

Wear Behavior of Al-SiC-Cu Metal Matrix Composites Prepared by Stir Casting and Optimization by using Taguchi Method

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Abstract

Aluminium Metal Matrix composites is a relatively attractive material for automobile, aerospace and other engineering application due to its mechanical and tribological properties. To improve wear resistance and mechanical properties has led to design and selection of newer variants of the composite. The present investigation deal with the study of wear behavior of Al-SiC-Cu MMCs for varying reinforcement content, applied load, sliding speed, and distance. Aluminium MMCs reinforced with three different percentage of reinforcement 3, 6, 9% wt. SiC and 0.5, 0.75, 1.00% wt. Cu prepared by stir casting method. Wear test was performed by using "pin on disk" apparatus. A plan of experiment based on L27 Taguchi orthogonal array is used to acquire the wear data. An analysis of variance is employed to investigate the influence of four controlling parameters, SiC content, Normal load, sliding speed and sliding distance on dry sliding wear of the composites. It is observed that SiC content, sliding speed and normal load significantly affect the dry sliding wear. The optimal combination of the four controlling parameters is also obtained for minimum wear. The microstructure study of worn surface indicates nature of wear to be mostly abrasive.

Keywords: Metal matrix composites; Al-SiC-Cu alloy; Stir casting; Wear; Optimization; SEM

Introduction

Metal Matrix Composites (MMCs) have emerged as a class of material capable of advanced properties, aerospace automotive, electronic, thermal management and wear application. The MMCs have many advantages over the conventional metal including higher specific modules, higher strength to weight ratio, better properties at elevated temperature, and lower coefficients of thermal expansion and better wear resistance. Aluminium composites are widely employed in the aerospace industry, automotive application and structural application. In the present study the composites were prepared by stir casting method reinforced with different weight % of SiC (3, 6 and 9% wt.) and Cu (0.5, 0.75 and 1.00% wt) as a reinforcement material.

Wear behavior of Al-Mg-Cu alloy reinforced with SiC particle were studied by Hassan [1] the comparative study of alloy and alloy reinforced with SiC suggested that wear resistance property of the alloy increased considerably with addition of SiC particle. Another similar study of wear behavior was performed by Kwok and Lim [2]. The composites were prepared by three different powder metallurgy techniques using different matrix metal, reinforcement weight fraction and reinforcement particle size [2]. In this work the wear studies were conducted at varying reinforcement, load, speed and distance. The wear rates are found to decrease with increasing reinforcement wt. %.

Taguchi Method

Taguchi method is one of the important tools based on performing evaluation or experiments to test the sensitivity of a set of response variables (independent or variables) by considering experiments in "orthogonal array" with the aim to attain the optimum setting of the control parameters. Orthogonal arrays provide a best set of well balanced (minimum) experiments. Array indicates the number of row and columns it has, and also the number of level in each of the columns. The number of row of an orthogonal array represents the requisite number of experiments. There are five basic phase, applied in Taguchi experiments design technique. Phase 1- Experiment planning, Phase 2- Design Experiment, Phase 3- Conducting Experiments, Phase 4- Analyzing Results, and Phase 5- Confirming Prediction Results.

The Taguchi method uses a statistical measure of performing called S/N ratio, which is logarithmic function of desired output to serve as objective function for optimization, help in data analysis and the prediction of the optimum results. There are three types of signal-to-noise ratio of common interest for optimization of Static Problem; Smaller-the-better, Larger-the-better, nominal-the-best. They formulate for signal-to-noise ratio are designed so that an experimenter can always select the largest factor level setting to optimize the quality characteristic of an experiment. For the minimization of wear Larger-the-Better needed to be used [3].

