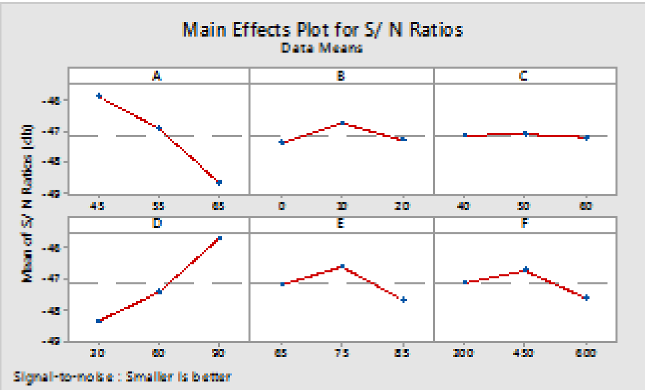
IV. RESULT AND DISCUSSION

A. *Erosion Wear Characteristics*

This part presents the analysis and comparison of erosion response of PALF-Vinylester and Glass-Vinylester composites filled with Flyash. The experiments have been carried out using Taguchi experimental design (L_{27} Orthogonal array) given in Table 5. and the subsequent analysis of the test results is made using the popular software specifically used for design of experiment applications known as MINITAB 18. Finally, the micro-structural features of the composite samples eroded under different operating conditions are described based on SEM micrographs.

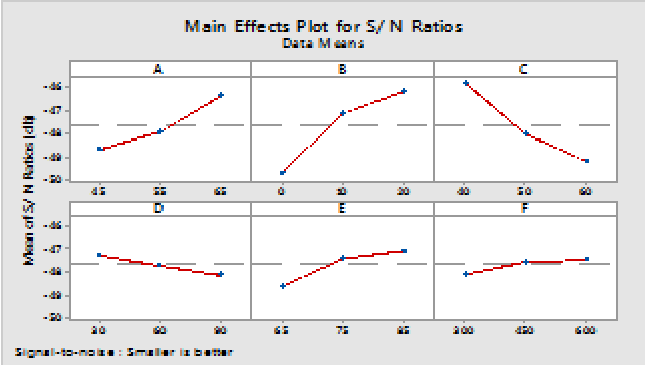
B. *Taguchi Experimental Analysis*

The results of erosion experiments carried out according to Taguchi experimental design on Flyash filled PALF-Vinylester and Glass-Vinylester composites, the overall mean of the S/N ratios is found to be - 47.1580 db for PALF based composites and - 47.6985 db for the Glass based ones. For similar test conditions, PALF-Vinylester composites exhibit much lower wear rates than those by Glass-Vinylester composites.



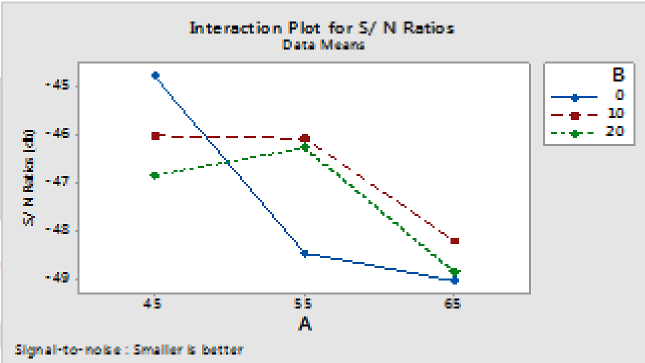
*A= Impact Velocity, B=Filler content, C= Erodent Temperature, D=Impingement angle, E= Stand –off-distance, F=Erodent Size

Figure 3. Effect of control factors on erosion rate (For Flyash filled PALF-Vinylester composites)



