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Erosion Wear Behaviour of Bamboo Fiber Reinforced Composites Filled with Red mud Particulate

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Abstract

The interest in natural fiber-reinforced polymer composite materials is rapidly growing both in terms of their industrial applications and fundamental research. Their availability, renewability, low density, and price as well as satisfactory mechanical properties make them an attractive ecological alternative to glass, carbon and man-made fibers used for the manufacturing of composites[1]. The natural fiber-containing composites are more environmentally friendly, and are used in many applications such as transportation (automobiles, railway coaches, aerospace), military applications, building and construction industries (ceiling paneling, partition boards), packaging, consumer products, etc. Due to the operational requirement in dusty environments, the erosion characteristic of polymeric composites may be of high relevance.

To this end the present investigation deals with the property characterization and utilization of abundantly available and renewable resources of plant fiber such as bamboo. These plant fiber along with industrial waste (red mud) have been used for synthesizing value added composite materials. Relevant engineering properties such as physical and mechanical, resistance to erosion wear etc., of the plant fiber reinforced polymer matrix composites so synthesized were characterized.

A plan of experiments, based on the techniques of Taguchi, was performed to acquire data in controlled way. An orthogonal array and the analysis of variance were employed to investigate the erosion wear behavior. The significant control factors and their interactions predominantly influencing the wear rate are identified. The erosion rates of these composites have been evaluated under different operating conditions. The morphology of eroded surfaces is examined by using scanning electron microscopy (SEM) and possible erosion mechanisms are discussed.

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INTRODUCTION

Composites

Composites are materials consisting of two or more chemically distinct constituents, on a macro-scale, having a distinct interface separating them. One or more discontinuous phases therefore, are embedded in a continuous phase to form a composite.

Polymer matrix composite

The discontinuous phase is usually harder and stronger than the continuous phase and is called the *reinforcement*, whereas, the continuous phase is termed the *matrix.* The matrix material can be metallic, polymeric or can even be ceramic. When the matrix is a polymer, the composite is called polymer matrix composite (PMC).

Fibre reinforced polymers

The fibre reinforced polymers (FRP) consist of fibres of high strength and modulus embedded in or bonded to a matrix with distinct interface between them. In this form, both fibres and matrix retain their physical and chemical identities.

Experimental details

a. Specimen preparation

- Bi-direction bamboo fiber are reinforced in red mud filled Epoxy LY 556, chemically belonging to the 'epoxide' family is used as the matrix material.
- The low temperature curing epoxy resin (LY 556) and corresponding hardener (HY951) are mixed in a ratio of 10:1 by weight as recommended.
- The epoxy resin and the hardener are supplied by Ciba Geigy India Ltd. Red mud collected from NALCO aluminium refinery at Damanjodi, India is sieved to obtain particle size in the range 70-90 μm.
- Composites of three different compositions (0wt%, 10wt% and 20wt% red mud filling) are made and the fiber loading (weight fraction of glass fiber in the composite) is kept at 50% for all the samples.
- The castings are put under load for about 24 hours for proper curing at room temperature.
- Specimens of suitable dimension are cut using a diamond cutter for physical characterization and erosion test.

Result and Discussion

Mechanical properties

Micro-hardness:

