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DRY SLIDING WEAR STUDIES ON HYBRID MMC'S – A TAGUCHI TECHNIQUE

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ABSTRACT

An attempt has been made to study the influence of wear parameters like applied load, sliding speed, percentage of reinforcement content and sliding distance on the dry sliding wear of the composites. A plan of experiments, based on the techniques of Taguchi, was performed to acquire data in controlled way. An orthogonal array and the analysis of variance were employed to investigate the wear behavior. The objective is to establish a correlation between dry sliding wear behavior of hybrid composites with wear parameters. These correlations were obtained by multiple regressions. Finally, conformation tests were done to make a comparison between the experimental results foreseen from the mentioned correlations.

Keywords: Metal matrix composites; Wear; Taguchi's techniques; orthogonal array; Analysis of variance.

1. INTRODUCTION

Discontinuous reinforced aluminium metal matrix composites are a class of composite materials which are having desirable properties, which include low density, high specific stiffness, high specific strength, controlled co-efficient of thermal expansion, increased fatigue resistance, superior dimensional stability at elevated temperatures.[1] The most commonly employed metal matrix composite system consists of aluminium alloy reinforced with hard ceramic particles usually silicon carbide, alumina,[2,3] and soft particles usually graphite, talc etc.[4,5] These materials have shown to have different strengthening mechanisms when compared to conventional materials or continuous reinforced composites.[6] Thus much research, both on experimental and analytical, has been performed to gain a better understanding of mechanical behavior of these materials and their excellent wear resistance. With continual development in fabrication technique, more MMC's have been found to be suitable to replace some of the conventional metallic monolithic alloys such as the various grades of aluminium alloys in application, where light weight and energy saving are important design considerations. The presence of hard reinforcement phases, particulates, fibers or whiskers 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] and abrasive wear behavior wears by R.L.Deuis, et. al,[8]. In their study and discussion, the effect of reinforcement volume fraction, reinforcement size, sliding distance, applied load, sliding speed, hardness of the counter face and properties of the reinforcement phase, which influences the dry sliding wear behavior of this group of composites are examined in greater detail. Graphite is one of the most important solid lubricants, which is used frequently. Several studies have been focused on application of aluminium /graphite composites [9-11]. However the main limitation in using graphite as a solid lubricant is the resulting loss in the strength of the whole composite.[9] Therefore in this study, SiCp reinforcement is added to the

Al/Graphite composite to form stronger hybrid Al/SiCp-Graphite composites[11] and to establish the influence of sliding speed, load, sliding distance and percentage reinforcement on wear of the composite

2. TAGUCHI TECHNIQUE

The Taguchi approach to experimentation provides an orderly way to collect, analyze, and interpret data to satisfy the objectives of the study. By using these methods, in the design of experiment, one can obtain the maximum amount of information for the amount of experimentation used. This is accomplished by the efficient use of experimental runs to the combinations of variables studied. 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. The most important stage in the plan of experiments is selection of factors. 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 are analyzed using analysis of means and variance to study the influence of factors.

3. EXPERIMENTAL PROCEDURE

3.1 MATERIALS

Aluminium alloy Al2219 was used as matrix material and its chemical composition was as shown in the table 1. The silicon carbide particles of size 25 microns and Graphite of average particles size 45 microns were used as the reinforcement materials. The composites were fabricated with 0-15 weight percentage of the SiC particles in steps of 5 weight percent and a fixed quantity of 3 weight percent of graphite.

3.2 PROCESSING OF COMPOSITE

A liquid metallurgy method was used to produce cast composites with better wettability and particle distribution. The Al 2219 alloy, which was in the form of bars, was cut into small pieces to accommodate into the silica crucible. The preheated calculated quantity of matrix material was fed into the crucible. The temperature was raised above the liquidus temperature of the aluminium alloy and then reduced slowly below liquidus temperature of the matrix material such that the melt was kept between the solidus and liquidus temperature (semi liquid state). The next step is addition the pre-heated blended mixtures of SiCp and Graphite particles into the semi liquid melt and manual mixing has to be initiated. Blending of graphite and silicon carbide particles helps in uniform distribution in the composite and SiC particles were acts as carriers for the graphite. After sufficient manual mixing, the melt has to be heated again to above liquidus temperature, at this stage stirring was carried out for above five minutes at an average stirring speed rate of 300-350 rpm. The slurry was then poured into a preheated cast ion permanent mould.

3.3. EXPERIMENTAL SETUP AND PROCEDURE

A pin- on- disc test apparatus was used to investigate the dry sliding wear characteristics of the composite. The wear specimen (pin) size of diameter 10 mm and height 30 mm was cut from ascast samples machined and then polished metalographically. The initial weight of the specimen was measured in a single pan electronic weighing machine with least count of 0.1mg. During the test the pin was pressed against the counter part rotating against EN32 steel disc with hardness 65HRC 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 difference in the weight measured before and after test gives the wear of the composite specimen. The wear of the composite was studied as a function of the volume percentage of the reinforcement, sliding distance, the applied load and the sliding velocity.