Procedure

Processing of composites

For Al-SiC-Cu alloy preparation commercially pure Al (99.99%), SiC (99.95%), Cu (99.95%) and Mg (99.99%) have used. The reason for using these high purity metals was to minimize the amount of impurities. The specific gravity of Al is 2.7 g/cc and melting point of Al 660°C. In this study, pit furnace has used to melt the alloy. Aluminium was first melted. After it had been melted completely, preheated SiC and Cu in 750°C (20 min.) were added to Aluminium (Figure 1). The weight percent of SiC and Cu were 3,6 and 9%. The preparation of this Metal matrix composites is not a very easy task. As there is very sharp specific gravity difference between the SiC particles and the Al alloy there arise a great probability of floating up of SiC particles during mixing. The SiC particles addition was made slightly before the melt gets viscous enough to be solid. The time for each of the addition was about 4-6 minutes. After the addition of particles the melt was stirred

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Figure 1: Stir Casting Furnace.



Figure 2: Specimen after casting.

for some time for the proper distribution of particles inside the matrix. In this process the molten metal was stirred to create a vortex to which SiC particles were added. It was then immediately poured into two metal mould made of mild steel (Figure 2).

Characterization by optical microscope

The micro-structural characterization was performed by an optical microscope. The sample was prepared by polishing with emery paper. After that, it was further polished in a fine grade wheel polisher. Afterwards, when the surface became scratch free, it was cleaned with acetone and investigated under optical microscope.

Rockwell B hardness test

In this study, we have measured Rockwell B hardness for the Al-SiC-Cu alloy and all of the three composites with great care to minimize inaccuracies.

Design of experiment

Design of Experiments" (DOE) refers to experimental methods used to quantify indeterminate measurements of factors and interactions between factors statistically through observance of forced changes made methodically as directed by mathematically systematic tables. Many tribological process parameters can affect the wear behavior of Al-SiC-Cu composites. For current study of wear behavior of Al-SiC-Cu, the control parameters chosen are weight % of reinforcement (wt), applied load (L), sliding speed (S), and sliding distance (D). Table 1 shows the design factors with their levels. Three levels for each parameter are considered.

Based on Taguchi method, an Orthogonal Array (OA) is considered to reduce the number of experiments required to determine the optical wear for Al-SiC-Cu Metal matrix composites [4]. For this experimental purpose L27 array is chosen. The L27 OA has 27 rows corresponding to the number of tests.

Design Factor	Units	Level 1	Level 2	Level 3
Reinforcement (R)	(gram)	3	6	9
Load (L)	(N)	10	20	30
Speed (S)	(m/s)	1.5	2.5	3.5
Distance (D)	(m)	500	1000	1500

Table 1: Design factors with levels.



Figure 3: PIN ON DISK apparatus using wear tests.

Wear Test

The Wear test was performed in a unidirectional pin-on-disk apparatus (Figure 3). It used to measure the wear behavior of Al-SiC-Cu under dry non lubricated condition.

Samples (sizes 10 mm diameter, 20 mm height) are pressed against rotating steel roller (diameter 80mm, thickness). The setup is placed in such a way that the rotating roller serves as the counter face material and stationary plate serves as the test specimen. A 3:2:1 ratio loading lever is used to apply normal load on top specimen. The loading lever is pivoted near the normal load sensor and carries a counter weight at one end while at the other end a loading pan is suspended for placing the dead weight. The wear rate is measured in terms of displacement with the help of linear voltage resistance transducer. The wear displacement sensor allows obtaining direct measurement of the loading lever's deflection, which corresponds to the wear of the specimen plate plus the wear of the counter face. It may be noted here that wear behavior is normally expressed as weight loss while in the present experimental set up, wear is measured in terms of displacement results for wear are compared with weight loss and it shows almost linear relationship for the range of test parameters considered in the present study. The wear tests are carried out as per L27 OA [5].

Microstructure Study

After wear tests Scanning Electron Microscopy (SEM) is done to study the wear tracks of the specimens. The microstructure study is conducted to know the nature of wear using a scanning Electron Microscope in Figure 4a-4c and before wear test SEM is done Figure 4d-4f.

Result and Discussion

The aim of this project is to achieve the minimum wear rate for Al-SiC-Cu Alloy metal matrix composite using Taguchi method. The investigation is carried out using four control parameters weight % of reinforcement, applied load, sliding speed and Sliding distance. Wear depth is taken as system response parameter.

