The Optimization of Sliding Wear Behaviour of Aluminium/$Be_3Al_2(SiO_3)_6$ Composite using Taguchi Approach

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ABSTRACT

In this investigation, an attempt was made to study the influence of wear parameters like sliding speed, applied load, sliding distance and wt.% of reinforcement on the sliding wear of aluminium/ $Be_3Al_2(SiO_3)_6$ (Beryl) composites. A Pin-on-disc apparatus was used to conduct the sliding wear tests. The Taguchi approach was employed to acquire data in controlled way to analyze the wear behavior of the composites. An orthogonal array, signal-to-noise ratio and analysis of variance were employed to investigate the wear behavior of the composite. The mathematical model was obtained to determine the wear of the composite and confirmation tests were conducted to verify the experimental results.

Key Words: **Beryl, MMC's, Wear, Orthogonal array, ANOVA, Taguchi method.**

1. INTRODUCTION

Aluminium and its alloys are widely used in automobile, aerospace and mineral processing applications, because of their excellent properties like low density and high thermal conductivity. To enhance the mechanical and tribological properties, hard reinforcement phase such as hard ceramic particles or fibers or whiskers are uniformly distributed in the soft matrix phase [1, 2]. As a result of reinforcement phase, the modulus and strength of the composites were increased while the ductility decreases [3, 4]. These materials have emerged as an important class of advanced materials giving engineers the opportunity to tailor the material properties according to their needs. Essentially these materials differ from the conventional engineering materials from the viewpoint of homogeneity [5]. The particulate reinforced composites can be prepared by injecting the reinforcing particles into liquid matrix through liquid metallurgy route and this casting method is preferred because of less expensive and amenable to mass production [6]. The presence of hard reinforcement phases has endowed these composites with good tribological (friction and wear) characteristics. These properties along with good specific strength, modulus makes them good candidate materials for many engineering situations where sliding contact is expected.

An extensive review work on dry sliding wear characteristics of aluminium alloy based composites was undertaken by A.P. Sannino et al., [7]. In this present investigation, an attempt was made to find the influence of wear parameters on dry sliding wear and to establish correlation between sliding speed, applied load, sliding distance, Wt.% of reinforcement and combined effect of these parameters on dry sliding wear of the composite.

2. TAGUCHI TECHNIQUE

The Taguchi technique is a powerful design of experiment 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 and for the design of high quality systems [8]. This method was been successfully used by many researchers in the study of wear behaviour of aluminium metal matrix composites [9]. Taguchi creates a standard orthogonal array to accommodate the effect of several factors on the target value and defines the plan of experiment. The experimental results were analyzed using ANOVA to study the influence of parameters [10].

3. EXPERIMENTAL DETAILS

3.1 Material: The matrix material selected was commercially available pure aluminium. The chemical composition of the matrix material is given in the table 1. The reinforcement material used was 'Beryl' particles and its chemical formula was $Be_3Al_2(SiO_3)_6$. The chemical composition of the reinforcement material is given 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

3.2 Preparation of the composite: The Aluminium/ $Be_3Al_2(SiO_3)_6$ composites were fabricated by liquid metallurgy method by varying the reinforcement content from 2Wt.% to 6Wt.% in terms of 2 . This method is the most economical to fabricate composite materials. The matrix was first superheated to 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 300 rpm. The melt at 750°C was poured into the preheated cast iron molds. The castings were tested to know the common casting defects using ultrasonic flaw detector.

3.3 Testing of composites: A pin-on-disc test apparatus was used to investigate the dry sliding wear characteristics of the composites. The wear specimens were machined to pin size of diameter 8 mm and height 30 mm and then polished. The initial weight of the specimen was measured in a single pan electronic weighing machine with a least count of 0.1mg. During the test the pin was pressed against the rotating counter part EN32 steel disc of hardness 60HRC by applying the load. After running through a fixed sliding distance, the specimens were removed, cleaned with acetone, dried and weighed to determine the weight loss due to wear. The differences in the weight measured before and after the test gives the weight loss due to wear of the specimen.

The each experiment was repeated thrice and mean response values were tabulated in table 4. The experiments were conducted as per the standard L_{27} orthogonal array. The wear parameters selected for the experiment were sliding speed in m/s, applied load in N, sliding distance in m and wt.% of reinforcement. The each parameter was assigned three levels which are shown in table 3.

Table 3 Process parameters with their values at three levels

Factors	units	Level 1	Level 2	Level 3
Sliding speed (S)	**m/s**	1.571	2.095	2.618
Load (L)	**N**	29.43	39.24	49.05
Sliding distance (D)	**m**	600	1200	1800
Reinforcement (R)	**wt.%**	2	4	6

The standard L_{27} orthogonal array consists of 27 tests as shown in the table 4. The second column is assigned by sliding speed, third column was assigned by applied load, fourth column was assigned by sliding distance and fifth column was assigned by wt.% of reinforcement. The response studied was wear in terms of milligrams with the objective of 'Smaller is the better' type of quality characteristic.

