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SAND ABRASIVE WEAR BEHAVIOR OF ALUMINIUM-BERYL METAL MATRIX COMPOSITE USING TAGUCHI TECHNIQUE

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ABSTRACT

In the present investigation, the influence of wear parameters like grain size, sliding distance, applied load and wt.% of reinforcement on the abrasive wear of Aluminium-Beryl composite materials. Sand abrasive wear tester was used to conduct the abrasive wear test of the composite materials. An L_{27} orthogonal array, signal-to-noise ratio and ANOVA were employed to investigate the wear behavior of Aluminium-Beryl composites. The objective is to establish a mathematical correlation between abrasive wear of the composites with wear parameters using multiple linear regression model. Abrasive grain size shows the greatest effect on abrasive wear followed by sliding distance and other parameters.

KEYWORDS: MMC's, Sand abrasive wear, L_{27} orthogonal array, ANOVA, Beryl.

INTRODUCTION

Aluminium and its alloys are suitable materials in most of the industrial applications in which light weight is a priority. Since a larger volume can be obtained for a particular weight, besides providing rigidity, energy losses and vibrations are reduced due to its light weight in machine components working at high speeds. One of the methods to increase the wear strength in these materials used in the production of machine parts exposed to friction is to reinforce them with ceramic particles [1]. Metal matrix composite materials reinforced with ceramic particles have an important place in the production of high wear strength materials due to the inclusion of hard ceramic particles. The hardness, stiffness and wearing properties were significantly increases and abrasive wear strength of the composite materials obtained by adding hard ceramic particles such as Al_2O_3, SiC, SiO_2, etc., to aluminum and its alloys of which mechanical and corrosion properties are improved in large quantity [2].

Leisk et al., [3] adopted statistical approach to optimize the heat treatment of alumina reinforced aluminium alloy composites. The effect of heat treatment variables solutionizing time, ageing time and ageing temperature on the yield strength and ultimate tensile strength (UTS) of the aluminium metal matrix composites. The heat treatment was carried out according to orthogonal array. The highest yield strength and UTS are obtained for the aging time (6h) and ageing temperature (160°C) for the composites. The statistical results are inline with the experimental results.

Esteban Fernandez et al., [4] 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 has a much lower effect and the environment was found to have minor effect. Basavarajappa S. et al., was evaluated the factors affecting the wear parameters experimentally and theoretically according to the process parameters and observed that SiC and graphite reinforcement increases the wear resistance [5].

Sahin Y. developed Al2014-15% SiC composite material by powder metallurgy method and while evaluating the adhesive wear resistance of the composite material, he used the Taguchi design and investigated the factors affecting the wear resistance of the composite experimentally and theoretically according to L_9 orthogonal array and also studied according to L_{16} orthogonal array [6-8]. The Taguchi technique is used by many researchers to study the wear behavior of the aluminium metal matrix composites [9, 10, 12, 13, 17]. In this present investigation, the abrasive wear behavior of the Aluminium/Beryl composites were studied experimentally, the Taguchi technique is employed to study the factors affecting the wear resistance of the composite and analyzed with the lowest is the best control characteristic theoretically according to L_{27} orthogonal array and the confirmation tests were conducted to verify the experimental results.

EXPERIMENTAL DETAILS

Material selection

The matrix material selected was commercially available pure aluminium. The chemical composition of the matrix material is given in the Table 1. Beryl, which is naturally occurring and chemically having beryllium–alumina–silicate $[Be_3Al_2(SiO_3)_6]$ was used as the reinforcement material. The sizes of particles used were of 45-65 µm. They have a density of 2760 kg/m^3, having hardness of 7.5 to 8.5 on Mho's scale and it has hexagonal crystal structure. The chemical composition of beryl particles used for development of the composite is mentioned in the Table 2.

Table 1. Composition of Aluminium (wt. %)

Al	Cu	Fe	Mg	Mn	Si	Ni	Zn
99.7	0.05	0.09	0.05	0.01	0.08	0.01	0.01

Table 2. Composition of Reinforcement (wt. %)

SiO_2	Al_2O_3	BeO	Fe_2O_3	CaO	MgO
68.0	16.7	12.0	1.91	0.86	0.001

Preparation of the composite

The Aluminium-Beryl composites were fabricated by liquid metallurgy method. This method is the most economical to fabricate composites materials. The matrix material was first superheated above its melting temperature and preheated reinforcement particles were added into molten metal. The molten metal was stirred for duration of 8 min using a mechanical stirrer and speed of the stirrer was maintained at 350 rpm. The melt at 750°C was poured into the preheated cast iron molds. Many researchers are used this method for preparation of composite material [9, 10, 12, 13, 16, 17]. The castings were tested to know the common casting defects using ultrasonic flaw detector.

