

## Dry sliding wear behavior of aluminium metal matrix composites

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### Abstract

The present study was undertaken to investigate the combination of factors levels, which yields minimum wear rate of the Aluminum alloy, and Titanium dioxide reinforced Aluminum alloy composite. Dry sliding wear test was conducted to understand the tribological behaviors of samples. A plan of experiment, based on design of experiment was used to acquire the data in a controlled way. The wear parameters chosen for the experiment were: Sliding speed, Load and sliding distance. Each parameter was assigned three levels. The analysis of variance was used to investigate the significant factors, which affect the dry sliding wear behavior of Aluminum alloy and its composite. A mathematical model was developed to determine the wear rate of the test samples.

**Keywords:** yield; dry sliding wear; mean; design of experiment

### 1. Introduction

Metal matrix composites (MMCs) are engineering materials that refer to a metal based materials reinforced with particulates, whisker or fiber, which can produce considerable alteration in the physical and mechanical properties of the base alloy. Metal matrix composites have proved to be an important class of materials with the potential to replace a number of conventional materials being used in automotive, aerospace, defense and leisure industries where the demand for lightweight and higher strength components is increasing <sup>[1]</sup>. The mechanical components that undergo sliding or rolling contact, such as bearings, clutches, seals, guides, piston rings, splines, brakes and clutches are subjected to some degree of wear. Wear is a surface phenomenon that occurs by the displacement and detachment of Materials, because it usually implies a progressive loss of weight and alteration of dimensions over period of time <sup>[2]</sup> MMCs generally possess superior wear resistance compared with unreinforced Aluminum alloy. A lot of researches on the dry sliding wear behavior of MMCs had been reported <sup>[4-6]</sup> and also reviewed <sup>[7-9]</sup>. Tribological behavior of

Materials depend on many factors such as properties of material combinations, experimental condition and type of wear tester. Miyajima *et al.* <sup>[3]</sup> carried out dry sliding wear tests using pin-on-disc wear tester where the pins were of 0.45% carbon steel and disc were made of Aluminum alloy composites reinforced with SiC-whisker, Al<sub>2</sub>O<sub>3</sub>-fibers and SiC particles. The result analysis shows that, the wear rate of MMCs decreased with increasing volume fraction of reinforcing material. Basavarajappa *et al.*, <sup>[4]</sup> investigated the dry sliding wear behavior of Aluminum alloy reinforced with SiC particles and reported that the wear rate of the MMCs reduces with increasing reinforcement content. Shipway *et al.*, <sup>[6]</sup> produced TiC reinforced AMCs using novel casting technique. The sliding wear behavior of the extruded composites has been studied as a function of load and volume fraction. The result reveals that, particle addition of TiC has

reduced the wear rates of the composites. Ranganath *et al.*, <sup>[10]</sup> studied the dry sliding wear of garnet reinforced Zinc-Al metal matrix composites and reported that wear resistance of the MMCs increases as the content of the Garnet increases. S.K. Acharya *et al.*, <sup>[11]</sup> investigated the wear behavior of Al / red mud composites and reported that coefficient of friction decreases as the load increases. Presences of red mud particles improve the hardness and wear resistance of the composites. Esteban Fernandez *et al.*, <sup>[12]</sup> used a statistical method, the factorial experimental design to investigate the effects of reinforcement, load and abrasive grain size of Ni based coating alloy. The summary of the result is grain size exerted the greatest effect on abrasive wear, followed by reinforcement. The load applied had a much lower effect and the environment was found to have minor effect. Leisk *et al.*, <sup>[13]</sup> adopted Statistical-approach to optimize the heat – treatment of Alumina reinforced AMCs. The heat treatment was carried out according to orthogonal array. The interpretation is that the highest yield strength and ultimate tensile strength are obtained for the optimal solutionizing time (6h) and aging temperature (160° C) for the both the 10 and 20 % alumina composites respectively. Hari Singh *et al.*, (2004) <sup>[14]</sup> used a design of experiment - Taguchi method to know the optimal setting of turning parameters that yield the optimal tool wear. The results indicated that selected process parameters affect significantly the tool wear characteristics of Tic coated carbide tool.

This study is carried out to know the effect of Titanium dioxide (TiO<sub>2</sub>) on dry sliding wear behavior of the Al alloy. The ANOVA was employed to find the significant factor, which affects the dry sliding wear of Aluminum alloy and the composite material.