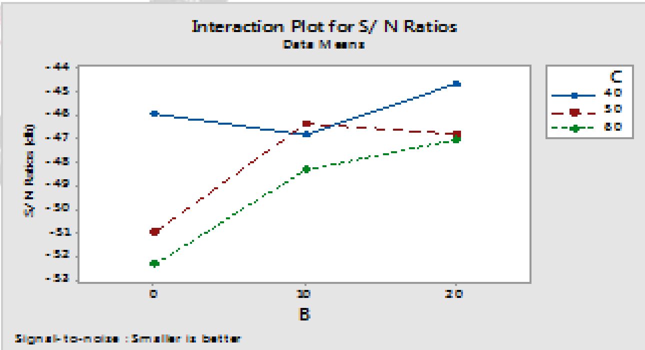
*A= Impact Velocity, B=Filler content, C= Erodent Temperature, D=Impingement angle, E= Stand –off-distance, F=Erodent Size

Figure 4. Effect of control factors on erosion rate (For Flyash filled Glass-Vinylester composites)



*A= Impact Velocity, B=Filler content

Figure 5. Interaction graph between impact velocity and filler content (A X B) for erosion rate (For Flyash filled PALF-Vinylester composites)



*B= Filler content, C=Erodent Temperature

Figure 6. Interaction graph between filler content and erodent temperature (B X C) for erosion rate (For Flyash filled Glass- Vinylester composites)

Figures 3. and Figure 4. Illustrate the effect of control factors on erosion rate of PALF-Vinylester and Glass-Vinylester composites respectively. Analysis of the results leads to the conclusion that factor combination of A1(Impact velocity: 45 m/sec), B2 (Filler content: 10wt%), C1(Erodent temperature: 400C), D3 (Impingement angle: 900), E2 (Stand-off distance: 75mm) and F2 (Erodent size: 450μm) gives minimum erosion rate (Figure 3) for PALF-Vinylester composites and the factor combination of A2 (Impact velocity: 55 m/sec), B2 (Filler content: 10wt%), C1(Erodent temperature: 400C), D1 (Impingement angle:

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300), E2 (Stand-off distance: 75mm) and F3 (Erodent size: 600µm) gives minimum erosion rate (Figure 4) for Glass-Vinylester composites. The respective interaction graphs are shown in the Figures 5. and Figure 6. For PALF-Vinylester and Glass-Vinylester composites respectively.

C. ANOVA and the Effects of Factors

In order to find out statistical significance of various factors like impact velocity (A), Flyash content (B), erodent temperature (C), impingement angle (D), stand-off distance (E) and erodent size (F) on erosion rate, analysis of variance (ANOVA) is performed on experimental data. Table 6. and Table 7. show the results of the ANOVA for the erosion rate of PALF-Vinylester composites and Glass-Vinylester composites respectively. The last column of the table indicates percentage contribution of the control factors and their interactions on the performance output i.e. erosion rate [9]. From Table 6. it can be observed for the Flyash filled PALF-Vinylester composites that impact velocity (p=0.358), impingement angle (p= 0.379), stand-off distance (p = 0.799), erodent size (p = 0.849) and Flyash content (p = 0.900) have considerable influence on erosion rate. The interaction of impact velocity and Flyash content (p = 0.613) as well as Flyash content and erodent temperature (p = 0.806) show significant contribution on the erosion rate but the remaining factors and interactions have relatively less significant effect.

Table 6. ANOVA table for erosion rate (For Flyash filled PALF-Vinylester composites)

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value
A	2	36.382	36.382	18.1911	1.79	0.358
B	2	2.249	2.249	1.1247	0.11	0.900
C	2	0.073	0.073	0.0364	0.00	0.996
D	2	33.258	33.258	16.6288	1.64	0.379
E	2	5.093	5.093	2.5463	0.25	0.799
F	2	3.607	3.607	1.8035	0.18	0.849
A X B	4	15.985	15.985	3.9962	0.39	0.806
A X C	4	11.689	11.689	2.9222	0.29	0.867
B X C	4	33.374	33.374	8.3436	0.82	0.613
Error	2	20.305	20.305	10.1526		
Total	26	162.015				

Similarly, from Table 7. one can observe that Flyash content (p=0.008), erodent temperature (p = 0.009), impact velocity (p=0.019), stand-off distance (p = 0.040) and impingement angle (p= 0.122) have great influence on erosion rate. The interaction of Flyash content and erodent temperature (p = 0.032) as well as impact velocity and Flyash content (p = 0.043) show significant contribution on the erosion rate but the remaining factor and interactions have relatively less significant contribution.

