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FRICTION AND DRY SLIDING WEAR BEHAVIOR OF RED MUD FILLED BANANA FIBRE REINFORCED UNSATURATED POLYESTER COMPOSITES USING TAGUCHI APPROACH

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Abstract. This present article describes the effect of red mud filler on wear responses of banana fiber reinforced unsaturated polyester composites. Banana fiber treated NaOH and untreated were taken for the wear studies as reinforcement along with unsaturated polyester and red mud. Red mud, polyester and banana fiber of different weight proportions were taken by keeping the fiber length as fixed (30 mm) which is optimal ones. Compression molding technique is used for preparing the specimens. Wear studies were carried out by using a pin-on-disc wear tester for the specimens prepared as per ASTM standard. Taguchi design of experiments with L9 orthogonal array is used to optimize the parameter with respect to sliding velocity, load and sliding distance.

1. Introduction

Wear is related to interactions between surfaces and more specifically the removal and deformation of material on a surface as a result of mechanical action of the opposite surface. The addition of ceramic fillers along with polyester matrix composites posses better results, the drawback involved in that is the costs involved, to avoid this issue composites are developed by using waste materials as reinforcement and reported that the compatibility of red mud with polyester is fairly good the usage of red mud along with polyester is justified [1].

Suresha et.al. reported that increase in sliding velocity/load increased the sliding wear loss. In particular, from the tests conducted the sliding wear behavior of 10 wt.% graphite filled glass epoxy composites are better compared to unfilled and lower graphite filled carbon fiber reinforced epoxy composites [2].

Unal et. al. reported for pure polytetrafluoroethylene (PTFE) and its composites where with load increases the friction coefficient decrease. In case of wear rate maximum reductions happened for the case of glass fibre with weight percentage 17 % reinforced PTFE. Also it is reported that adding fillers such as carbon and bronze along with PTFE found to be better in reducing wear rate [3].

Wear studies on polyester resin filled with ZnO nano particles were carried out by Nagaraju et.al. It is strongly proved that the addition of filler graphite improves the wear resistance to a much greater extent along with glass fibre reinforced epoxy composites when compared with other sample combinations [4, 5].

Vishwanath et al reported about wear studies on both polyester and phenolic reinforced glass fibre composites. It is observed that in both case of composites 30 wt.% of resin gives low wear and coefficient of friction, also with resin beyond 30 wt.% results in high wear rate [6].

S.B. Basvarajappa et al carried out wear studies on glass fibre reinforced epoxy composites along with fillers SiC and graphite. Wear resistance of the composites increases by the addition of fillers to a greater extent. In addition by using Taguchi approach the optimal parameters on the wear studies were reported. It is also reported that load and sliding distance were the factors that influence the wear more rather than the sliding velocity [7].

Abrasive wear behavior of untreated sugarcane reinforced polymer composites were carried out by S.S. Mahapatra and Vedansh Chaturvedi and developed empirical model using neural network and using Taguchi method the optimal parameter of wear was reported [8].

Study on erosion wear behavior of e-glass fiber reinforced polyester composites carried out by S.S. Mahapatra et. al., by means of air jet type erosion rig, by using design of experiments approach the optimal parameters were obtained. The impact of erosion wear rate of glass fiber reinforced polyester composites done by using ANOVA and S/N ratios. From the optimal parameter obtained the material loss due to erosion is reduced. Further work on erosion studies carried out by using fly ash as particulates along with glass fiber polyester composites [9, 10].

From this through survey it is found that the literature on red mud with banana fiber is not reported by researchers. Hence an investigation is prepared to carryout experimentation on red mud filled with banana fiber reinforced composite.

2. Experimental details

2.1. Materials. The materials used in this work are:

- Natural fiber - Banana fiber,
- Resin - Polyester (General purpose),
- Catalyst - Methyl ketone peroxide,
- Accelerator - Cobalt Naphathanate,
- NAOH - High medium.

Banana fiber are prepared from Banana plant, Polyester resins are produced by the poly condensation of saturated and unsaturated dicarboxylic acids with glycols and red mud is an industrial waste generated during the production of alumina by Bayer's process.

2.2. Methods. Specimens were prepared as per ASTM standard using Pin-On-Disc wear testing machine. The Pin-On-Disc machine is a versatile unit designed to evaluate the wear and friction characteristics a variety of materials exposed to sliding contacts in dry or lubricated environments. The sliding friction test occurs between a stationary pin stylus and a rotating disk. Normal load is varied. Electronic sensors monitor wear and the frictional force of friction as a function of load, speed, lubrication, or environmental condition. Pin on disc wear test machine is shown in Fig. 1.

Fig 1. Pin-On-Disc wear testing machine.

Fig. 2. Wear specimens.

A pin-on-disc test setup was used for slide wear experiments. The surface of the sample comes in contact with a hardened disc of hardness 62 HRC. The counter surface disc was made of EN 32 steel having dimensions of 165 mm diameter, 8 mm thick and surface roughness (Ra) of 0.84 μm. The test was conducted on a track of 100 mm diameter for a specified test duration, load and velocity. The specimen was initially weighed using a digital electronic balance (0.1 mg accuracy). The test was carried out by applying normal load (10, 20, 30 N) and run for a constant sliding distance (3000 m) at constant sliding velocity (3 m/s). At the end of the test, the sample was again weighed. The difference between the initial and final weights was a measure of weight loss.