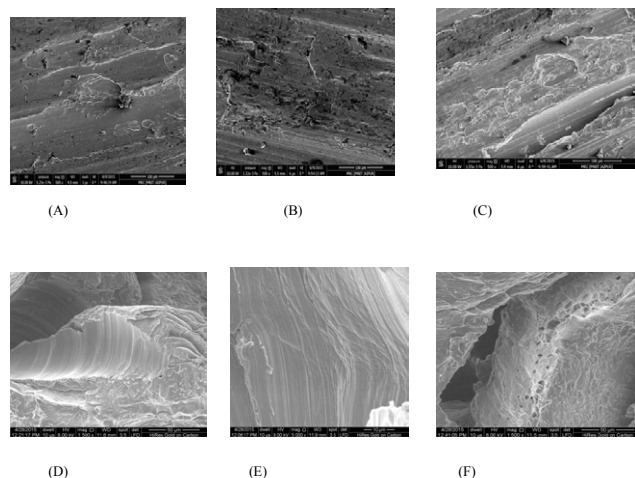


Figure 4: SEM Micrograph of wear surface of (A) Al-3%SiC and 0.5% Cu, (B) Al-6%SiC and 0.75% Cu, (C) Al-9%SiC and 1.00% Cu. and SEM figure before wear of (D) Al-3%SiC and Cu 0.5% Cu, (E) Al-6%SiC and 0.75% Cu (F) Al-9% SiC and 1% Cu.

SL. No	R Wt. %	L (N)	S. D (m)	S. S (m/s)	Wear (gram)	S/N ratio
1	3	10	500	1.5	0.0060	-24.437
2	3	10	1000	2.5	0.1370	-17.2656
3	3	10	1500	3.5	0.3430	-9.2941
4	3	20	500	2.5	0.1220	-18.2728
5	3	20	1000	3.5	0.2014	-13.9188
6	3	20	1500	1.5	0.1710	-15.3401
7	3	30	500	3.5	0.0891	-21.0024
8	3	30	1000	1.5	0.3320	-9.5772
9	3	30	1500	2.5	0.3920	-8.1343
10	6	10	500	1.5	0.0020	-53.9794
11	6	10	1000	2.5	0.0700	-23.098
12	6	10	1500	3.5	0.3050	-10.314
13	6	20	500	2.5	0.1270	-17.9239
14	6	20	1000	3.5	0.2200	-13.1515
15	6	20	1500	1.5	0.0160	-35.9176
16	6	30	500	3.5	0.1680	-15.4938
17	6	30	1000	1.5	0.0840	-21.5144
18	6	30	1500	2.5	0.3390	-9.396
19	9	10	500	1.5	0.0060	-44.437
20	9	10	1000	2.5	0.00937	-40.5652
21	9	10	1500	3.5	0.0160	-35.9176
22	9	20	500	2.5	0.0108	-39.3315
23	9	20	1000	3.5	0.0397	-28.0242
24	9	20	1500	1.5	0.0280	-31.0568
25	9	30	500	3.5	0.0644	-23.8223
26	9	30	1000	1.5	0.0536	-25.4167
27	9	30	1500	2.5	0.1370	-17.2656

Table 2: Experimental result for wear with S/N ratio.

Wear test results and Taguchi analysis

The wear rates of SiC and Cu reinforced Al-SiC-Cu metal matrix composites under various test. The difference between the weight of the composites before and after the wear test is the wear loss or the mass loss of the specimen due to solid particles impact.

The experimental observation is then transformed into signal-to-noise (S/N) ratios, in the Table 2, the column represent S/N ratio of the wear rate. The S/N ratio for minimum wear rate coming under larger-is-better characteristic can be calculated as logarithmic transformation of the loss function as:

$$S/N = -10 \log (\sum Y^2/N)$$

Table 2 shows the experimental results for wear tests and the corresponding S/N ratio for each experiment. The experimental design being orthogonal, it is possible to separate out the effect of each control factor at different levels. The mean S/N ratio for each level of the controlling factors is shown. In addition, the total mean S/N ratio for the 27 experiments is in Table 2 [6].