#### 1.1 Design of experiment

Design of experiment is a critically important engineering tool for improving a manufacturing process. It also has extensive application in the development of new processes. Application

of these techniques early in process development can result in improved yield, reduced variability and closer conformance to nominal, reduced development time and reduced overall costs. This technique is a powerful tool for acquiring the data in a controlled way and to analyze the influence of process variable over some specific variable, which is unknown function of these process variables. The overall aim of this technique is to make the products that are robust with respect to influencing parameters.

**2. Experimental procedure**

**2.1 Materials**

Aluminum2618 alloy that contains Copper and Magnesium as major constituent was used as matrix material and its composition is shown in Table 1. Titanium dioxide of laboratory grade was used as a reinforcing material. 4wt % TiO2 reinforced Al alloy composite was produced using stir-casting technique, which was used by researcher, Mahindra *et.al.*, [15]. Both Aluminum alloy and composite specimen were subjected to T-6 heat treatment standards.

**2.2 Selection of Orthogonal array**

In the present study, the experiments were conducted as per the Standard orthogonal array. The wear parameters chosen for the experiment were: Sliding speed in m/s, Load in N and sliding distance in m. Each parameter was assigned three levels, which are tabulated in table 2. The experiment consists

of nine tests according to L<sub>9</sub> orthogonal array shown in Table 3. The first column was assigned to sliding speed, second column was assigned to load and the third column was assigned to sliding distance. The response to be studied is the wear rate in grams with the objective of ‘smaller is the better’.

**2.3 Experimental set –up**

In order characterize the dry - sliding wear behavior of the specimens, wear tests were performed using a Pin-on-disc machine shown in Figure 1, which was similar to the machine described by C.S.Ramesh *et al.*, [17]. Circular pins of diameter 8 mm and height 30 mm was used as a test specimen. The initial weight of the specimen was measured using an electronic weighing machine which as a resolution of 0.001gram. The test specimen was gripped in the wear testing machine to avoid rolling during the test. The wear test was conducted as per the orthogonal array L<sub>9</sub> shown in table 4. The wear rate of the specimen was studied as a function of the sliding velocity, applied load and sliding distance. Wear test were conducted as per procedure reported in the paper Uyyuru *et al.*, [18]. At the end of each experiment, the specimen was removed from the testing set-up, cleaned with acetone dried and weighed to determine the weight loss due to dry sliding wear. The difference in the weight measured before and after test gives the wear rate in grams. Each experiment was repeated thrice and mean response values were tabulated in table 4.



**Fig 1:** Schematic diagram of wear test

**3. Result discussion**

The selected quality characteristic, sliding wear is a ‘smaller is the better’ type and signal to noise ratio(S/N ratio) for ‘smaller is the better’ type of response was used as given below.

$$\eta = -10 \log_{10} \left\{ \frac{1}{n} \sum_{i=1}^n y_i^2 \right\} \text{----- (1)}$$

Where r = number of tests in a trial (3).

The S/N ratio was computed using equation (1) for each of the nine trial and the values are reported in table 5.

Figure 3 and 5 shows the mean effect of process parameters on the wear quality characteristics for both Aluminum alloy and composite material. The average mean wear for Aluminum

alloy is 0.0112grams, whereas for the composite material it is 0.0101grams. This shows that wear resistance of composite material is more than Aluminum alloy.

The average values of S/N ratios of three parameters at three levels for both Aluminum alloy and composite material are plotted in Figure 2 and 4. It is evident from the figure that, Wear quality characteristic is least, when the process parameters is at, 3<sup>rd</sup> level of parameter S, 1<sup>st</sup> level of parameter L and also at 1<sup>st</sup> level of parameter D. The analysis of means also suggested the same level for minimum dry sliding wear.

**3.1 Analysis of variance.**

The analysis of variance (ANOVA) establishes the relative significance of factors in terms of their percentage

contribution to the response. ANOVA is also needed for estimating the error variance for the effects and variance of the prediction error. Based on ANOVA the optimal combinations of the process parameters are predicted. The analysis is carried out for the significance of 5 % (95% confidential level). The table 6 shows analysis of variance for Aluminum alloy. From the results of ANOVA, it is found that Distance factor has major influence on sliding wear characteristic (P = 49.11%). The second significant factor is sliding speed which as P = 19.20 %1. The table7 shows analysis of variance for Aluminum composite material. From the results of ANOVA, it is found that distance factor has major influence on sliding wear characteristic (P = 68.88 %). The second significant factor is sliding speed which as P = 11.54 %.