Table 7. ANOVA table for erosion rate (For Flyash filled Glass-Vinylester composites)

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value
A	2	25.977	25.977	12.9883	52.00	0.019
B	2	61.659	61.659	30.8295	123.42	0.008
C	2	54.597	54.597	27.2987	109.28	0.009
D	2	3.583	3.583	1.7913	7.17	0.122
E	2	12.045	12.045	6.0225	24.11	0.040
F	2	2.015	2.015	1.0077	4.03	0.199
A X B	4	23.493	23.493	5.8732	23.51	0.041
A X C	4	22.523	22.523	5.6308	22.54	0.043
B X C	4	30.145	30.145	7.5362	30.17	0.032
Error	2	0.500	0.500	0.2498		
Total	26	236.536				

D. Confirmation Experiment

The Justification experiments are the final test during the design of experiment process. The motivations behind the Justification experiments are to be approving the conclusions drawn at the time of the analysis stage. But, last proceed in any design of experiment approach is to anticipate and check upgrades in experimental values using the optimal combination level of control factors. The Justification experiment is carried out for PALF-Vinylester composites by taking a random arrangement of combination of factor $A_2B_3C_3D_2E_1F_3$. In spite of the fact that factor C has minimal.

Table 8. Results of the confirmation experiments for erosion rate

	Parameter of Optimal controls (PALF-Vinylester composite)		Parameter of Optimal controls (Glass-Vinylester composite)	
	Predictive	trial	Predictive	trial
Levels	$A_2 B_3C_3 D_2 E_1F_3$	$A_2B_3C_3 D_2 E_1F_3$	$A_2 B_2C_2D_2E_3$	$A_2 B_2C_2D_2E_3$
S/N ratio for Rate of Erosion (db)	-45.2397	-43.0007	-45.2106	-42.2192

impact on execution values, they were not ignored from this arrangement because their cooperation by means of factor B have noteworthy impact since apparent from Table 6. Additionally, in favor of Glass-Vinylester composites, a discretionary arrangement with combination of factor $A_2B_2C_2D_2E_3$ be considered. Factors F are discarded because they have minimum impact on execution attributes. The evaluated S/N proportion for rates of erosion can be ascertained with the assistance of subsequent predictive equations:

$$\bar{\eta}_{PALF-Flyash} = \bar{T} + (\bar{A}_2 - \bar{T}) + (\bar{B}_3 - \bar{T}) + [(\bar{A}_2\bar{B}_3 - \bar{T}) - (\bar{A}_2 - \bar{T}) - (\bar{B}_3 - \bar{T})] + (\bar{C}_3 - \bar{T}) + [(\bar{B}_3\bar{C}_3 - \bar{T}) - (\bar{B}_3 - \bar{T}) - (\bar{C}_3 - \bar{T})] + (\bar{D}_2 - \bar{T}) + (\bar{E}_1 - \bar{T}) + (\bar{F}_3 - \bar{T}) \quad (3.1)$$

$$\bar{\eta}_{GF-Flyash} = \bar{T} + (\bar{A}_2 - \bar{T}) + (\bar{B}_2 - \bar{T}) + [(\bar{A}_2\bar{B}_2 - \bar{T}) - (\bar{A}_2 - \bar{T}) - (\bar{B}_2 - \bar{T})] + (\bar{C}_2 - \bar{T}) + [(\bar{B}_2\bar{C}_2 - \bar{T}) - (\bar{B}_2 - \bar{T}) - (\bar{C}_2 - \bar{T})] + (\bar{D}_2 - \bar{T}) + (\bar{E}_3 - \bar{T}) \quad (3.2)$$

$\bar{\eta}_{PALF-Flyash}$ and $\bar{\eta}_{GF-Flyash}$: Predictive averages for Flyash filled PALF fibers based as well as Glass fiber-based composite correspondingly.