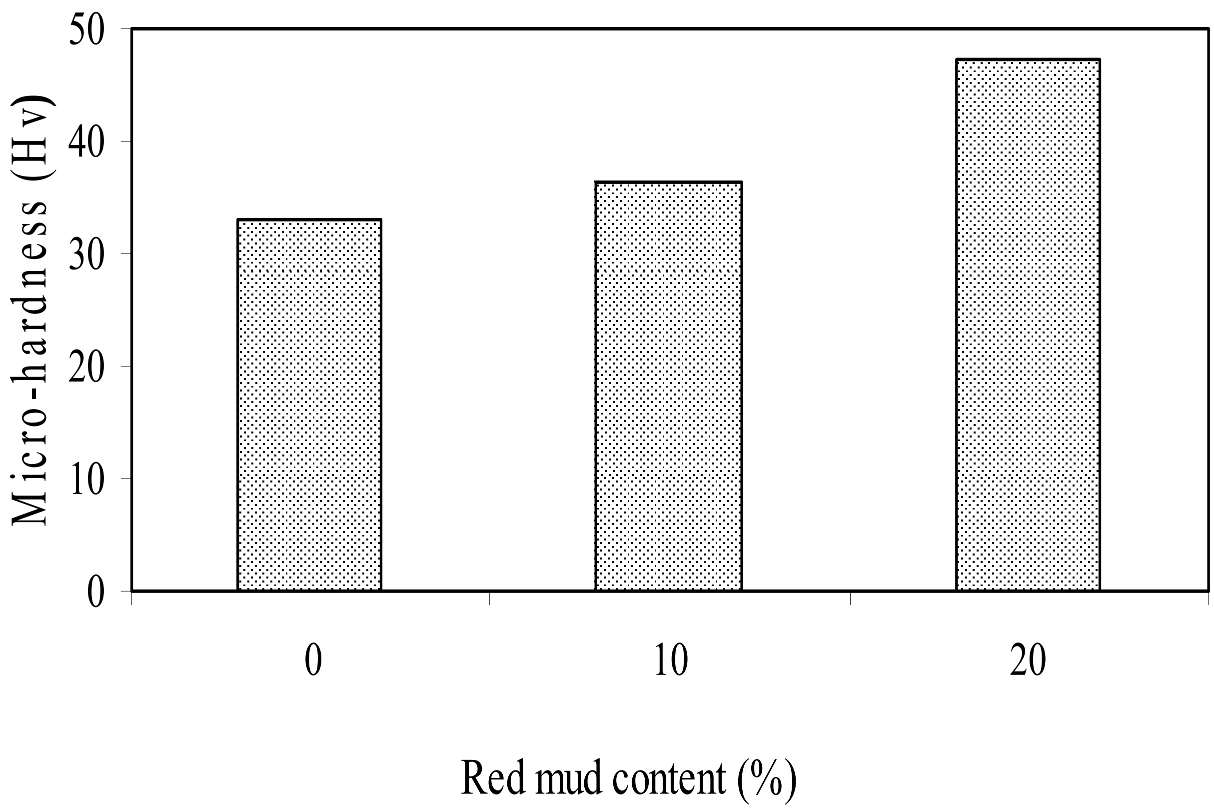

Figure 1 (a) Variation of micro-hardness of the composites with red mud content

Tensile and Flexural Strength

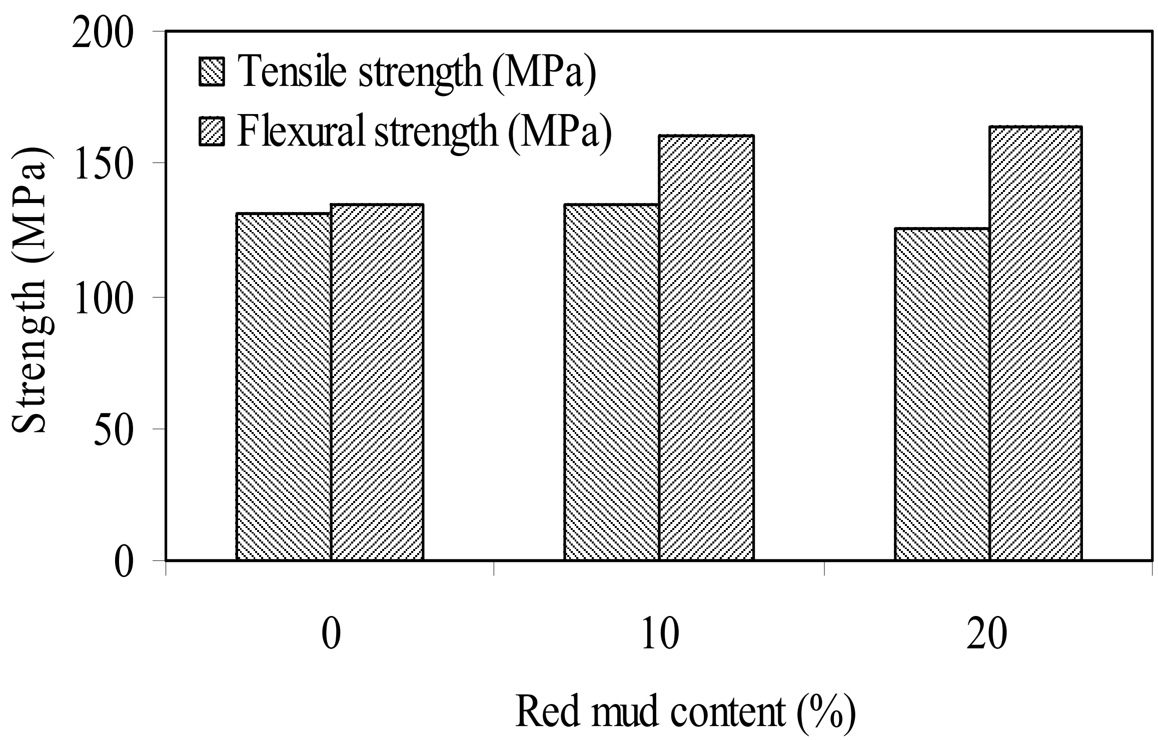

Figure 1 (b) Variation of tensile and flexural strength with red mud content

Tensile modulus

