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TRIBOLOGICAL STUDIES ON DISCONTINUOUSLY REINFORCED METAL MATRIX COMPOSITE USING – DESIGN OF EXPERIMENT

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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 the 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 it's composite. A mathematical model was developed to determine the wear rate of the test samples.

Keywords: *Yield, Dry Sliding Wear, Design of Experiment and ANOVA.*

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 are increasing [1,2].

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 [3].

MMCs generally posses superior wear resistance compared with unreinforced Aluminum alloy. A lot of researches on the dry sliding wear behavior of MMCs had been reported [4,5,6,7,8]. Tribological behavior of materials depends on many factors such as properties of material combinations, experimental condition and type of wear tester. Miyajima et al.[9] 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 , Al2O3-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., [10] 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., [11] 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., [12] 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., [13] 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., [14] 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., [15] adopted Statistical-approach to optimize the heat – treatment of Alumina

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reinforced aluminum alloy composites. 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 solutionzing time (6h) and aging temperature (160° C) for the both the 10 and 20 % alumina composites respectively. Hariharan et.al., [16] adopted Taguchi technique for optimization of heat treatment factors using Design of experiment.

This study is carried out to know the effect of Titanium dioxide (TiO2) 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 its composite material.

2. Design of Experiment

Design of experiment is a important engineering tool for improving a manufacturing process. It also has extensive application in the development of new processes or material. Application of these techniques early in process development can result in improved yield, reduced variability and closer conformance to nominal value, 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.

3. Experimental Procedure

3.1 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.,[17]. Both Aluminum alloy and composite specimen were subjected to T-6 heat treatment standards.

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

3.2. Selection of orthogonal array

In the present study, the experiments were conducted as per the Standard L_9 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_9 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 gram with the objective of 'smaller is the better' type of quality characteristic.

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	L	N	39.24	49.05	58.86
Sliding Distance	D	m	500	1000	1500

3.3 Experimental setup

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., [18]. 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. 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 L9 shown in Table 3.

Table: 3 Orthogonal Array (L_9) of Taguchi for Wear Test & Results

L_9	S	L	D	Wear rate of Al alloy (Gram)	Wear rate of Composite material (Gram)
1	1.674	39.24	500	0.0060	0.0070
2	1.674	49.05	1000	0.0090	0.0080
3	1.674	58.8	1500	0.0165	0.0150
4	2.09	39.24	1000	0.0120	0.0090
5	2.09	49.0	1500	0.0150	0.0160
6	2.09	58.86	500	0.0012	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

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., [19]. 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 gram. Each experiment was repeated thrice and mean response values were tabulated in Table 3.

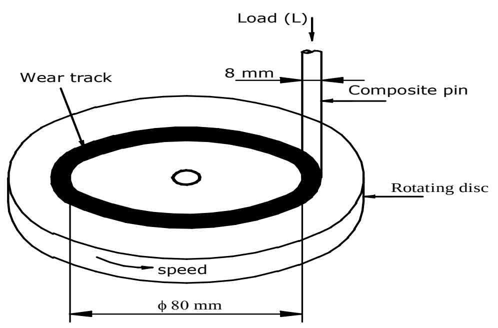

Fig. 1 Schematic Diagram of Wear Test

4. Wear Mechanism

The mechanism of material removal during the wear process of the unreinforced alloy is by plastic deformation and gouging. The improvement in wear resistance of the composite material is attributed to the changes in the wear mechanism induced by the presence of the reinforcing particles. In composite material the wear mechanism is by plastic deformation, gouging and fracture of reinforcing material (TiO2) leading to the formation of a thin layer at the interface, there by providing protection to the matrix material. The layer formed at the surface of the specimen may have high hardness, but at the expense of low fracture toughness.