2.3. Experimental design using Taguchi's technique.

2.3.1 Eight steps in Taguchi methodology.

Step-1: Identify the main function, side effects, and failure mode.
Step-2: Identify the noise factors, testing conditions, and quality characteristics.
Step-3: Identify the objective function to be optimized.
Step-4: Identify the control factors and their levels.
Step-5: Select the orthogonal array matrix experiment.
Step-6: Conduct the matrix experiment.
Step-7: Analyze the data, predict the optimum levels and performance.
Step-8: Perform the verification experiment and plan the future action.

There are three Signal-to-Noise ratios of common interest for optimization of Static Problems. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.

(1) Smaller-the-better:

$n = -10 \text{ Log}_{10}$ [mean of sum of squares of measured data].

This is usually the chosen S/N ratio for all undesirable characteristics like "defects" etc. for which the ideal value is zero. Also, when an ideal value is finite and its maximum or minimum value is defined then the difference between measured data and ideal value is expected to be as small as possible.

The generic form of S/N ratio then becomes

$n = -10 \text{ Log}_{10}$ [mean of sum of squares of {measured - ideal}].

(2) Larger-the-better:

$n = -10 \text{ Log}_{10}$ [mean of sum squares of reciprocal of measured data].

This case has been converted to smaller-the-better by taking the reciprocals of measured data and then taking the S/N ratio as in the smaller-the-better case.

(3) Nominal-the-best:

n =10 Log [Square of mean/Variance].

This case arises when a specified value is MOST desired, meaning that neither a smaller nor a larger value is desirable.

2.3.2 Identification of parameters

The factors influence the output response must be identified, before conducting the experiment which are as follows:

1. sliding velocity (m/s),
2. load (N),
3. sliding distance (m).

2.3.3 Decided the number of levels

After deciding the independent variables, the number of levels for each variable is decided. The selection of number of levels depends on the trend in which, the parameter influences the output response.

2.3.4 Level settings

In this investigation three levels for all factors are considered. Table 1 shows the control factors and levels.

Table 1. Control factors and levels.

Parameters		Levels		
		L1	L2	L3
A	Sliding velocity (m/s)	3	4	5
B	Load (n)	10	20	30
C	Sliding distance (m)	1000	2000	3000

Table 2. Process parameters and cycle of experiment.

Levels	Experiment no	A	B	C
		Sliding velocity, m/s	Load, N	Sliding distance, m
L1	1	3	10	1000
	2	3	20	2000
	3	3	30	3000
L2	4	4	10	2000
	5	4	20	3000
	6	4	30	1000
L3	7	5	10	3000
	8	5	20	1000
	9	5	30	2000

2.3.5 Selection of Orthogonal Array.

Selection of suitable orthogonal array is an important step in conducting an experiment. There are three parameters, and each one has three levels. The highest number of levels is three, so a value of three when choosing our orthogonal array. In this design appropriate

orthogonal array L9 layout is chosen.The corresponding process parameters and the cycle of experiment is presented in Table 2.

3. Results and discussions

3.1. Wear results of untreated banana fibre composites. Specific wear rate for red mud filled untreated banana fiber composite is shown in Fig. 3. Specific wear rate result shows that 30 % weight fraction of fiber with 10 % of red mud having lower wear rate and higher wear resistance at 10N, 20 N load compare to 40% weight fraction of fiber without red mud. Condition of without and 10 % of red mud at 10 N loading shows decrease in specific wear rate decrease from $3.1x10^{-5}$ to $2.5x10^{-5}$ and applying the load of 20 N wear rate decrease from $2.4x10^{-5}$ to $2.0x10^{-5}$,same combination at load of 30 N wear rate increase from $2.5x10^{-5}$ to $3.6x10^{-5}$. Addition of 20 % and 30 % red mud composites wear rate increase compare to the 10 % and without red mud composites.

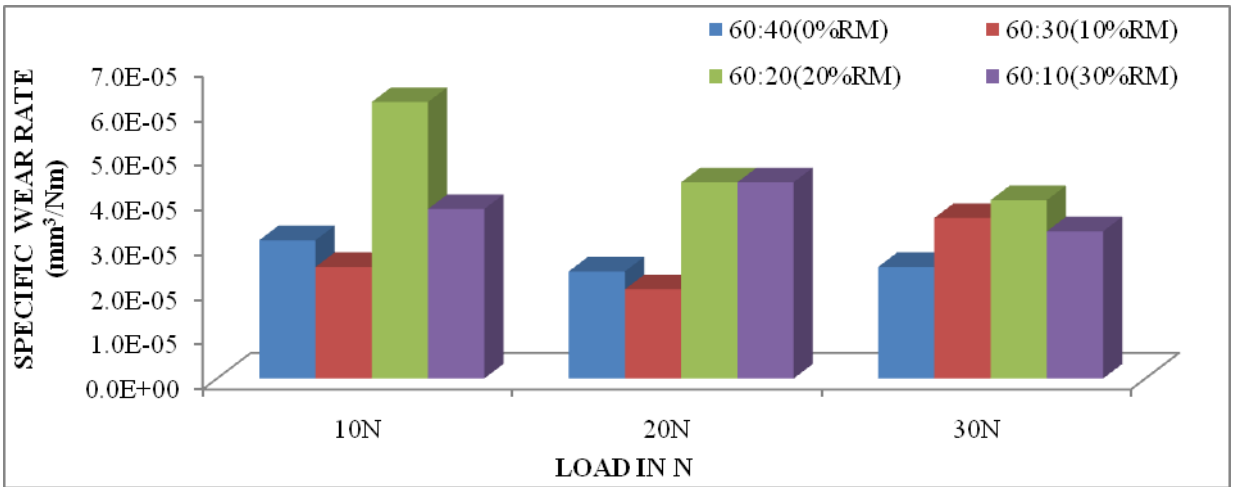

Fig 3. Specific wear rate for untreated banana fiber composites.