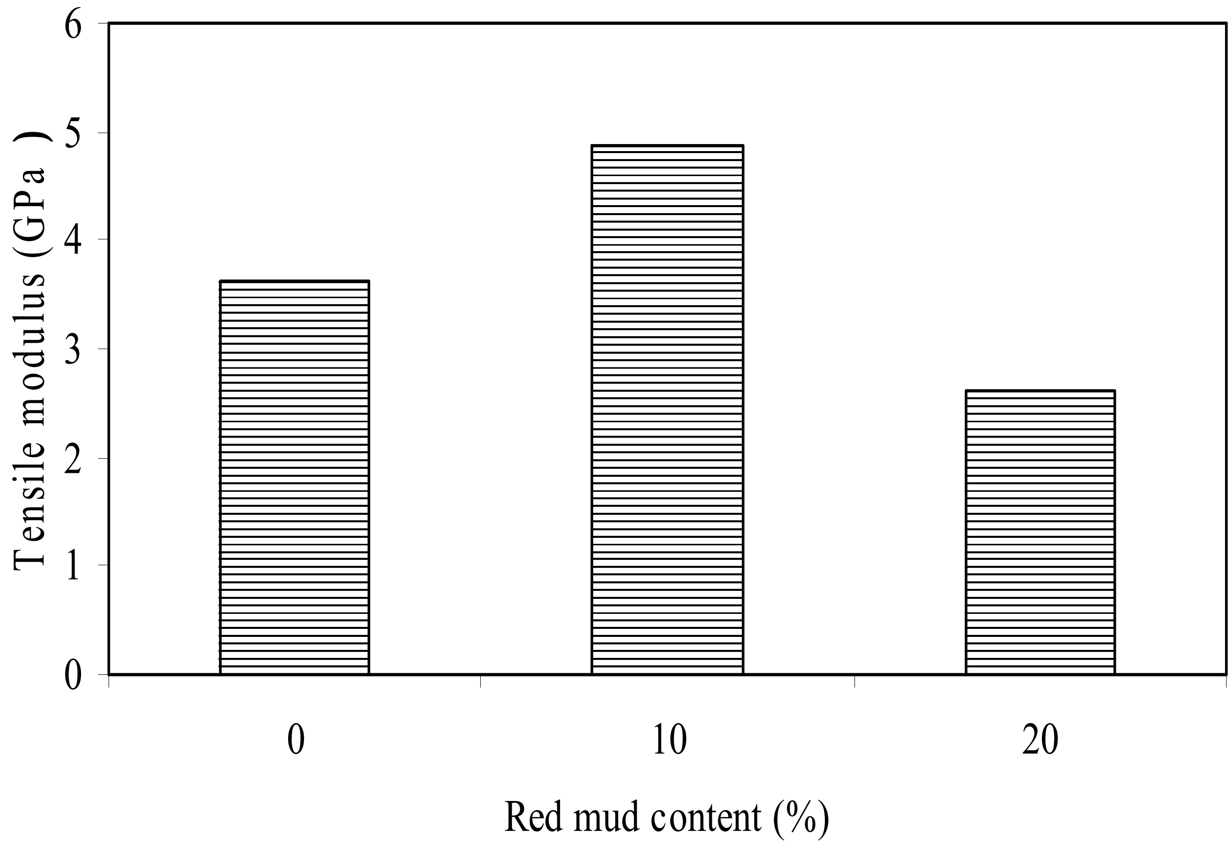

Figure 1 (c) Variation of tensile modulus of the composites with red mud content

Inter-laminar shear strength

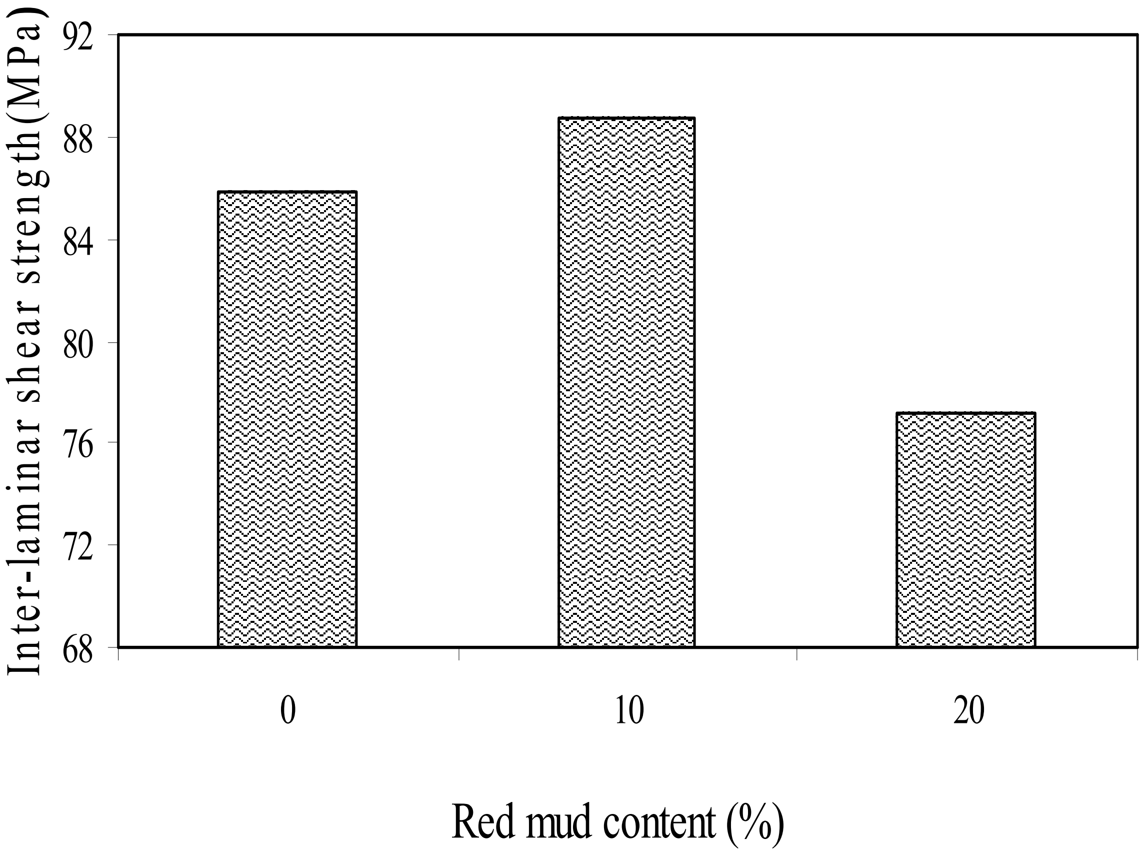

Figure 1 (d) Variation of inter-laminar shear strength with red mud content

Impact Strength