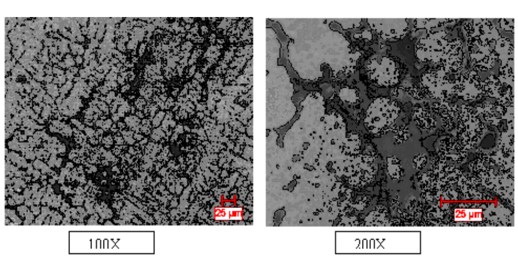

Fig. 2 Optical Micrograph of 4 wt % of TiO_2 Reinforced Aluminium Composite

The sub surface deformed layer beneath the worn surface of MMC pins is composed of a number of distinct layer like mechanically mixed surface (Mms). The Mms layer withstands high stresses without plastic deformation or fracture and is very effective in reducing the wear. Figure 2 shows the optical micrograph of 4 wt % of TiO2 reinforced Al alloy composite.

5. Results and 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.

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

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 4.

Table: 4 S/N Ratios for Al Alloy and Composite Material

L_9 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

The average values of S/N ratios of three parameters at three levels for both Aluminum alloy and composite material are plotted in Figure 3 and 5. It is evident from the figure that, Wear quality characteristic is least, when the process parameters is at, 3rd level of parameter S, 1st level of parameter L and also at 1st level of parameter D. The analysis of means also suggested the same level for minimum dry sliding wear.

Fig. 4 and 6 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 0.0112gram, where as for the composite material it is 0.0101gram**.** This shows that wear resistance of composite material is more than Aluminum alloy.

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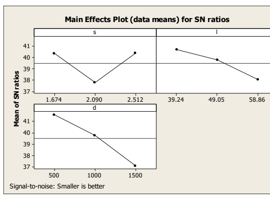

Fig. 3 S/N Ratio of Alumium Alloy

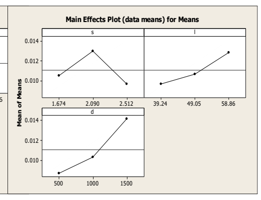

Fig. 4 Analysis of Means for Aluminum Alloy

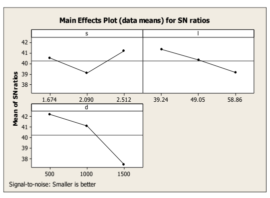

Fig. 5 SN Ratio of Composite Material

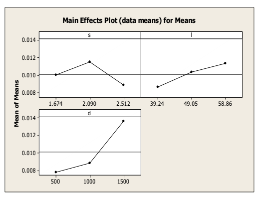

Fig. 6 Analysis of Means for Composite Material

5.1 Analysis of variance

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

Table: 5 ANOVA Test for S/N Ratio for Al Alloy

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	15.351	7.64	0.116	49.11
Error	8	4.019	4.019	2.009			16.58
Total	26	58.978					100

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 5 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 %. The table 6 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 load which as P = 12.61 %.

Table: 6 ANOVA Test for S/N Ratio for Composite Material

Factors	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
S	2	6.812	6.812	3.4065	4.65	0.177	11.54
L	2	7.3724	7.3724	3.6862	5.032	0.166	12.61
D	2	36.9995	36.9995	18.4997	5.26	0.038	68.88
Error	8	1.4649	1.4649	0.732			6.99
Total	26	52.649	52.6496				100

5.2 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,

Wear rate $_{\text{Al alloy}}$ = 0.00391 - 0.00099 X S - 0.000022 X L + 0.000009 X D *(2)*

The regression equation for composite material is

Wear rate $_{\text{Composite}}$ = 0.00168 + 0.00058 X S + 0.000051 X L + 0.000004 X D *(3)*

6. Confirmation Test

The confirmation test was performed for composite material by selecting the levels of parameters as shown in table 7. Each test was conducted twice in order to eliminate the bias if present. The wear rate was calculated using equation 3 and the results obtained were compared with the actual values. The results shows that maximum of 9.54 % error was observed.

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Table: 7 Parameters for Confirmation Wear Test

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	49.0	1400
4	3.00	9.8	1500
5	4.52	29.4	1200

7. 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 0.0112 gram, where as for the composite material it is 0.0101 gram.
4. Wear quality parameter is least, when the process parameters are at 3rd level of parameter S 1st level of parameter L and D.
5. During dry sliding wear test the significant factor is distance.
6. From the mathematical model it is seen that regression coefficient is minimum for composite material when compared to Aluminum alloy.