Testing of composites

The Sand Abrasion Tester was used to investigate the abrasive wear characteristics of the aluminium and its composites. The abrasive wear test specimens of size 75 x 24 x 8 mm were made flat on either surface by milling. A surface roughness of 2–3 µm was maintained. The tests were carried out as per ASTM G-65 standards. The sand abrasion tester consisted of a rubber beading around the circumferential periphery of the wheel. The specimen was suitably held by means of specimen holder against the rubber wheel by means of lever arrangement. The wheel rotated and the pressure was applied by means of load suspended over the lever arrangement. Sand held in the top of the reservoir was allowed to fall through a nozzle at a constant flow rate between the rotating rubber wheel and the specimen. The rubbing of the abrasive sand particles against the specimen leads to the physical wear of the specimens. The initial and final weights of the specimen before and after the wear tests were measured. The difference of the two weights determines the weight loss which was an indicator of abrasive wear resistance [11-13, 17]. The specimens were tested as per the procedure

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reported by Deuis R.L. et al., [14] and Sahin, Y [6]. The each experiment was repeated thrice and mean response values were tabulated in Table 4.

Table 3. Process parameters with their values at three levels

Factors	Units	Level 1	Level 2	Level 3
Sliding distance (D)	m	1500	2500	3500
Load (L)	N	19.62	29.43	39.24
Grain Size (Z)	microns	50	60	70
Reinforcement (R)	Wt.%	2	4	6

Table 4. Orthogonal array (L_{27}) of Taguchi, for wear test and S/N ratios of composite material

L_9 Test	Sliding distance D (m)	Load L (N)	Grain size (microns)	Wt.% of Reinforcement content	*Wear of Composite (gm)	S/N ratio for Composite material (db)
1	1500	19.62	50	2	0.37	8.63597
2	1500	19.62	60	4	0.59	4.58296
3	1500	19.62	70	6	0.65	3.74173
4	1500	29.43	50	4	0.61	4.29340
5	1500	29.43	60	6	0.69	3.22302
6	1500	29.43	70	2	0.98	0.17548
7	1500	39.24	50	6	0.54	5.35212
8	1500	39.24	60	2	0.97	0.26457
9	1500	39.24	70	4	0.99	0.08730
10	2500	19.62	50	4	0.64	3.87640
11	2500	19.62	60	6	0.76	2.38373
12	2500	19.62	70	2	0.97	0.26457
13	2500	29.43	50	6	0.67	3.47850
14	2500	29.43	60	2	0.68	3.34982
15	2500	29.43	70	4	0.96	0.35458
16	2500	39.24	50	2	0.70	3.09804
17	2500	39.24	60	4	0.86	1.31003
18	2500	39.24	70	6	0.96	0.35458
19	3500	19.62	50	6	0.64	3.87640
20	3500	19.62	60	2	0.99	0.08730
21	3500	19.62	70	4	0.97	0.26457
22	3500	29.43	50	2	0.57	4.88250
23	3500	29.43	60	4	0.91	0.81917
24	3500	29.43	70	6	0.85	1.41162
25	3500	39.24	50	4	0.98	0.17548
26	3500	39.24	60	6	0.94	0.53744
27	3500	39.24	70	2	0.99	0.08730

The experiments were conducted as per the standard L_{27} orthogonal array. The wear parameters selected for the experiment were grain size in microns, load in N, sliding distance in m and wt.% of reinforcement. The each parameter was assigned three levels which are shown in Table 3. The standard L_{27} orthogonal array consists of 27 tests as shown in Table 4. The first column is assigned by sliding distance, second column was assigned by applied load, third column was assigned by grain size and fourth column was assigned by wt. % of reinforcement. The response studied was abrasive wear in terms of weight loss with the objective of 'Smaller is the better' type of quality characteristic.

RESULTS AND DISCUSSION

S/N Ratio Analysis

The value of the overall loss function is further transformed into a signal-to-noise (S/N) ratio. Usually, there are three categories of the quality characteristic in the analysis of the S/N ratio, i.e., the lower-the-better, the larger-the-better and the more-nominal-the-better. The S/N ratio for each level of process parameters is computed based on the S/N analysis. The influence of control parameters such as sliding distance (D), applied load (L), grain size (Z) and wt.% of reinforcement (R) on abrasive wear has been evaluated using S/N ratio response analysis. Process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance. The wear quality characteristic selected was "smaller is the better type" and same type of response was used for signal to noise ratio which is given below Table 4. The S/N ratio response was analyzed using the equation (1) for all 27 tests.