Table: 4 Orthogonal array (L_{27}) of Taguchi for wear test and SN ratio's of composite material

L_9 Test	Sliding speed S (m/s)	Load L (N)	Sliding distance D (m)	Wt.% of Reinforcement content	*Wear of Composite (mg)	SN ratio for Composite material (db)
1	1.571	29.43	600	2	0.0059	44.5830
2	1.571	29.43	1200	4	0.0093	40.6303
3	1.571	29.43	1800	6	0.0116	38.7108
4	1.571	39.24	600	4	0.0096	40.3546
5	1.571	39.24	1200	6	0.0126	37.9926
6	1.571	39.24	1800	2	0.0167	35.5457
7	1.571	49.05	600	6	0.0098	40.1755
8	1.571	49.05	1200	2	0.0159	35.9721
9	1.571	49.05	1800	4	0.0178	34.9916
10	2.095	29.43	600	4	0.0101	39.9136
11	2.095	29.43	1200	6	0.0120	38.4164
12	2.095	29.43	1800	2	0.0154	36.2496
13	2.095	39.24	600	6	0.0106	39.4939
14	2.095	39.24	1200	2	0.0098	40.1755
15	2.095	39.24	1800	4	0.0152	36.3631
16	2.095	49.05	600	2	0.0111	39.0935
17	2.095	49.05	1200	4	0.0136	37.3292
18	2.095	49.05	1800	6	0.0151	36.4205
19	2.618	29.43	600	6	0.0096	40.3546
20	2.618	29.43	1200	2	0.0169	35.4423
21	2.618	29.43	1800	4	0.0153	36.3062
22	2.618	39.24	600	2	0.0099	40.0873
23	2.618	39.24	1200	4	0.0143	36.8933
24	2.618	39.24	1800	6	0.0134	37.4579

25	2.618	49.05	600	4	0.0161	35.8635
26	2.618	49.05	1200	6	0.0156	36.1375
27	2.618	49.05	1800	2	0.0279	31.0879

* Wear of the composite materials is in terms of weight loss.

4. RESULTS AND DISCUSSION

4.1 S/N Ratio Analysis: The influence of control parameters such as sliding speed (S), applied load (L), sliding distance (D) and wt.% of reinforcement content (R) on wear of composite materials were evaluated using S/N ratio response analysis. Process parameter settings with the highest S/N ratio will always yield the optimum quality with minimum variance [11]. The sliding wear quality characteristic selected was "Smaller is the better type". The S/N ratio response was analyzed using the equation (1) for all 27 tests.

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

4.2 Analysis of Variance: The purpose of analysis of variance (ANOVA) is to investigate the percentage contribution of variance over the response parameter and to find the influence of wear parameters. The ANOVA is also needed for estimating the error of variance and variance of the prediction error. This analysis was carried out for a level of significance of 5% (i.e., the level of confidence 95%). The table 5 shows analysis of variance for S/N ratios of the composite material.

Table: 5 Analysis of Variance results for SN ratio of composite material

Source	DF	Seq SS	Adj SS	Adj MS	F	Percentage contribution
S	2	22.032	22.032	11.016	9.75	11.81
L	2	33.034	33.034	16.517	14.63	19.03
D	2	75.656	75.656	37.828	33.50	42.11
R	2	8.385	8.385	4.1925	3.71	4.1
S*L	4	6.599	6.599	1.65	1.46	3.1
S*D	4	13.182	13.182	3.393	3.01	6.82
S*R	4	6.720	6.720	1.68	1.49	3.1
L*D	4	9.616	9.616	4.808	2.56	4.81
Error	35	6.776	6.776	1.129		5.11
Total	53	176.967				100

Form the table 5, it is observed that the sliding speed, applied load, sliding distance and wt.% of reinforcement have the influence on wear of composite material. The last column of the table 5 indicates the percentage contribution of each factor on the total variation indicating their degree of influence on the result. The interaction between the above factors does not have significant influence on the wear of the composite material. It is observed from the ANOVA table that the speed (11.81%), applied load (19.03%), sliding distance (42.11%) have great influence on the wear**.** The effect of the reinforcement content in the matrix was influencing minimum (4.1%), which indicates that there was appreciable increase in the wear resistance by increasing the reinforcement content. However, the interaction between speed and applied load (3.1%), speed and sliding distance (6.82%), speed and reinforcement (3.1%) and Load and sliding distance (4.81%). The pooled error associated in the ANOVA table was approximately about 5.11%. This approach gives the variation of means and variance to absolute values considered in the experiment and not the unit value of the variable.

4.3 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 [12]. In order to establish the correlation between the wear parameters: sliding speed, applied load, sliding distance and the wear. The multiple linear regression model was used [13].

The regression equation for composite material

$W_{Composite}$ = - 0.00548 + 0.00316 S + 0.000208 L + 0.000005 D - 0.000533 R …………. (2)

4.4 Confirmation Test: The confirmation test was performed for composite material by selecting the set of parameters as shown in 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 5.43% to 9.84%. The mathematical model obtained from the multiple linear regression models evaluates the wear of the composite materials with reasonable degree of approximation.

TABLE 6 Parameters used in the confirmation wear test

Test	Sliding speed (m/s)	Load (N)	Sliding distance (m)	Wt.% of Reinforcement
1	1.58	19.6	800	2
2	2.59	29.4	1250	4
3	3.09	39.2	1450	6

TABLE 7 Confirmation wear test and comparison with regression model

Test	Expt.	Reg. model (Eq. (2))	% of Error
1	0.0092	0.0087	5.43
2	0.0183	0.0172	6.01
3	0.0254	0.0229	9.84

5. CONCLUSION

Based on the above analysis the following conclusions are drawn from this present study.

1. The DOE technique was successfully used to study the dry sliding wear of aluminium/$Be_3Al_2(SiO_3)_6$ (Beryl) composite material.
2. The analysis of variance shows that the sliding distance is the wear factor that has the highest statistical influence on the dry sliding wear of the composites (42.11%), the applied load (19.03%), sliding speed (11.81%) and reinforcement (4.1%), the interaction of sliding speed and sliding distance will contribute (6.82%) and the applied load and sliding distance will contribute (4.81%) and other interactions will influence very less.
3. The pooled error associated with the ANOVA analysis was 5.11 % for the factors and the correlation between the wear parameters was obtained by multiple linear regressions model.
4. The conformation tests showed that error associated with wear of the composite varies from 5.52% to 9.8%.

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