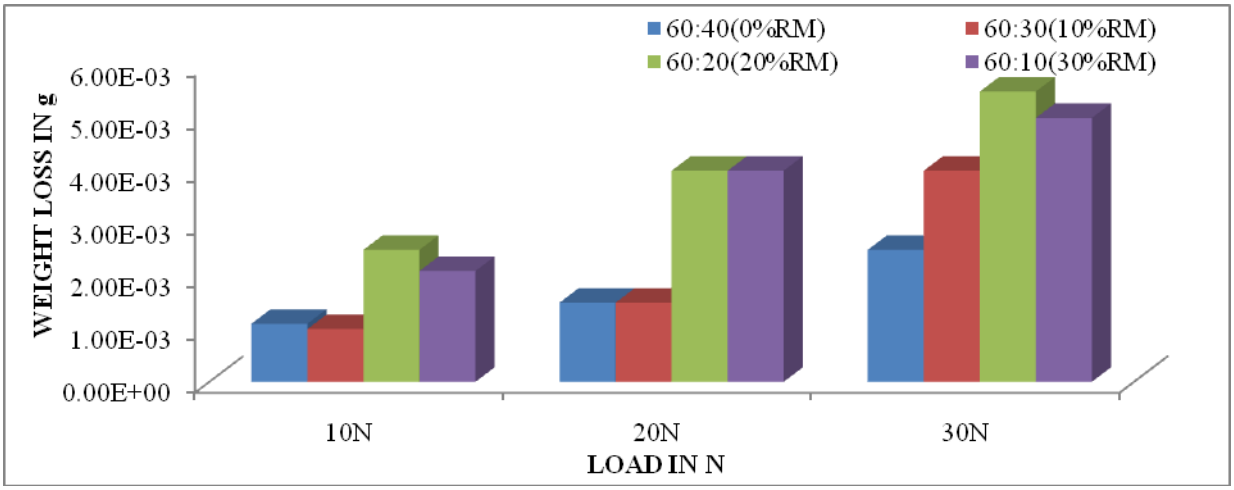

Fig. 4. Weight loss for untreated banana fiber composites.

Weight loss for untreated banana fiber composite is shown in Fig. 4.

The weight loss result shows that increasing weight loss depends on the increasing load and addition of red mud content.

Coefficient of friction for untreated banana fiber composites is shown in Fig. 5.

The result shows that the coefficient of friction gradually increasing based on the condition of applying load 10 N, 20 N, 30 N and amount of red mud content and decreasing the weight fraction of fiber.

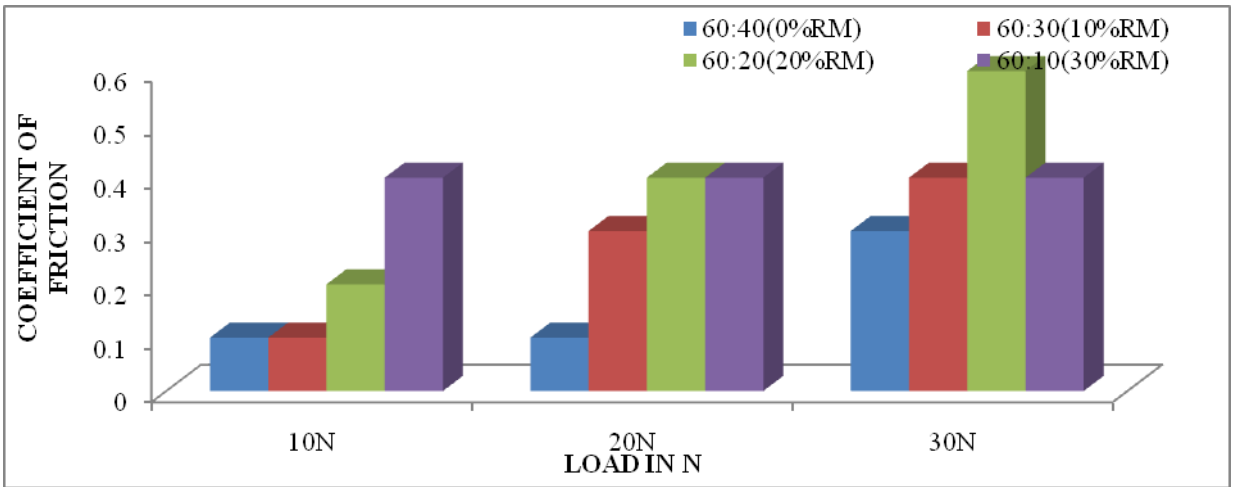

Fig. 5. Coefficient of friction for untreated banana fiber composites.