**3.2 Regression equation**

In order to establish the correlation between the wear parameters: Sliding speed, load and distance the wear rate of multiple linear regression models was developed.

The regression equation for Aluminum alloy is

$$\text{Wear rate} = 0.00391 - 0.00099 \times S - 0.000022 \times L + 0.000009 \times D \text{ ----- (1)}$$

The regression equation for composite material is

$$\text{Wear rate} = 0.00168 + 0.00058 \times S + 0.000051 \times L + 0.000004 \times D \text{ ----- (2)}$$

**3.3 Confirmation test**

The confirmation test was performed for composite material by selecting the levels of parameters as shown in table 8. Each test was conducted twice in order to eliminate the bias if present. The wear rate was calculated using equation 2 and the results obtained were compared with the actual values. The results shows that maximum of 10 % error was observed.

**Table 1:** Composition of Al 2618 alloy.

Cu	Mg	Ni	Fe	Si	Ti	Mn	Al
2.18	1.43	1.1	0.93	0.16	0.04	0.028	Bal

**Table 2:** Process parameters with their different levels.

Factors	Code	Units	Level 1	Level 2	Level 3
Sliding speed	S	m/S	1.674	2.09	2.512
Load in	L	N	39.24	49.05	58.86
Sliding Distance	D	m	500	1000	1500

**Table 3:** Orthogonal array L9 matrix

L9 test run	Factor 1	Factor 2	Factor3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

**Table 4:** Orthogonal array of Taguchi for Wear test & test results

L9 test run	Sliding velocity In M/Sec.	Load in N.	Sliding distance in M	Wear rate of Al alloy (Grams)	Wear rate of Composite material (Grams)
1	1.674	39.24	500	0.006	0.0070
2	1.674	49.05	1000	0.009	0.0080
3	1.674	58.8	1500	0.016	0.0150
4	2.09	39.24	1000	0.012	0.0090
5	2.09	49.0	1500	0.015	0.0160
6	2.09	58.86	500	0.001	0.0095
7	2.512	39.24	1500	0.011	0.0100
8	2.512	49.0	500	0.008	0.0070
9	2.512	58	10	0.001	0.0095

**Table 5:** S/N ratio for Al alloy and composite Material.

Factors	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
S	2	13.334	13.334	6.667	3.32	0.232	19.20
L	2	10.924	10.924	5.462	2.72	0.269	15.11
D	2	30.701	30.701	15.35	7.64	0.116	49.11
Error	8	4.019	4.019	2.009			16.58
Total	26	58.978					100

**Table 6:** ANOVA test for S/N Ratio for Al alloy.

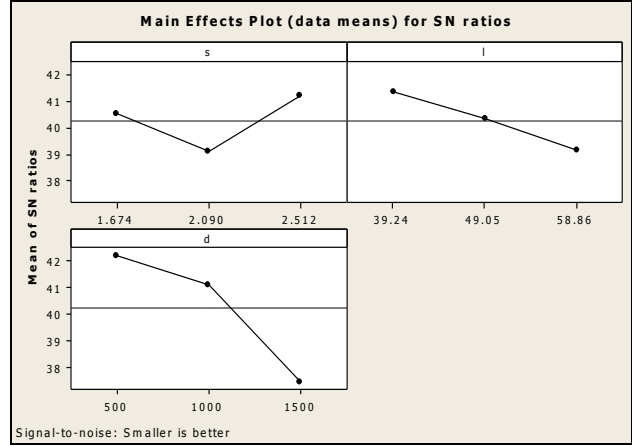
Factors	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
S	2	6.812	6.81	3.40	4.65	0.177	11.54
L	2	7.3724	7.3724	3.6862	5.03	0.166	12.61
D	2	36.9995	36.9995	18.4997	25.26	0.038	68.88
Error	8	1.4649	1.4649	0.732			6.99
Total	26	52.649	52.6496				100