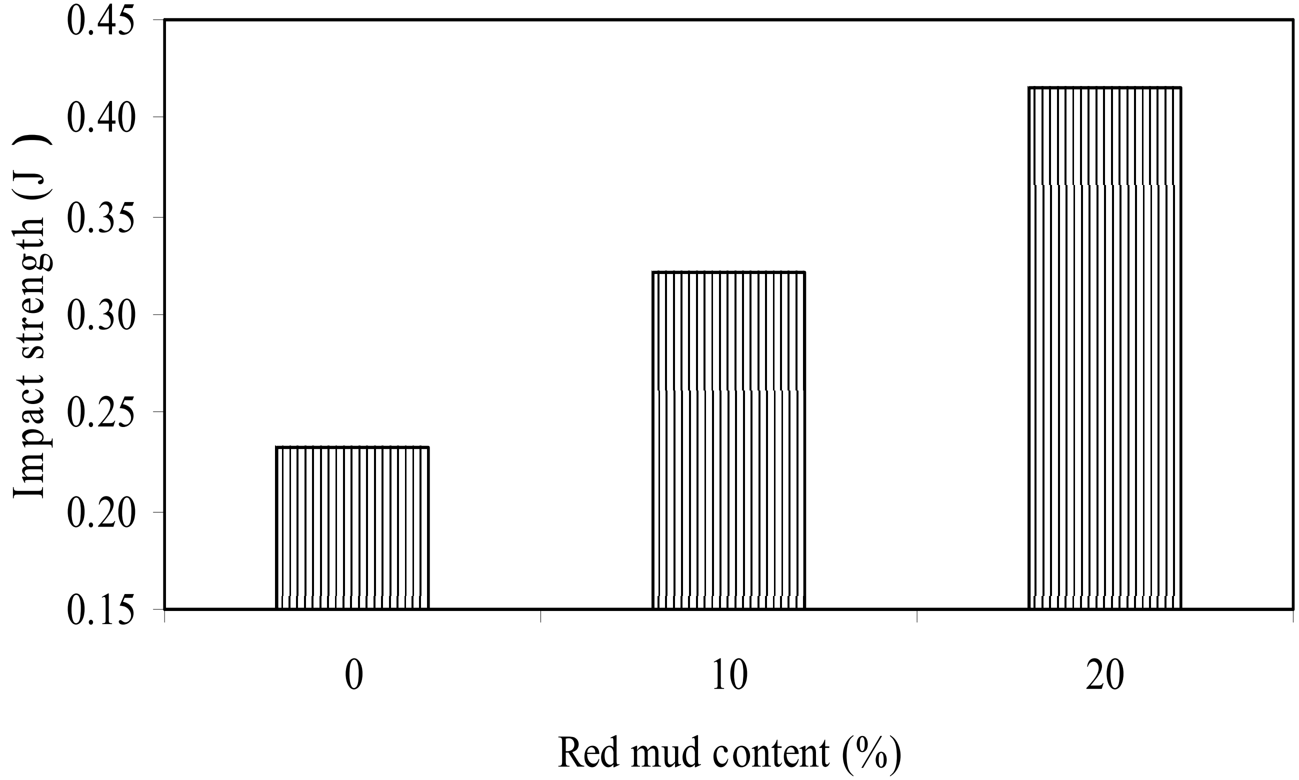

Figure 1 (e) Variation of impact strength of the composites with red mud content

Research Methodology

Design of experiment is a powerful analysis tool for modeling and analyzing the influence of control factors on performance output.