3.2. Wear results of NAOH treated banana fibre composites. Specific wear rate for red mud filled NAOH treated banana fiber composite is shown in Fig. 6. Specific wear rate result shows that 30 % weight fraction of fiber with 10 % of red mud having low wear rate at 10 N load compare to 40 % weight fraction of fiber without red mud. Condition of without and 10 % of red mud at 10 N loading condition specific wear rate decrease from $3.7x10^{-5}$ to $3.3x10^{-5}$ and applying the load of 20 N wear rate increase from $2.9x10^{-5}$ to $3.1x10^{-5}$ same combination at load of 30 N wear rate increase from $2.5x10^{-5}$ to $4.2x10^{-5}$. Addition of 20 % red mud gradually increases the wear rate. Weight fraction of 10 % fiber with more amount of 30 % red mud composites at load of 30 N wear rate increases to $1.0x10^{-3}$ having low wear resistance compare to the 10 % and without red mud composites.

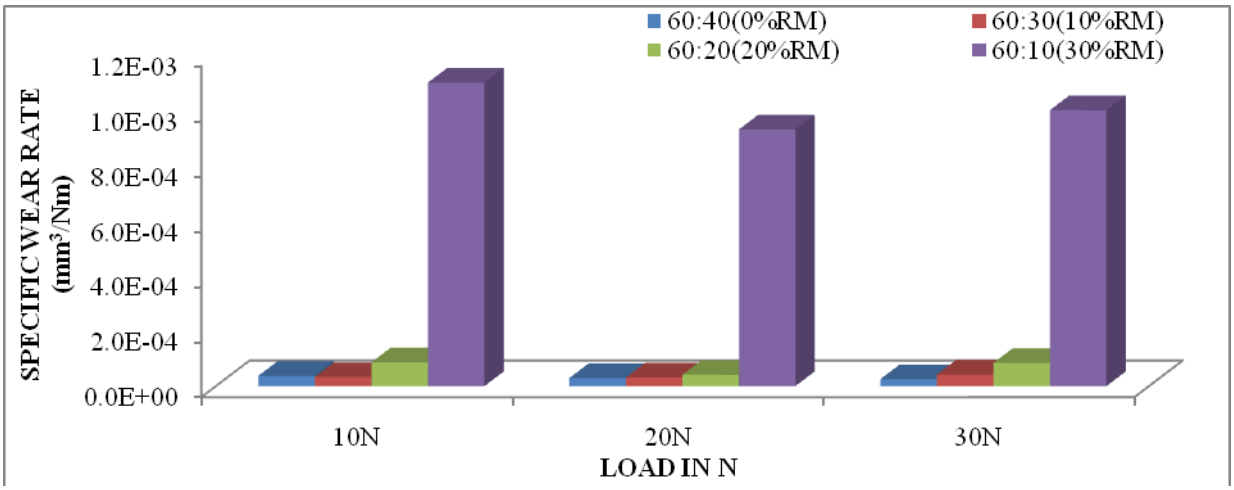

Fig. 6. Specific wear rate for NAOH treated banana fiber composites.

Weight loss for NAOH treated banana fiber composite is shown in Fig. 7.

The weight loss result shows that increasing weight loss depends on the increasing load and addition of red mud content 10 % weight fraction of fiber with 30 % red mud composite having more material loss due to more amount of red mud.

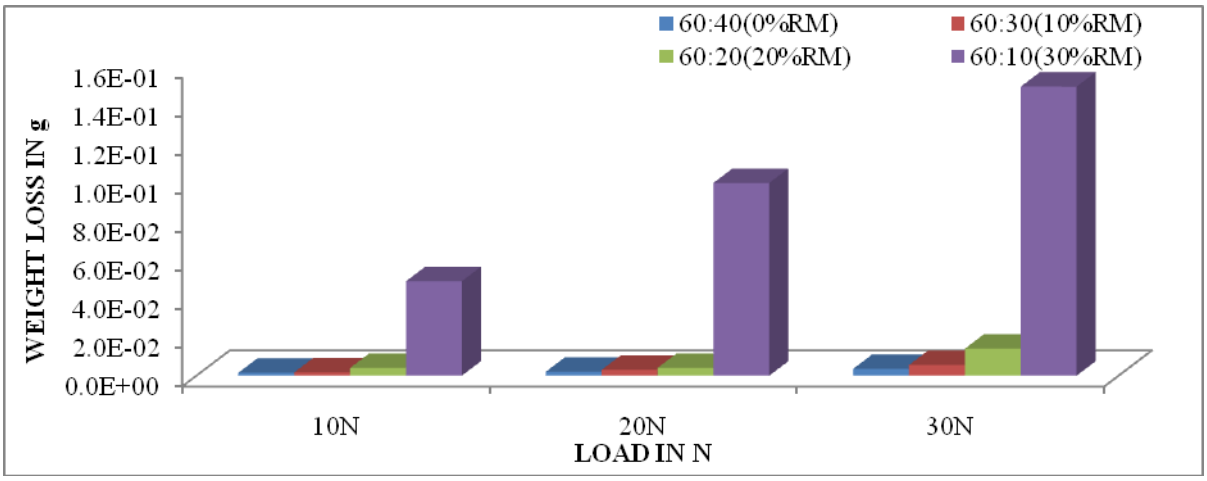

Fig. 7. Weight loss for NAOH treated banana fiber composites.