$\bar{T}$ = Overall average of experimented.

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$\overline{A}_2, \overline{B}_2, \overline{B}_3, \overline{C}_2, \overline{C}_3, \overline{D}_3, \overline{E}_1, \overline{E}_3$ and $\overline{F}_3$: Average reaction factors as well as relations on designated levels.

With adding terms, the equation (3.1) as well as equation (3.2) converted into,

$$\overline{\eta}_{PALF-Flyash} = \overline{A}_2\overline{B}_3 + \overline{B}_3\overline{C}_3 - \overline{B}_3 + \overline{D}_2 + \overline{E}_1 + \overline{F}_3 - 3\overline{T} \quad (3.3)$$

$$\overline{\eta}_{GF-Flyash} = \overline{A}_2\overline{B}_2 + \overline{B}_2\overline{C}_2 - \overline{B}_2 + \overline{D}_2 + \overline{E}_3 - 2\overline{T} \quad (3.4)$$

Another combination of factor levels A_2, B_3, B_2, C_2, C_3, D_3, E_1, E_3 and F_3 is utilized to estimate rate of erosion through prediction equation and it is observed to be $\overline{\eta}_{PALF-Flyash}$ = - 45.2397db and $\overline{\eta}_{GF-Flyash}$ = - 45.2106 db correspondingly.

For every performance measure, a test is led for a similar arrangement of combination of factors and they got S/N proportion esteem is contrasted and that acquired from the prediction equations as appeared from Table 8. The subsequent models are by all accounts fit for foreseeing rate of erosion to a sensible precision. An error of 4.94 % as well as 6.61 % for the S/N proportion of rates of erosion is watched for PALF Vinylester composite and Glass-Vinylester composites correspondingly. By event that the watched S/N proportions in the prescribed settings are near their separate forecast, at that point we reason that the picked configuration is practically sufficient. Something else, another plan cycle will be started while this will demonstrate that a portion of the suspicions made amid the examination may not be substantial, for instance, the impacts of disregarding connection between various outline factors. In any case, the error might additionally decrease but the quantities of estimations are expanded. It approves the numerical models for anticipating the measures of execution in light with information of information parameter.

E. Effect of Impingement Angle and Erodent Temperature on Erosion

Generally, the erosion behavior of materials is broadly classified as either ductile or brittle depending on the variation of erosion rate with impingement angle. Ductile behavior is characterized by maximum erosion occurring at low impingement angles in the range of 10^0- 30^0. On the other hand, if maximum erosion occurs at 90^0, then the behavior is said to be brittle. However, most of the reinforced polymer composites have been found to exhibit semi-ductile behavior with maximum erosion rate at intermediate angles typically in the range of 45-60^0 [11].

In the present study, the variation of erosion rate of the Flyash filled PALF-Vinylester and Glass-Vinylester composites with impingement angle is obtained by conducting experiments under specified operating conditions (Figure 7). The results show that the peak erosion takes place at an impingement angle of 60^0 for the unfilled composites whereas for the Flyash filled composites it occurs at 45^0 impingement angle for both glass and PALF fiber reinforcement. This clearly indicates that these composites respond to solid particle impact neither in a purely ductile nor in a purely brittle manner, rather the erosion behaviour is semi ductile. This behaviour may be attributed to the incorporation of fibers and Flyash particles within the PALF body. Similarly, the variation of erosion rate of unfilled and Flyash filled composites with erodent temperature is shown in Figure 8. This figure also presents a comparison between the erosion rate of PALF-Vinylester composites and Glass-Vinylester composites for different erodent temperatures.