**Table 7:** ANOVA test for S/N Ratio for composite material.

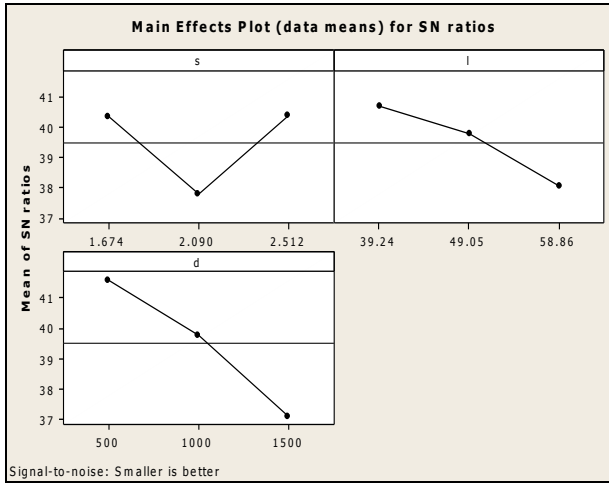
Test	Sliding Speed m/s	Load in N	Distance in m
1	1.56	19.6	1630
2	2.34	39.2	2050
3	2.98	49	1400
4	3.00	9.8	1500
5	4.52	29.4	1200

**Table 8:** Parameters for confirmation wear test

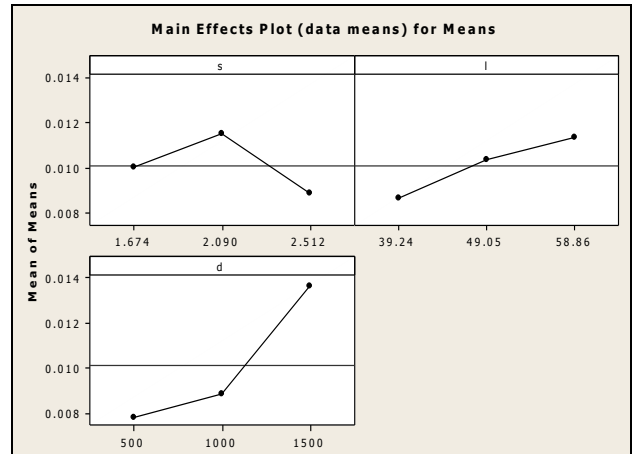
L <sub>9</sub> test run	SN ratio for Al alloy in (db)	SN Ratio for Composite material. in (db)
1	44.4370	43.0980
2	40.9151	41.9382
3	35.6503	36.4782
4	38.4164	40.9151
5	36.4782	35.9176
6	38.4164	40.4455
7	39.1721	40.0000
8	41.9382	43.0980
9	40.0000	40.4455



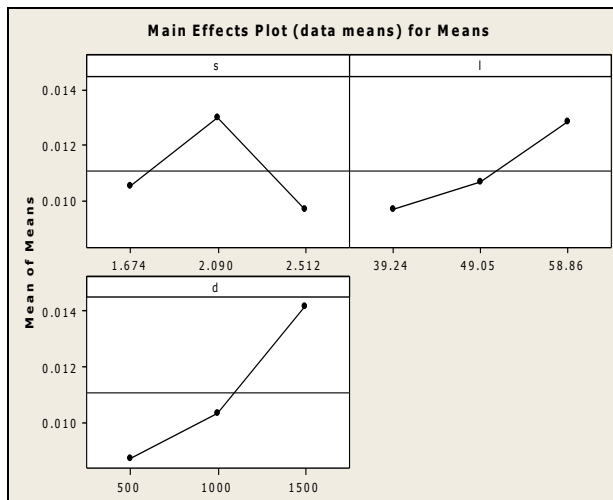
**Fig 4:** SN ratio of composite material.



**Fig 2:** SN ratio of Aluminum alloy.



**Fig 5:** Analysis of means for composite material.



**Fig 3:** Analysis of means for Aluminum alloy.

**4. Conclusion**

Following conclusions were drawn from the present investigation.

- 1 Design of experimental technique is successfully used to determine dry sliding Wear.
- 2 Titanium Dioxide reinforcement Aluminum alloy increases the wear resistance of Aluminum alloy.
- 3 The average mean wear for Aluminum alloy is 0.012 grams, whereas for the composite material it is 0.0101 grams.
- 4 Wear quality parameter is least, when the process parameters are at 3<sup>rd</sup> level of parameter S 1<sup>st</sup> level of parameter L and D.
- 5 During dry sliding wear test the significant factors are distance and sliding speed.

- 6 From the mathematical model it is seen that regression coefficient is minimum for composite material when compared to Aluminum alloy.

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