Coefficient of friction for NAOH treated banana fiber composites is shown in Fig. 8. Result shows that applying load of 10 N and 30 N the coefficient of friction increasing from 0.1 to 0.6 conditions of 40 % of fiber without red mud filler. Addition of more and more red mud filler at different load increases the coefficient of friction gradually.

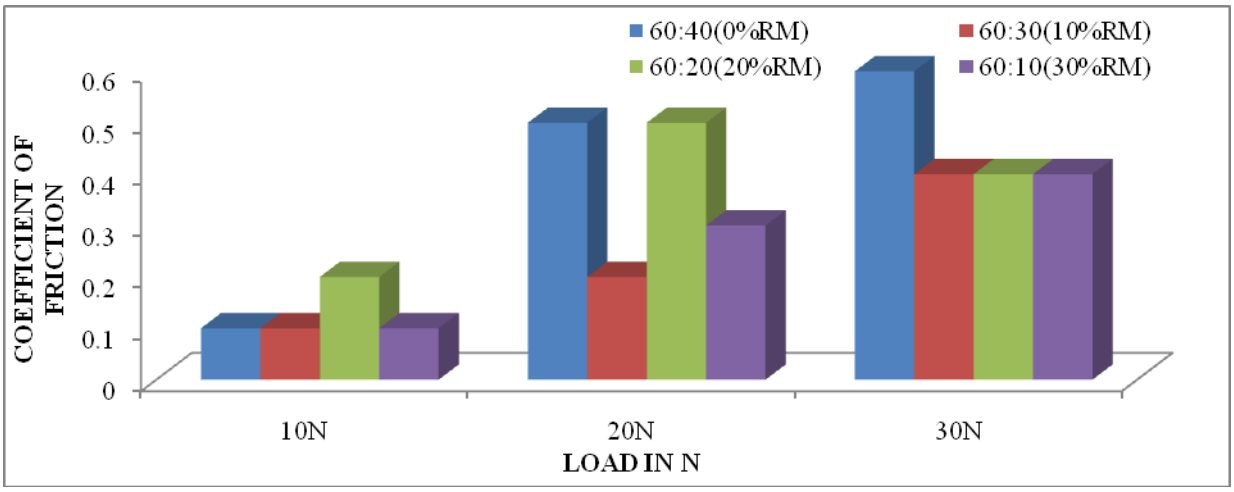

Fig. 8. Coefficient of friction for NAOH treated banana fiber composites.

Comparison of specific wear rate for untreated and NAOH treated banana fiber composites is shown in Fig. 9. Comparative study of wear rate indicates the 40 % weight fraction of NAOH treated fiber without red mud different loading condition increasing wear rate compare to 40 % weight fraction of untreated fiber. Untreated treated fiber weight of 30 % reinforcing with 10 % of red mud having low wear rate and achieving higher wear resistance property compare to 30 % of NAOH treated fiber with 10 % of red mud composites and other composite combinations.

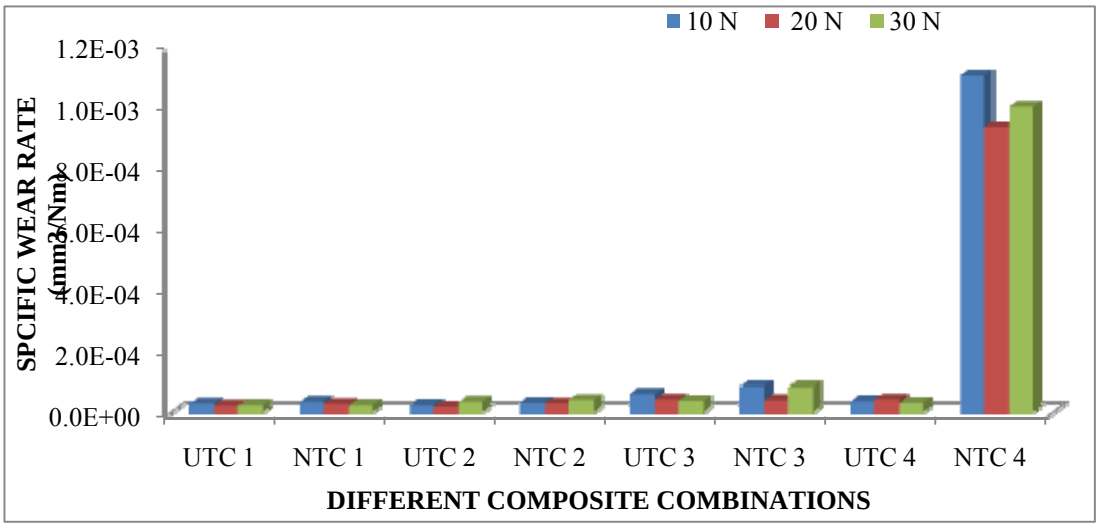

Fig. 9. Comparison of specific wear rate for untreated/NAOH treated banana fiber composites.
Here UTC-Untreated combinations, NTC-NAOH treated combinations.