References

1. *Pradeep Rhotagi (2001), "Cast M.M.C. Past, Present & Future. AFS Transanctions. University of Wisconsi, Milwaukee, Wisconsin. Silver Anniversary Paper, Div.2. 01-25.*
2. *Das S (2004), "Development of Aluminium Alloy Composites for Engineering Applications". Trans. Indian Institute of Met. Vol57 (4), 325-334.*
3. *Surappa M K (2003), "Aluminum Metal Composites". Challenges & opportunities by Sadhana, Vol.28 (1 & 2) Feb/Apr, 319-334.*
4. *Shashidara S M, Mallikarjuna C and Muralidhara (2008), "Stir casting of Al-7075 – Corundum MMC Produced in Co2 Moulds", Journal of Manufacturing Engineering, Vol. 3(1), 122-126*
5. *Rosenberger M R, Forlerer E and Schvezov C E (2009), "Wear Behavior of AA1060 Reinforced with Alumina under Different Loads", Wear, Vol. 266, 356-359.*
6. *Prabhu Swamy N R, Ramesh T and Chandrashekar (2010), "Effect of Heat Treatment on Strength and Abrasive Wear Behavior of Al6061 –Sic Composites", Bull. Mater. Sci., Vol. 33(1),49-54.*
7. *Wlodarczyk –Flingier A and Dobrzeanski Adamiak L A (2008, "Wear Resistance of PM Composite Material Reinforced with the Ti Ceramic Particle", Journal of Achivements in Mat and Manu. Engg., Vol 30(2),147-150.*
8. *Chikanna N, .Sankaran P and Mukunda P G (2008), "Tribological Behavior of Centrifugal Cast Al-Si Composite". Journal of manufacturing engineering. Vol.1 (1), 40-44.*
9. *Miyajima T and Iwai Y (2003), "Effect of Reinforcement on Sliding Wears Behavior of Aluminum Metal Matrix Composite", Wear, Vol.255, 606 – 616.*
10. *Basavarajappa S, Chandramohan G, and Subramanian chandrasekar R (2006), "Dry Sliding Wear Behavior of Al 2219 / SiC Metal Matrix Composites", Materials Science Poland. Vol. 24 (2 /1), 542-546.*
11. *Shipway P H, Kennedy A R and Wilkas A J (1998), "Sliding Wear Behaviour of Al Based Metal Matrix Composites Produced by a Novel Liquid Route", Wear, Vol. 216, 160 – 171.*
12. *Ranganath G, Sharma S C and Krishna M (2001), "Dry Sliding Wear of Garnet Reinforced Zink / Al MMCs", Wear, Vol. 251, 1408 – 1413.*
13. *Acharya S K, Prasad N and Uma – Shankar (2006), "Wear Behaviour of Aluminum Red Mud Composites", IE (I) Journal – MM. Vol.87, Oct 3-6.*
14. *Esteban Fernandez J, Madel rocio Fernandez, Vijande diaz R and Tucho Navarro R (2003), "Abrasive Wear Analysis using Factorial Experimental Design", Wear, Vol.255, 38 – 43.*
15. *Leisk G and Saigal (1992), "A Stastical Approach to the Heat Treatment Optimization of Al-Al2o3 Particulate Composite", Journal of Materials Engineering and Performance, Vol. 1(1) Feb 45.*
16. *Hariharan P, Ratna Kumari G N, Suresh Babu A, Rajadurai D and Mohanial (2008), "Optimization of Heat Treatment Factors for Improved Wear Resistance and Impact Strength of Bearing Steel using L16 OA", Journal of Manufacturing Engineering. Vol. 1(1), 45-50.*
17. *Mahindra K V and Radhakrishna K (2007), "Fabrication of Al – 4.5 % Cu Alloy with Fly Ash MMC and its Characterization," Material Science – Poland. Vol/ 25(1), 57 – 67.*
18. *Ramesh C S, Seshadri S K and Iyer K J L (1991), "A Survey of Aspects of Wear of Metals", Indian Journal of Technology. Vol. 29, 179 -185.*
19. *Uyyuru R K, Surappa M K and Brusethaug S (2006), "Effect of Reinforcement Volume Fraction and Size Distribution on the Tribological Behavior of Al – Composite", Wear, Vol. 260, 1248 – 1255.*

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