All the calculations are performed using MINITAB [4]. Figure 5 shows graphically the effect of the four control factors on the wear rate. Tables 2 and 3 show the R=Reinforcement, L=Load, S.D=Sliding distance, S.S=Sliding Speed.

Confirmation test

After the optimal level of testing parameters have been found, the result show in Table 4 that using the parameter setting (R3L1D3S1). It is necessary that verification tests are carried out in order to evaluate the accuracy of the analysis and to validate the experimental results.

Wear mechanism

Microstructure study of the wear tracks are carried out to analyze the wear mechanism that the composites undergo during tribological testing. Figure 4a-4c shows wear tracks of samples having three different volume fraction of reinforcement, Al-3%SiC, Al-6%SiC and Al-9%SiC. From the SEM micrographs, it can be observed that the wear surface mainly consists of longitudinal grooves and partially irregular pits. The presence of grooves indicates micro cutting and micro ploughing effect. Thus wear mechanism is found to be dominated by abrasive wear. Also presence of pits and prowls can be observed in the micrographs, thus occurrence of adhesive wear is also visible. So, from overall microstructure study it can be concluded [7-10].

That mostly abrasive wear has taken place with some traces of adhesive wear. In the present investigation the effect of four process parameters weight fraction, applied load, sliding speed and distance on the wear behaviour of Al-SiC-Cu particulate composite is studied. Apart from these, other factors like heat treatment, temperature change and particle size of reinforcement are assumed constant during this experimental study.

Level	R Wt. %	L (N)	S.D (m)	S.S (m/s)
1	0.20528	0.10537	0.12745	0.08362
2	0.14789	0.10399	0.19411	0.14935
3	0.04054	0.18434	0.07214	0.16073
Delta	0.16474	0.08036	0.12197	0.07711
Rank	1	3	2	4

Table 3: Response table for Mean wear.

Initial Parameter		Optimal Parameter	
Level	RLDS	Prediction R3L1D3S1	Experimental R3L1D3S1
Wear		0.02834	0.03034
S/N ratio		-45.265	-44.673

Table 4: Result of conformation test.

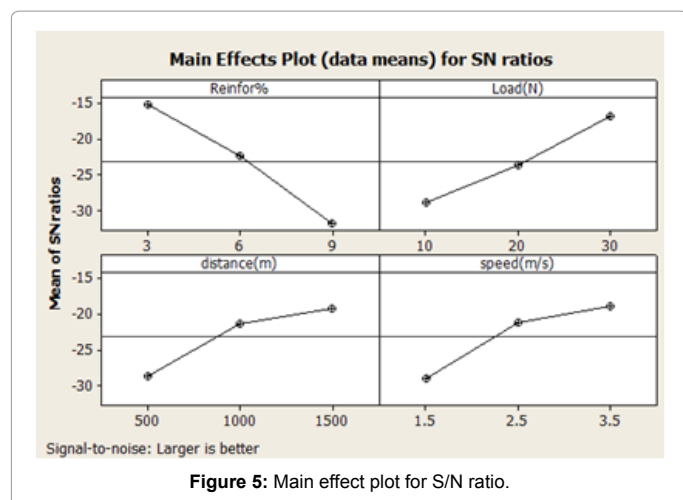


Figure 5: Main effect plot for S/N ratio.

Conclusion

Wear behaviour of Al-SiC-Cu metal matrix composite is studied for varying reinforcement content, applied load, sliding speed and distance using Taguchi orthogonal array design. It is observed that parameter wt, i.e. weight % of reinforcement is the most significant parameter influencing the wear behaviour while parameters L (applied load) and S (sliding speed) are also significant within the specific test range. Sliding distance has smallest influence on wear property of the composite. From the Taguchi analysis the optimal combination of process parameter for minimum wear is found on the level, highest level of weight % of reinforcement along with the lowest levels of applied load, sliding speed and sliding distance. From the present study it is revealed that a proper control of process parameters can result in improved design of the Al-SiC-Cu composite for tribological applications. From the microstructure study of worn surfaces, it is observed that mostly abrasive wear mechanism has occurred on the wear tracks with some traces of adhesive wear mechanism.

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