The most important stage in the design of experiment lies in the selection of the control factors.

Six parameters viz., impact velocity, filler content, erodent temperature, impingement angle, stand-off distance, and erodent size, each at three levels, are considered in this study in accordance with L_{27} (3^{13}) orthogonal design.

Six parameters each at three levels would require 3^6 = 726 runs in a full factorial experiment. Whereas, Taguchi's factorial experiment approach reduces it to 27 runs only offering a great advantage.

The experimental observations are transformed into a signal-to-noise (S/N) ratio. There are several S/N ratios available depending on the type of characteristics. The S/N ratio characteristics can be divided into three categories given by Eqs. (1) - (3) when the characteristic is continuous.

Smaller is the better characteristic: $\frac{S}{N} = -10 \log \frac{1}{n}(\sum y^2)$ (1)

Nominal the better characteristics: $\frac{S}{N} = -10 \log \frac{1}{n}\left(\sum \frac{\bar{Y}}{S_Y^2}\right)$ (2)

Larger the better characteristics : $\frac{S}{N} = -10 \log \frac{1}{n}\left(\sum \frac{1}{y^2}\right)$ (3)

Erosion Test

Erosion test apparatus

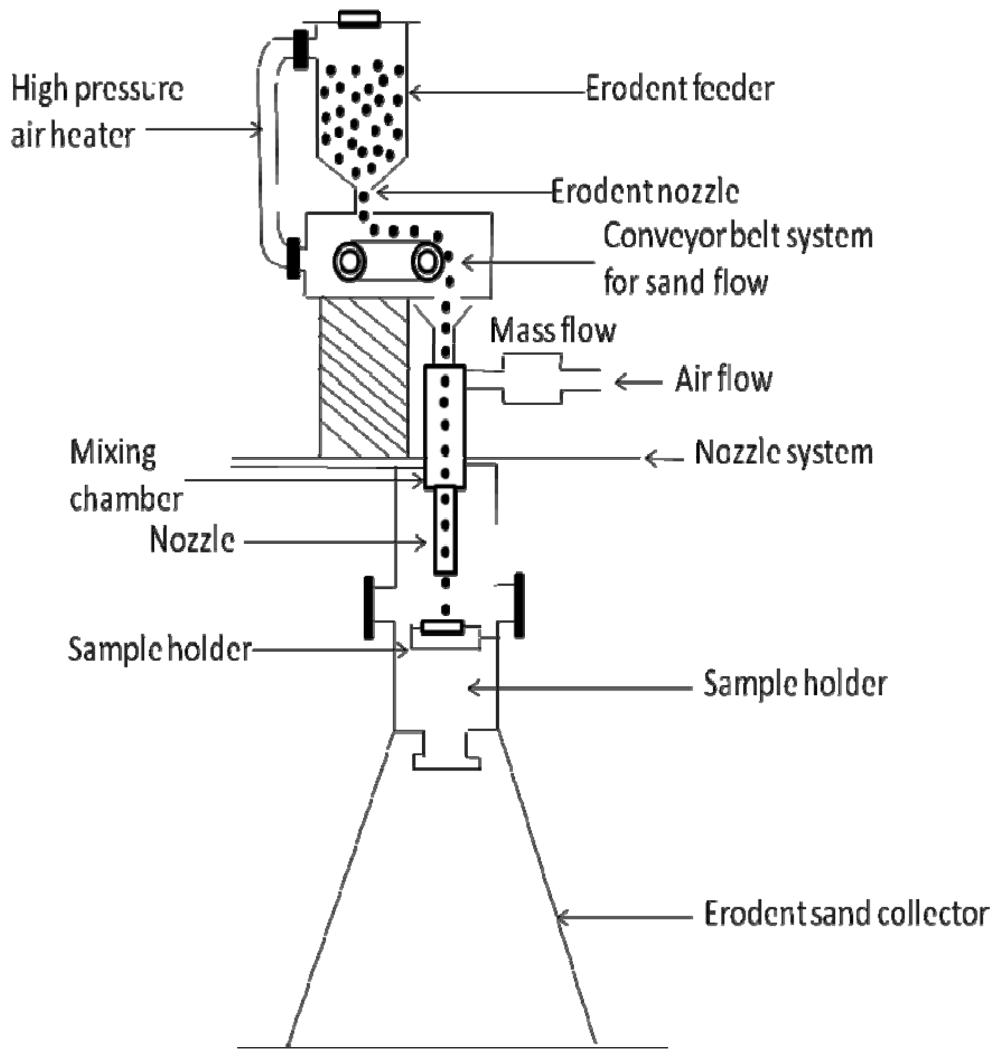

Figure 2 Schematic diagram of an erosion test rig

Table 1. Parameters of the setting

Control Factors	Symbols	Fixed parameters	
Velocity of impact	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
Stand-off distance	Factor E		
Erodent size	Factor F		