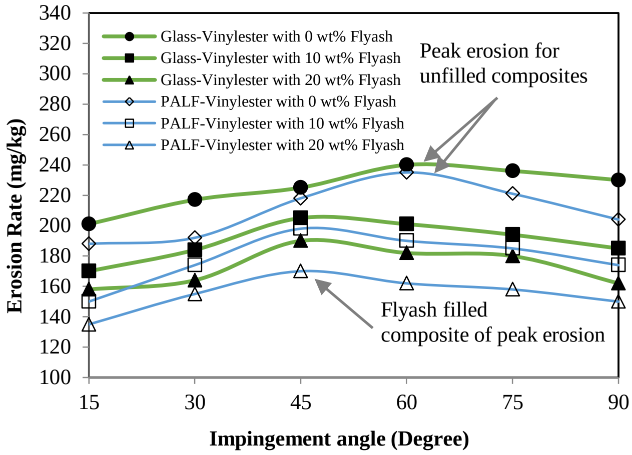

Figure 7. Effect of impingement angle on the erosion wear rate of Flyash filled composites

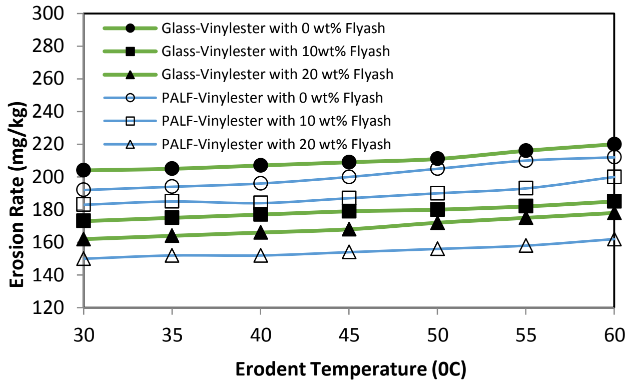

Figure 8. Effect of erodent temperature on the erosion wear rate of Flyash filled composites

It is seen, in this figure, that for all the composite samples, the erosion rates remain almost unaffected by the change in erodent temperature from ambient to 40^0C. The effect of erodent temperature on erosion is significant above 40^0C and the rate of increase in erosion rate is greater at higher temperatures. The increase in erosion rate with erodent temperature can be attributed to increased penetration of particles on impact as a result of dissipation of greater amount of particle thermal energy to the target surface. This

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leads to more surface damage, enhanced sub-critical crack growth etc.

F. Discussion on Surface Morphology

To find out the wear component in composite, scanning electron microscopy (SEM) are done as well as the microstructure of the un-eroded surface of a Flyash filled PALF-Vinylester composites be shows from Figs. 9 a and 9 b. Flyash particle are supposed to be sprinkled on the upper surface and their dissemination be sensibly even in spite of fact that at places the particles are supposed to have framed little and huge bunches. On account of the wear out composites surface eroded with less impact velocity as shown in Figs. 9 c and 9 d, be that as it may, break and regularly plastic deformations are noticeable. Fibers break and disappointment within the lattice are not unmistakably observed with an impingement angles of 30^0 albeit just matrixes splits and deformations are apparent.