3.3. Taguchi experimental design for wear studies.

3.3.1 S/N ratio.

Response curves are graphical representation of change in performance characteristics with the variation on process parameter levels. This analysis is aimed at determining influential process parameter. A smaller the Better characteristics formula has been used to identify the combination of influence parameters to enhanced the wear rate of optimum.
Formula for smaller the better :

$S/N = -10 \log (1/n\sum y_i^2)$.

3.3.2 L9 experimental result of wear test.

The experimental result of wear test is shown in Table 3, and the corresponding chat is presented in Figs. 10, 11, and 12. To find the optimum value of response, the average S/N ratio was calculated for all experiments in Table 3.

Table 3. L9 experimental result of wear test.

Density, g/cm^3	W1, g	W2, g	Δm, g	Δv, cm^3	X	P, n	K_o, mm^3/nm	μ	S/N ratio
1.35	1.315	1.313	$2.40\cdot10^{-3}$	$1.8\cdot10^{-3}$	1000	10	$1.8\cdot10^{-4}$	0.7	74.9
1.40	1.265	1.260	$5.00\cdot10^{-3}$	$3.6\cdot10^{-3}$	2000	20	$8.9\cdot10^{-5}$	0.8	81.0
1.26	1.271	1.263	$7.30\cdot10^{-3}$	$5.8\cdot10^{-3}$	3000	30	$6.4\cdot10^{-5}$	0.6	83.9
1.20	1.171	1.168	$3.00\cdot10^{-3}$	$2.5\cdot10^{-3}$	2000	10	$1.2\cdot10^{-4}$	1.2	78.4
1.41	1.171	1.168	$2.60\cdot10^{-3}$	$1.8\cdot10^{-3}$	3000	20	$3.1\cdot10^{-5}$	0.7	90.2
1.34	1.093	1.089	$3.40\cdot10^{-3}$	$2.5\cdot10^{-3}$	1000	30	$8.5\cdot10^{-5}$	0.8	81.4
1.29	1.111	1.108	$2.90\cdot10^{-3}$	$2.3\cdot10^{-3}$	3000	10	$7.5\cdot10^{-5}$	0.8	82.5
1.35	1.154	1.148	$5.90\cdot10^{-3}$	$4.4\cdot10^{-3}$	1000	20	$2.2\cdot10^{-4}$	0.8	73.2
1.45	1.087	1.083	$4.20\cdot10^{-3}$	$2.9\cdot10^{-3}$	2000	30	$4.8\cdot10^{-5}$	0.7	86.4

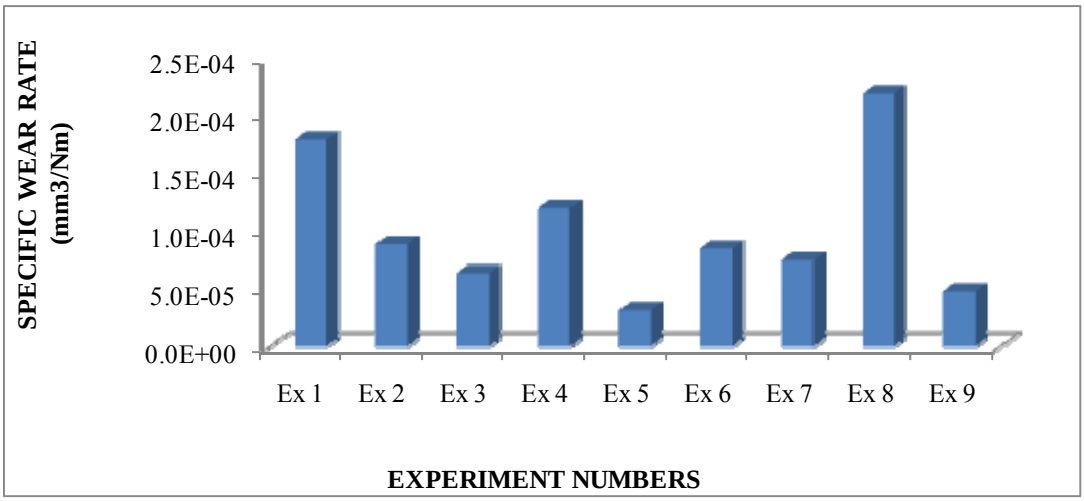

Fig. 10. Specific wear rate for L9 experiment.

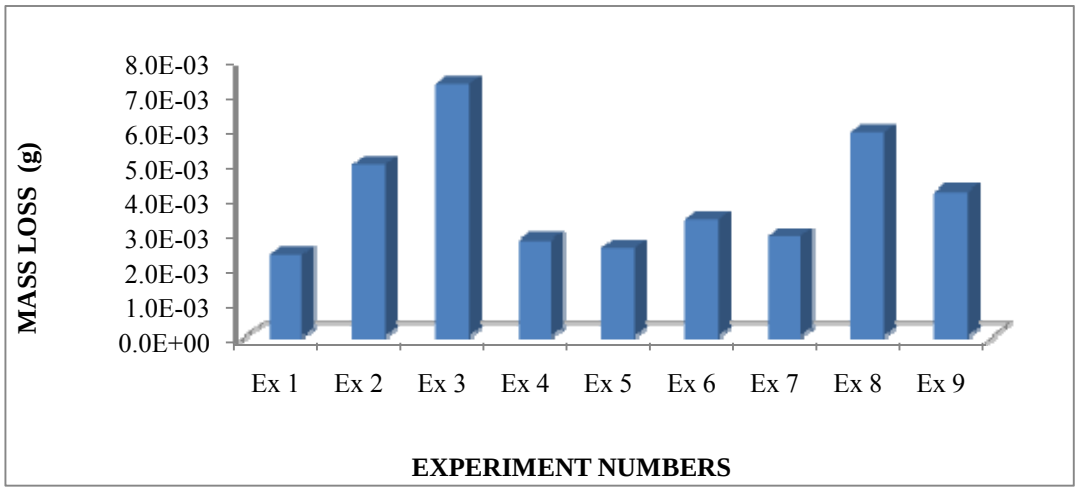

Fig. 11. Mass loss for L9 experiment.