Table 2. Levels for various control factors

Control factor	Level I	II	III	Units
A:Velocity of impact	43	54	65	m/sec
B:Filler content	0	10	20	%
C:Erodent Temperature	40	50	60	^{0}C
D:Impingement angle	30	60	90	degree
E:Stand-off distance	65	75	85	mm
F:Erodent size	300	450	600	µm

Experimental design

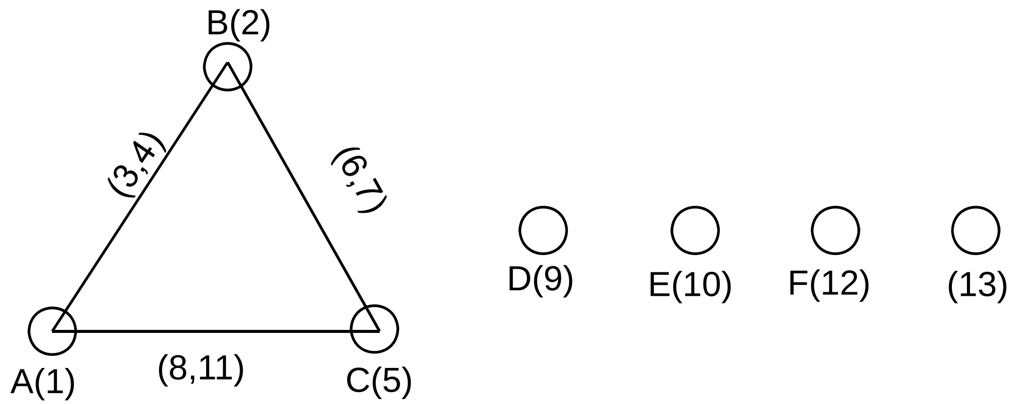

Figure 3 Linear graphs for L27 array

Smaller is the better characteristic: $$\frac{S}{N} = -10 \log \frac{1}{n}\left(\sum y^2 \right)$$

Table 3. Experimental design using L27 orthogonal array

Expt. No.	A (m/sec)	B (%)	C (^{0}C)	D (Degree)	E (mm)	F (µm)	E_{rb} (mg/kg)	S/N ratio (db)
1	43	0	40	30	65	300	150.000	-43.5218
2	43	0	50	60	75	450	133.330	-42.4986
3	43	0	60	90	85	600	250.000	-47.9588
4	43	10	40	60	75	600	150.000	-43.5218
5	43	10	50	90	85	300	201.000	-46.0639
6	43	10	60	30	65	450	137.220	-42.7483
7	43	20	40	90	85	450	200.000	-46.0206
8	43	20	50	30	65	600	350.000	-50.8814
9	43	20	60	60	75	300	140.000	-42.9226
10	54	0	40	60	85	450	277.770	-48.8737
11	54	0	50	90	65	600	225.000	-47.0437
12	54	0	60	30	75	300	290.000	-49.2480
13	54	10	40	90	65	300	165.000	-44.3497
14	54	10	50	30	75	450	152.220	-43.6494
15	54	10	60	60	85	600	182.500	-45.2253
16	54	20	40	30	75	600	125.000	-41.9382
17	54	20	50	60	85	300	320.000	-50.1030
18	54	20	60	90	65	450	211.111	-46.4902
19	65	0	40	90	75	600	175.000	-44.8608
20	65	0	50	30	85	300	390.000	-51.8213
21	65	0	60	60	65	450	322.220	-50.1630
22	65	10	40	30	85	450	244.440	-47.7634
23	65	10	50	60	65	600	215.000	-46.6488
24	65	10	60	90	75	300	250.000	-47.9588
25	65	20	40	60	65	300	330.000	-50.3703
26	65	20	50	90	75	450	155.550	-43.8374
27	65	20	60	30	85	600	275.000	-48.7867