3.4. PLAN OF EXPERIMENTS

The experiments were conduct as per the standard orthogonal array. The selection of the orthogonal array is based on the condition that the degrees of freedom for the orthogonal array should be greater than or at least equal sum to those of wear parameters. In the present investigation an L27 orthogonal array was chosen, which has 27 rows and 13 columns as shown in Table 2. The wear parameter chosen for the experiment are (i) sliding speed (ii) load (iii) sliding distance (iv) weight percentage reinforcement of SiCp. Table 3, indicates the factors and their level. The experiment consists of 27 tests (each row in the L27 orthogonal array) and the columns were assigned with parameters.

The first column was assigned to sliding speed (S), second column was assigned to load (L), fifth column was assigned to sliding distance (D) and eighth column was assigned to weight percentage reinforcement(R) and the remaining columns were assigned to their interactions. The response to be studied was the wear with the objective as smaller the better. The experiments were conducted as per the orthogonal array with level of parameters given in each array row. The wear test results were subject to the analysis of variance.

4. EXPERIMENTAL RESULTS, DATA ANALYSIS AND DISCUSSION

The plan of tests was developed with the aim of relating the influence of sliding speed (S), load (L), sliding distance (D) and percentage of SiCp reinforcement with constant 3 % of graphite with the wear of the composite. On conducting the experiment as per orthogonal array, the wear result for various combinations of parameters was obtained and was shown in table 4.

4.1. ANALYSIS OF VARIANCE

The use of ANOVA is to analyze the influence of wear parameters like (i) sliding speed (ii) load (iii) sliding distance (iv) weight percentage reinforcement of SiCp and graphite on the tribological performance character - wear. This analysis was carried out for a level of significance of 5% (i.e., the level of confidence 95%). Table 5 shows the results of ANOVA analysis.

We can observe from the ANOVA analysis (table 5) that the (i) sliding speed (ii) load (iii) sliding distance (iv) weight percentage reinforcement of SiCp and graphite has the influence on wear of the composite. The last column of the table 5 shown indicates the percentage contribution (p) 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. One can observe from the ANOVA table that the speed (p=21.50%), load (p=23.24%), sliding distance (34.35%) have great influence on the wear**.** The effect of the reinforcement is influencing minimum (p=0.53%), which indicates that there is no appreciable increase in wear by increasing the reinforcement content from 5 weight percent to 15 weight percent. However, the interaction between speed and load (P=6.96%), speed and sliding distance (p=3.5%), speed/reinforcement (1.7%) and other interactions are very minimum and can be neglected. The pooled error associated in the ANOVA table was approximately about 7.2%.

4.2 MULTIPLE LINEAR REGRESSION MODEL

In order to establish the correlation between the wear parameters (i) sliding speed (ii) load (iii) sliding distance (iv) weight percentage reinforcement of SiCp and the wear rate multiple linear regression model was used.

The equation obtained were as follows

$$WR= -1.8535+0.5839 * S + 0.3178* L+0.0047*D-0.2346*R-0.058714*S*L-0.0008*S*D+0.0525 *S*R \text{--}(1)$$

Regression co-efficient (r) = 0.84

4.3. CONFIRMATION TEST

The confirmation test was performed by selecting the set of parameters as shown table 6.

The table 7 shows the results obtained where comparison was carried out between the foreseen values from the model developed in the present work (Equation 1), with the values obtained experimentally. From the analysis of the referred table we can observe that the calculated error is varies from 7.1% to 13.68% for wear. Therefore the multiple regression equation derived above correlate the evaluation of the wear of the composite with the reasonable degree of approximation.

5. CONCLUSION

From the analysis of the results of wear of the metal matrix composites, the following can be concluded from the present study.

1. Taguchi's robust design method can be used to analyze the wear problem of the metal matrix composites as described in this paper.
2. Sliding distance is the wear factor that has the highest physical as well as statistical influence on the wear of the composites (34.35%), the load (23.24), and sliding speed (21.5%). Out of the interactions the sliding speed and load will contribute more (6.96%) ahead of sliding speed and distance (3.57) and other interactions will influence very less.
3. The pooled error associated with the ANOVA is 7.2 % for the factors and the coefficient of regression obtained with the multiple regression value of 0.84 shows that the satisfactory correlation was obtained.
4. The conformation tests showed that error associated with wear of the composite varies from 7.1% to 13.68%.