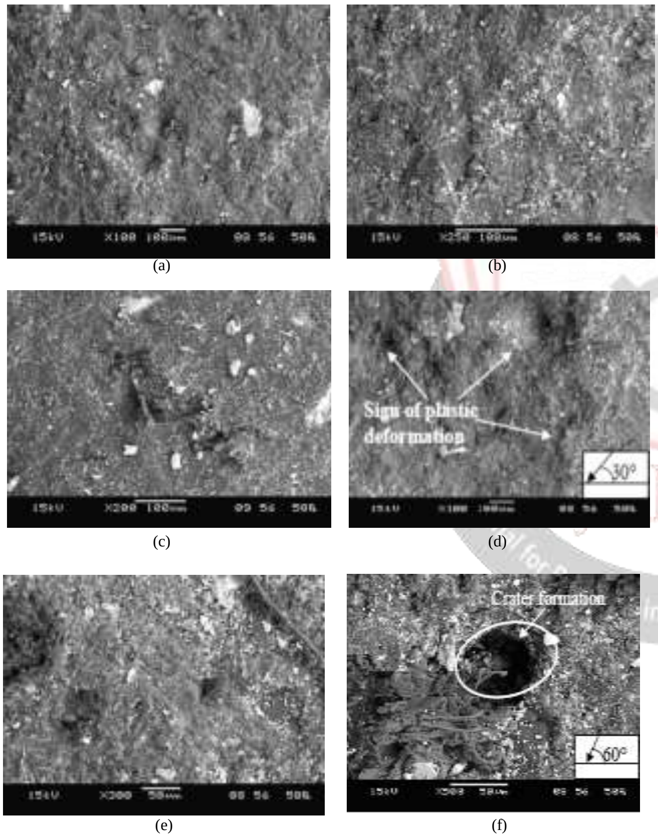

Figure 9. SEM images of the eroded Flyash filled PALF-Vinylester Composites

Fig. 9 e for the composites eroded at 900 show primarily lattice break. At this impingement angles, there is no parallels segment of impact velocity of the molecule also subsequently, no wears are normal. Fig. 9 f presented the SEM picture of the eroded surfaces of a similar composite anywhere fiber be supposed to has broken into little fragment and it has expelled from it is places somewhat in the encompassing lattice i.e. spalled parts. The wear out surfaces displays cavity arrangement as well as indication of plastic deformations in the matrixes administration. Rehashed impacts step by step shape bigger pits and fiber-Matrix de-bonding. Fig. 10 a demonstrates the small-scale basic highlights of Flyash filled (10 wt %) Glass-Vinylester composites eroded at an impingement angles of 90^0 and a speed of 45 m/sec at room temperatures. For it situation the erodent particle and the composites sample are at similar encompassing condition. At this point, while the composites are subjected to erosion preliminary by a surge of sands particle it is having a raised temperature of 50^0C, the small-scale structures of the eroded surfaces show up very unique. These distinctions are outlined in Figs. 10 a and 10 b. The deformations of the surfaces eroded by the erodent's' particle at room temperatures seem, by all accounts, to be for the most part because of plastic disfigurement and infrequent smaller scale splitting. It has apparent in Figs. 10 a and 10 b that the matrixes is worn down and the materials left with its area is by all accounts in the smooth stage under plastically misshapen conditions. Several morphological contrasts may likewise is found in corona zones of the erosions cavity shaped, like appeared in Fig. 10 b. The harmed surfaces provide a look of restricted adjusted highlights as well as there are a few proofs of ploughing.

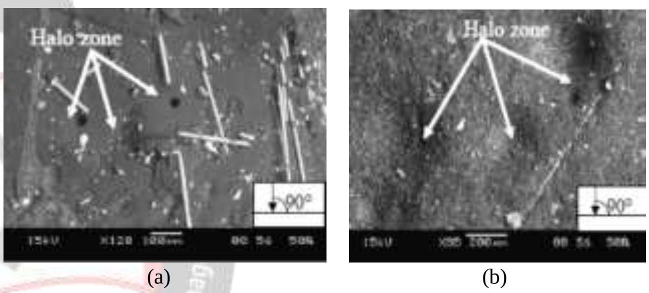

Figure 10. Scanning electron micrograph of the Glass-Vinylester composite (with10 wt% flyash) at 45 m/sec impact velocity and erodent size 450 µm (a) Erodent at room temperature and (b) erodent temperature 50^0C

V. CONCLUSION

1. This study reveals the semi-ductile response for most of these particulates filled PALF/Glass Vinylester composites with respect to erosion wear. The peak erosion rate is found to be occurring at 60^0 impingement angles for the unfilled composites as well as for Flyash filled composites with both PALF as well as glass reinforcement.

2. The presence of particulate fillers in PALF- Vinylester composites improves their erosion wear resistance and this improvement depends on the type and content of the fillers. It is interesting to note that Flyash in spite of being industrial waste, show lower erosion rates. Further, the filler materials considered in this study, Flyash emerges as the best filler material to be used in Vinylester based composites, irrespective of fiber type, as far as the resistance to solid particle erosion is concerned.

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