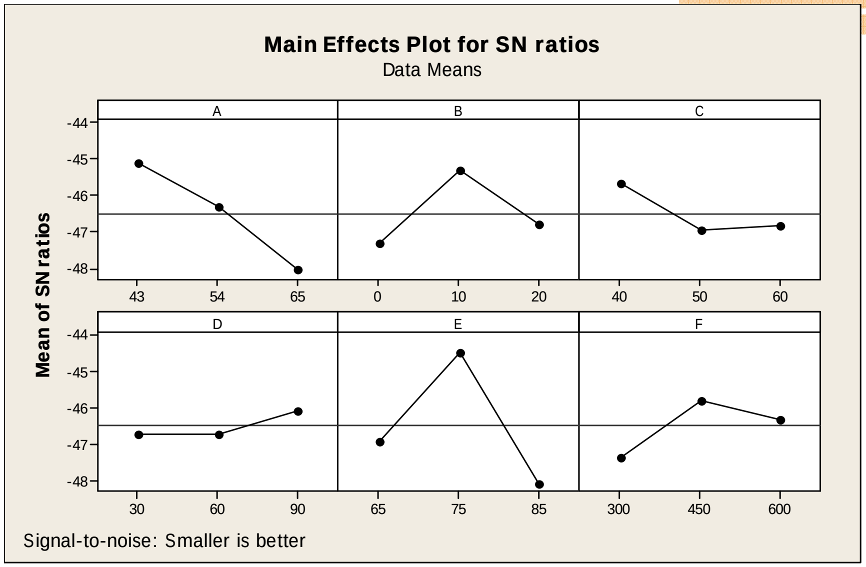

Fig. 4 Effect of control factors on erosion rate

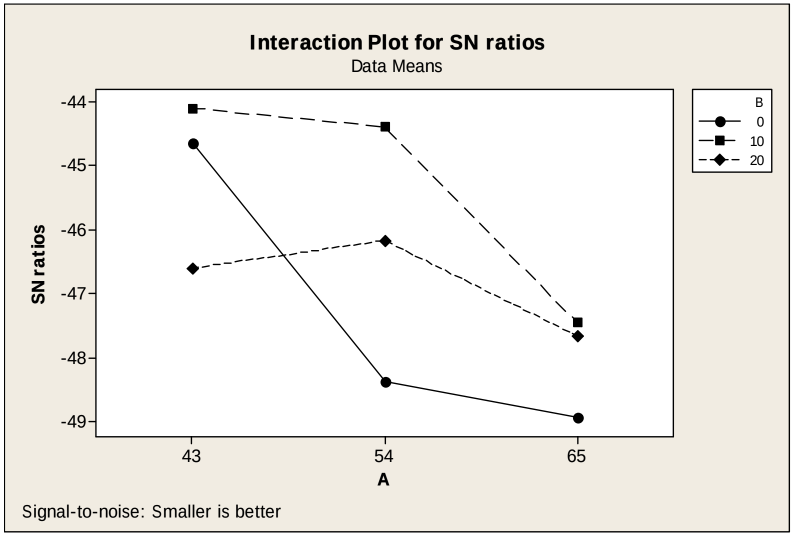

Fig. 5a Interaction graph between A × B

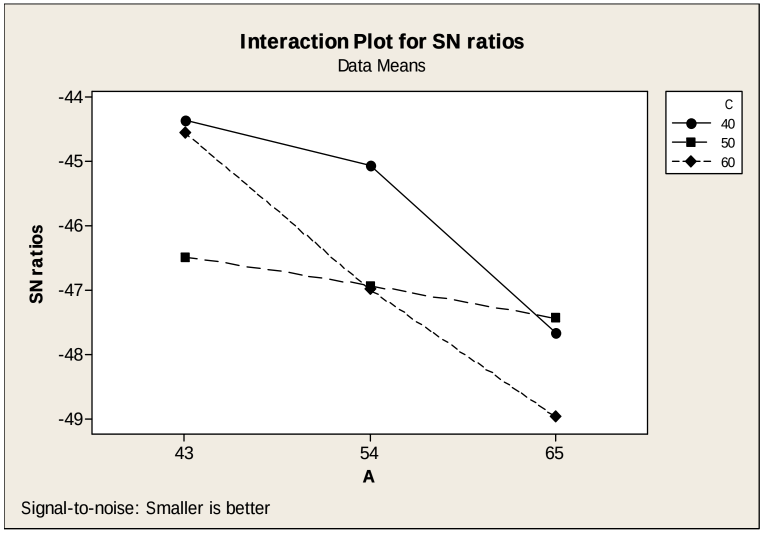

Fig. 5b Interaction graph between A × C

Surface morphology

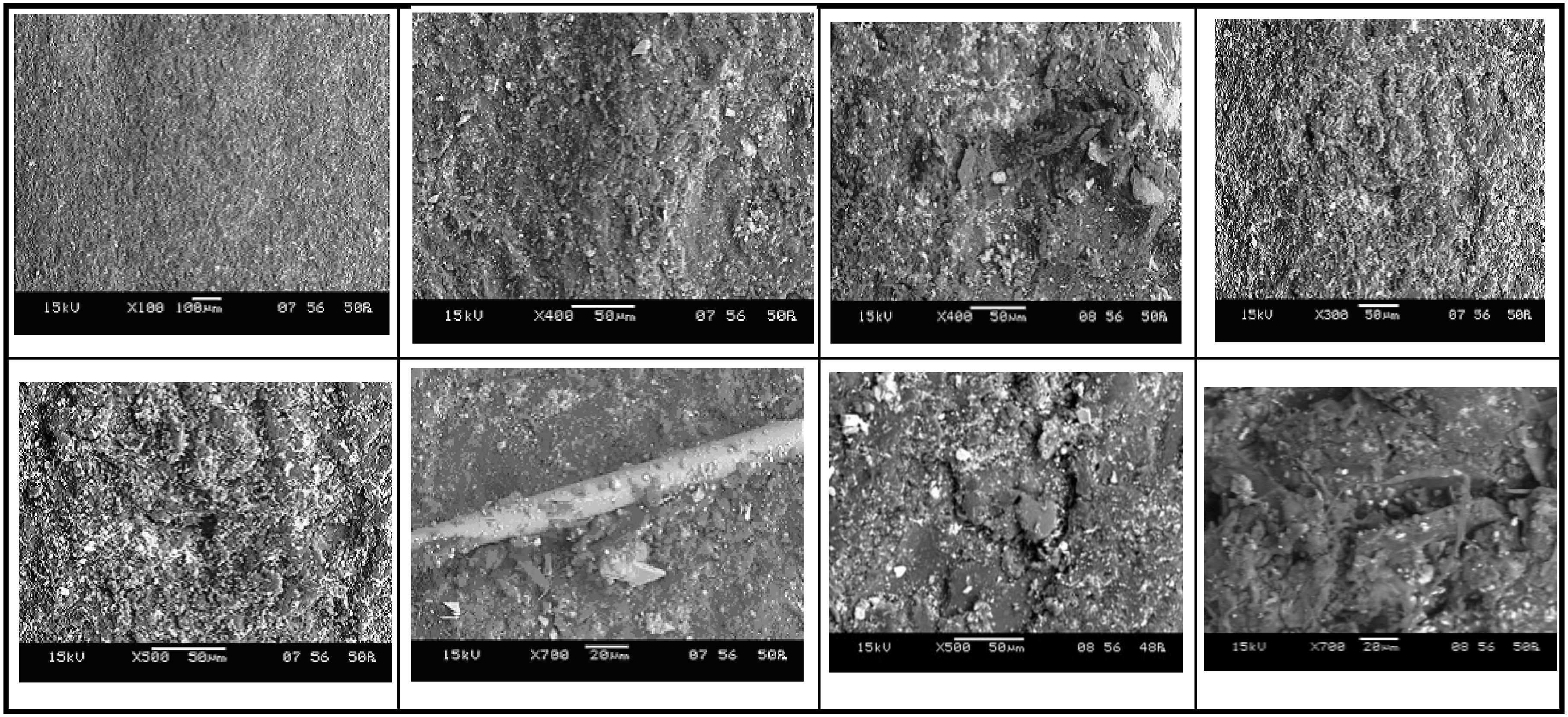

Figure 6 SEM micrographs of bamboo-epoxy composites

Table 4. ANOVA table for erosion rate (Red mud filled composites)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	38.14	38.14	19.07	1.22	0.450
B	2	19.55	19.55	9.77	0.63	0.615
C	2	8.71	8.71	4.35	0.28	0.782
D	2	2.46	2.46	1.23	0.08	0.927
E	2	59.93	59.93	29.97	1.92	0.342
F	2	11.79	11.79	5.89	0.38	0.726
A*B	4	18.56	18.56	4.64	0.30	0.861
A*C	4	10.98	10.98	2.75	0.18	0.932
B*C	4	18.19	18.19	4.55	0.29	0.864
Error	2	31.17	31.17	15.59		
Total	26	219.48				

Table 5. Results of the confirmation experiments for Erosion rate

	Optimal control parameters Prediction	Experimental
Level	$A_2 B_3 C_2 E_1 F_3$	$A_2 B_3 C_2 E_1 F_3$
S/N ratio for Erosion rate (db)	-47.8828	-45.6658

Conclusions

This analytical and experimental investigation into the erosion behaviour of red mud filled bamboo-epoxy hybrid composites leads to the following conclusions:

- Hybrid composites suitable for applications in highly erosive environments can be prepared by reinforcement of bamboo fibres and filling of micro-sized red mud particles in epoxy resin. The erosion wear performance of these composites improves quite significantly by addition of red mud filler.
- Erosion characteristics of these composites can be successfully analyzed using Taguchi experimental design scheme. Taguchi method provides a simple, systematic and efficient methodology for the optimization of the control factors.

- Study of influence of impingement angle on erosion rate of the composites filled with different weight percentage of red mud reveals their semi-ductile nature with respect to erosion wear. The peak erosion rate is found to be occurring at 60^0 impingement angle for all the composite samples under various experimental conditions. The erosion rate is also greatly affected by the erodent temperature.

- Possible use of these composites in components such as pipes carrying coal dust, helicopter fan blades, industrial fans, desert structures, low cost housing etc. is recommended. In future, this study can be extended to new hybrid composites using other potential fillers and the resulting experimental findings can be similarly analyzed.

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Thank You !!