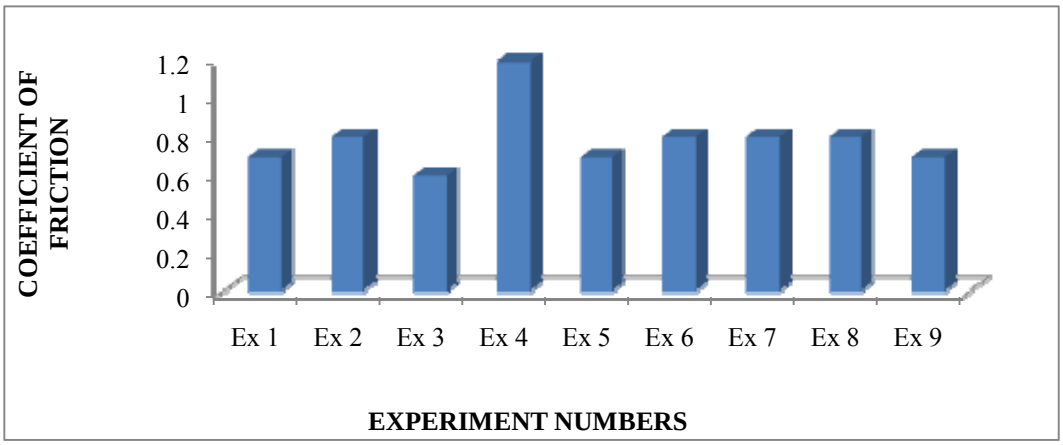

Fig. 12. Coefficient of friction for L9 experiment.

Experiment no five enhance the lower wear rate than other combination of experiment. The computation of variation using L9 orthogonal array for wear rate is shown in Table 4.

The scheme for ANOVA for wear parameters is shown in Table 5.

Table 4. Computation of variation using L9 orthogonal array for wear parameters.

Factors		Sliding velocity, m/s	Load, N	Sliding distance, m	Error	Total
		A	B	C	D	
Sum at factor level	L1	**239.8**	**235.8**	**229.5**	251.4	731.8
	L2	250	244.3	245.8	244.9	
	L3	242	251.7	256.5	235.4	
Sum of square of differences, s		173	377.7	1116.5	388.3	2055.6
Contribution ratio, %		8.42	18.33	54.32	18.89	100 %

Table 5. Scheme for ANOVA for wear parameters.

Source of variations		Sum of squares	Degree of freedom ψ	Mean sum of square s/ψ	Variance f_o
Sliding velocity, m/s	A	173	2	86.52	
Load, N	B	377.7	2	188.86	4.37
Sliding distance, m	C	1116.5	2	555.26	12.90
Error	D	388.3	2	194.14	4.49

The percentage contribution ratio of parameters on wear test is shown in Table 6 and Fig. 13. The significant factors are chosen from the left hand side in the chat which is cumulatively contribution about 90 %.

Table 6. Contribution ratio for wear parameters.

Factors	C	D	B	A
Contribution ratio, %	54.32	18.89	18.38	8.42
Cumulative contribution ratio, %	54.32	73.2	91.58	100

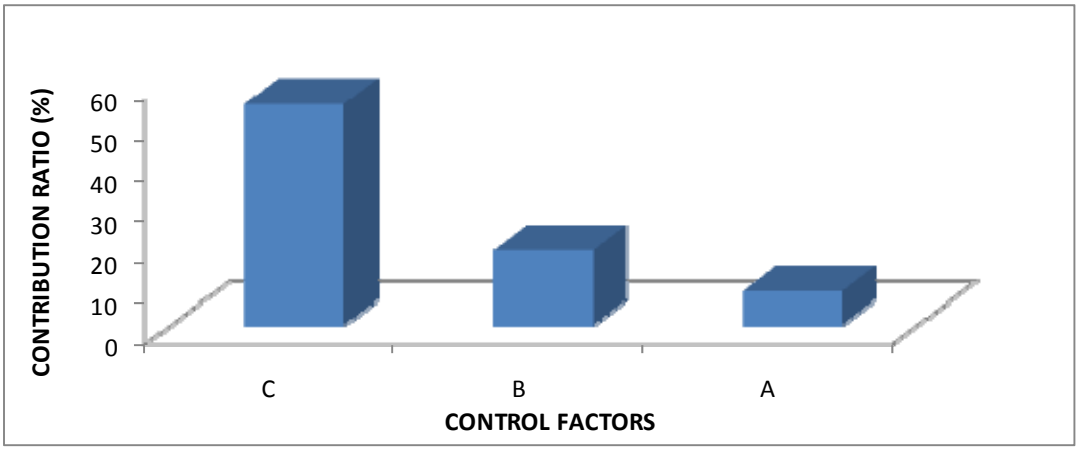

Fig. 13. Contribution ratio for wear parameters.