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

Analysis of Variance

The analysis of variance was used to analyze the influence of wear parameters and establishes the relative significances of factors in terms of their percentage contribution to the response. This analysis was carried out for a level of significance of 5% (i.e., the level of confidence 95%). Table 5 shows the ANOVA results of Aluminium-Beryl composites. We can observe from the ANOVA Table 5, that the sliding distance, applied load, grain size and wt.% of reinforcement have the influence on abrasive wear of the Aluminium/beryl composite materials. The last column of the Table 5 indicates the percentage of contribution of each factor on the total variation indicating their degree of influence on the result. It is observed from the ANOVA table that the grain size (P=42.85%) and the sliding distance (P=14.13%) have great influence on the wear of the composite materials while the applied load has minimum contribution (P=11.36%). The effect of the reinforcement content in the matrix was influencing minimum (2.44%), which indicates that there was appreciable increase in the wear resistance by increasing the reinforcement content. The interaction between sliding distance and applied load (P=11.98%), sliding distance and grain size (P=5.39%) and sliding distance and wt.% of reinforcement (1.13%). The pooled error associated in the ANOVA table was approximately about 6.59%. This approach gives the variation of means and variance to absolute values considered in the experiment and not the unit value of the variable.

Multiple Linear Regression Model

A multiple linear regression analysis attempts to model the relationship between two or more predictor variables and a response variable by fitting a linear equation to the observed data [15]. In order to establish the correlation between the wear parameters: sliding distance, load, grain size wt.% of reinforcement and the abrasive wear of the composites the multiple linear regression model was used [16, 17, 18].The regression equation for wear of the composite.

$$W_{composite} = -0.442 + 0.000081\,D + 0.00765\,L + 0.0144\,Z - 0.0144\,R \quad \text{.... (2)}$$

The above equation is obtained by using statistical software "MINITAB R14" after substituting the recorded values of the variables. The positive value of the coefficients suggests that the abrasive wear of composite material increases with their associated variables. Whereas the negative value of the coefficients suggests that the abrasive wear of the composite material will decreases with the increase in associated variables. The magnitude of the variables indicates the weightage of each of these factors. It is observed from the Eq.(2) that the grain size, applied load and sliding distance have more effect on abrasive wear of the composite material for the tested range of the variables. The important factor affecting the abrasive wear is the wt.% of reinforcement and the co-efficient associated with it is negative. This suggests that the abrasive wear decreases with increasing in the wt.% of reinforcement for the tested range. The positive load co-efficient indicates that the applied load increases the penetration ability of the fractured particles which will increase the wear rate. The co-efficient of sliding distance is positive which indicates the increase in wear rate with increasing the sliding distance. The co-efficient of grain size is positive which indicates the increase in wear rate with increasing the abrasive grain size which has greatest effect on abrasion. Wear loss obviously increases as grain size increases due cating action.

Table 5. Analysis of Variance results for S/N ratio of composite material

Source	DF	Seq SS	Adj SS	Adj MS	F	Percentage contribution (P)
D	2	19.004	19.004	9.502	9.07	14.13
L	2	15.490	15.490	7.745	7.40	11.36
Z	2	55.500	55.500	27.75	26.5	42.85
R	2	4.150	4.150	2.075	1.98	2.44
D*L	4	16.277	16.277	4.069	3.89	11.98
D*Z	4	7.898	7.898	1.974	1.89	5.39
D*R	4	2.483	2.483	0.621	0.59	1.13
Error	35	6.283	6.283	1.047		6.59
Total	53	127.085				100

Confirmation Test

The confirmation test was performed by selecting the set of parameters as shown Table 6. The Table 7 shows the results obtained using regression equation (Equation (2)) and the experimental results. Both the results were compared and observed that the calculated error varies from

4.88% to 8.22%. Therefore the multiple linear regression equation evaluates the abrasive wear of the composites with reasonable degree of approximation. [16, 17]

Table 6. Parameters used in the confirmation wear test

Test	Sliding distance (m)	Load (N)	Grain size (microns)	Wt.% of Reinforcement
1	2700	19.62	45	2
2	5000	29.43	55	6
3	3500	39.24	68	4

Table 7. Confirmation wear test results

Test	Expt.	Reg. model (Eq. (2))	% of Error
1	0.574	0.546	4.88
2	0.956	0.894	6.49
3	0.876	0.948	8.22

CONCLUSION

Abrasive grain size exerted the greatest effect on abrasive wear, followed by sliding distance and load applied had a lower effect. The analysis of variance shows that the grain size (42.85%) and sliding distance (14.13%) have significant influence on the wear of the composite material and the applied load has minimum contribution (11.36%).The interaction between sliding distance and applied load (11.98%), sliding distance and grain size (5.39%) and other interactions will influence very less. The pooled error associated with the ANOVA analysis was 6.59 % for the factors and the correlation between the wear parameters was obtained by multiple linear regression models. The confirmation tests showed that error associated with wear of the composite varies from 4.88% to 8.22%.

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