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TABLES

Table-1: Composition of Al-2219 (weight %)

Si	0.20 max.
Fe	0.30 max
Cu	5.8 to 6.8
Mn	0.20 to 0.40
Mg	0.02 max
Zn	0.10 max
V	0.05 to 0.15
Ti	0.02 to 0.1
Zr	0.1to 0.25
Al	balance

Table 2: Orthogonal array $L_{27}(3^{13})$ of Taguchi

L_{27} (3^{13}) test	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2	2	2	2	2	2
3	1	1	1	1	3	3	3	3	3	3	3	3	3
4	1	2	2	2	1	1	1	2	2	2	3	3	3
5	1	2	2	2	2	2	2	3	3	3	1	1	1
6	1	2	2	2	3	3	3	1	1	1	2	2	2
7	1	3	3	3	1	1	1	3	3	3	2	2	2
8	1	3	3	3	2	2	2	1	1	1	3	3	3
9	1	3	3	3	3	3	3	2	2	2	1	1	1
10	2	1	2	3	1	2	3	1	2	3	1	2	3
11	2	1	2	3	2	3	1	2	3	1	2	3	1
12	2	1	2	3	3	1	2	3	1	2	3	1	2
13	2	2	3	1	1	2	3	2	3	1	3	1	2
14	2	2	3	1	2	3	1	3	1	2	1	2	3
15	2	2	3	1	3	1	2	1	2	3	2	3	1
16	2	3	1	2	1	2	3	3	2	1	2	3	1
17	2	3	1	2	2	3	1	1	2	3	3	1	2
18	2	3	1	2	3	1	2	2	3	1	1	2	3
19	3	1	3	2	1	3	2	1	3	2	1	3	2
20	3	1	3	2	2	1	3	2	1	3	2	1	3
21	3	1	3	2	3	2	1	3	2	1	3	2	1
22	3	2	1	3	1	3	2	2	1	3	3	2	1
23	3	2	1	3	2	1	3	3	2	1	1	3	2
24	3	2	1	3	3	2	1	1	3	2	2	1	3
25	3	3	2	1	1	3	2	3	2	1	2	1	3
26	3	3	2	1	2	1	3	1	3	2	3	2	1
27	3	3	2	1	3	2	1	2	1	3	1	3	2

Table 3. Process parameters with their values at three levels.

Leve l	Sliding speed, S (m/sec)	Loa d, L (N)	Sliding distanc e D (m)	Wt. % of SiCp R
1	1.53	9.81	500	5
2	3.06	19.6	1500	10
3	4.59	39.2	2500	15

Table 4.Orthogonal array of Taguchi for wear

Test	Sliding speed S (m/sec)	Load L (N)	Sliding distance D (m)	wt% of Sicp R (%)	Wear WR (mg)
1	1.53	9.81	500	5	2.1
2	1.53	9.81	1500	10	4.7
3	1.53	9.81	2500	15	7.4
4	1.53	19.6	500	10	4.4
5	1.53	19.6	1500	15	10.5
6	1.53	19.6	2500	5	12.5
7	1.53	39.2	500	15	7.2
8	1.53	39.2	1500	5	12.5
9	1.53	39.2	2500	10	14.8
10	3.06	9.81	500	5	2.2
11	3.06	9.81	1500	10	1.7
12	3.06	9.81	2500	15	5.7
13	3.06	19.6	500	10	2.0
14	3.06	19.6	1500	15	3.4
15	3.06	19.6	2500	5	9.0
16	3.06	39.2	500	15	4.7
17	3.06	39.2	1500	5	10.2
18	3.06	39.2	2500	10	10.8
19	4.59	9.81	500	5	3.0
20	4.59	9.81	1500	10	3.1
21	4.59	9.81	2500	15	5.8
22	4.59	19.6	500	10	3.0
23	4.59	19.6	1500	15	3.7
24	4.59	19.6	2500	5	4.9
25	4.59	39.2	500	15	4.6
26	4.59	39.2	1500	5	3.4
27	4.59	39.2	2500	10	6.8

Table 5.ANOVA results

Source of variances	ss	dof	variance	Test F	F,5%	p[a](%)
S	74.45	2	38.725	69.23	3.27	21.50
L	83.64	2	41.820	74.75	3.27	23.24
D	123.08	2	61.540	110.01	3.27	34.35
R	3.0	2	1.500	3.68	3.27	0.53
SL	25.85	2	12.925	23.1	3.27	6.96
SD	13.85	2	6.925	12.38	3.27	3.57
SR	7.28	2	3.640	6.50	3.27	1.7
LD	4.42	2	2.210	3.95	3.27	0.98
LR	3.64	2	1.82.	3.25	3.27	----
Pooled error	19.58	35	0.559	----	3.27	7.20
Total	361.79	53				100

ss = Sum of squares. dof = Degree of freedom.
[a] Percentage of contribution.

Table 6. Parameters used in the Confirmation wear test.

Test	Sliding speed (m/sec)	Load (N)	Sliding distance(m)	% wt SiCp
1	2.29	14.71	750	5
2	3.06	24.5	1750	10
3	4.20	29.43	2250	15

Table 7. Confirmation wear tests and their comparison with regression model.

Test	Expt	Reg Model (Eq.(1))	%error
1	3.2	3.7	13.5
2	7.0	6.5	7.1
3	11.3	9.94	13.68