Average S/N ratio for control factors is shown in Fig. 14. The maximum values of average S/N ratio are the optimum values for the parameters. Identify the optimum parameters to get enhanced smaller wear rate.

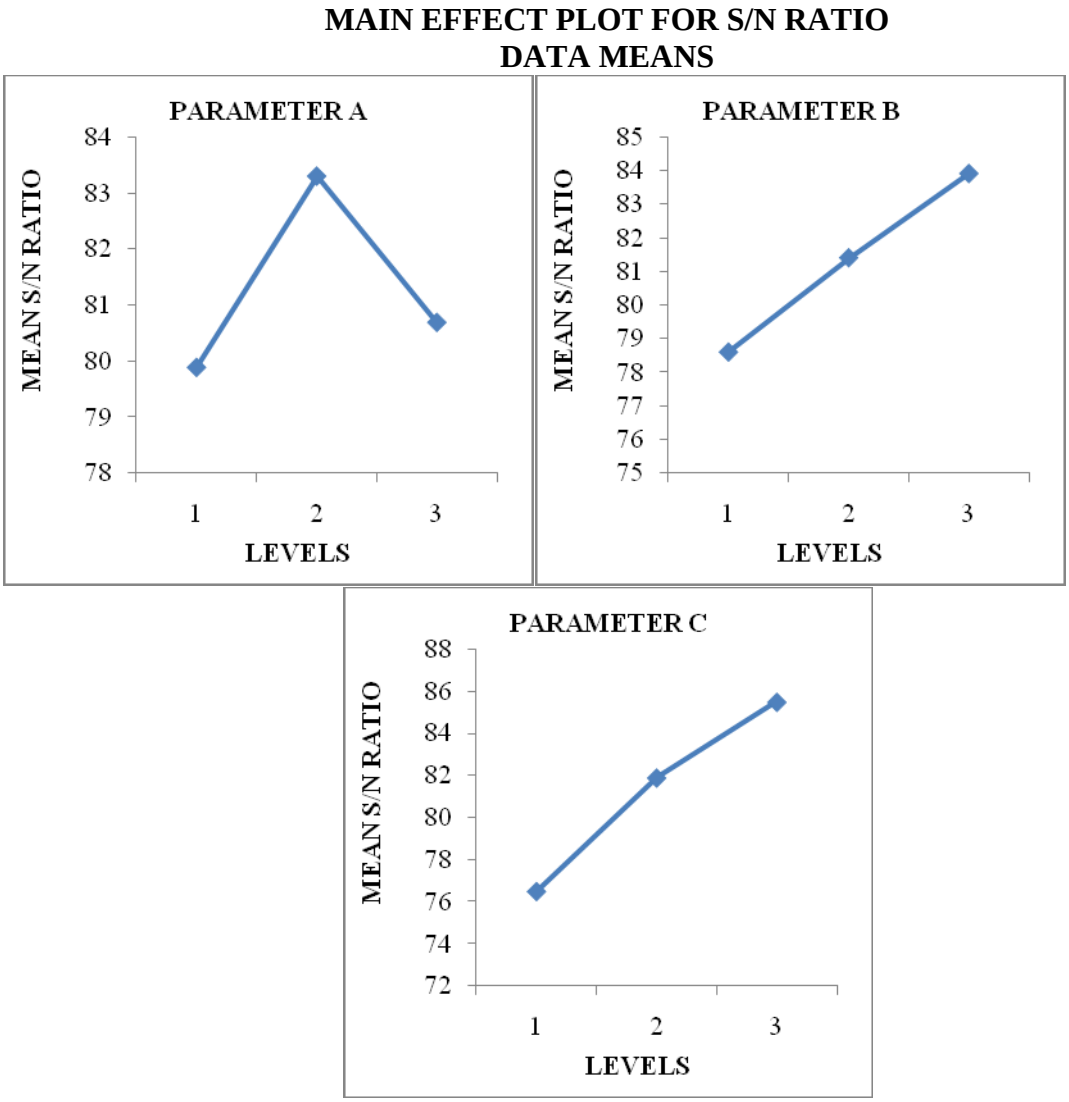

Fig. 14. Average S/N ratio for control factors.

4. Conclusions

This experimental and investigation on the reinforcement of red mud filled Banana polyester treated / untreated composites lead to the following conclusions:

Banana fiber reinforced polyester composites filled with red mud was made successfully by simple compression moulding technique.

An industrial waste like red mud can also be gainfully utilized for the composite making purpose. Incorporation of these fillers modifies the wear strength of the composites.

In dry sliding wear test shows that the 10 % red mud filler on 30 % weight fraction of untreated / NAOH treated fiber having low wear rate at load of 10 N only and condition of 3 m/s sliding velocity, 3000 m sliding distance.

Design of experiments approach by Taguchi method enabled to analyze successfully the wear behaviour of composites with load, sliding distance, sliding velocity as test variables.

Found that optimum parameters for wear test are 4 m/s sliding velocity, load of 30 N and 3000 m sliding distance.

Environmental pollution related issues are minimized drastically by consuming the red mud for the useful composite fabrication

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