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Friction Performance Optimization of Al-SiC Metal Matrix Composite

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Abstract

In the present paper the friction performance of Al-SiC metal matrix composite is optimized using Taguchi method. The composites are prepared by sand casting process using LM6 aluminium alloy and silicon carbide particles (size ~ 37 µm) by varying the weight fraction of SiC in the range of 5% - 10%. The prepared composite is then subjected to friction testing in a multi-tribotester using block on roller setup. The experimental procedure is designed based on L_{27} orthogonal array using volume fraction, applied load and sliding speed as design variables. From the results coefficient of friction is taken as response for the present optimization study. Analysis of variance (ANOVA) is performed to find out the significance of each process parameter and their interactions. Lastly, confirmation tests are carried out for validate the results. It is found that highest level of volume fraction, mid level of load and highest level of sliding speed yields minimum friction. Also, scanning electron microscopy (SEM) reveals the wear mechanism to be predominantly abrasive.

Keywords

Al-SiC Composite, Friction, Taguchi Method

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1. Introduction

Aluminium alloys reinforced with ceramic particles show enhanced tribological properties, making it suitable for a number of engineering applications. The study of tribological behaviour of aluminium composites reinforced with ceramic whiskers, particles and fibres have become an important topic of research in recent years. Mostly researchers have studied the wear behaviour of Al-SiC composites. Some of the studies included study of friction behaviour of Al-SiC. The effect of volume fraction [1-3], applied load [2-7], sliding speed [7-10] and heat treatment [4] on the friction behaviour of Al-SiC was studied. The friction coefficient value decreased with increase in volume fraction. But some of the studies showed increase in friction coefficient with increase in volume fraction of reinforcement [2, 3]. Similar nature of friction coefficient was also noted for variation of sliding speed. With increase in sliding speed, friction coefficient increased [8] whereas Onat [7] found that friction coefficient of Al-SiC decreased with increase in sliding speed. For variation of load friction coefficient value increased [2-4] in some studies and decreased [5, 6, 8] in other cases. The friction coefficient of Al-SiC decreased with heat treatment of the material [4].

From the literature presented here we can conclude that study of friction performance has been performed numerous times but optimization of testing parameters is rare. Thus in the present paper the testing parameters viz. volume fraction, applied load and sliding speed is optimized using Taguchi method. L_{27} orthogonal array is designed using the testing parameters and their levels. The friction results are then analysed to minimize friction coefficient.

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2. Experimental Details

2.1. Fabrication Process

For the casting process of fabricating Al-SiC MMC, LM6 aluminium casting alloy is used as the base/matrix metal and silicon carbide is used as reinforcement. The aluminium alloy is melted at 800-900°C in a clay graphite crucible using an electric resistance melting furnace. The composites have been reinforced with 5%, 7.5% and 10% (by weight) of silicon carbide (SiC) particle of 400 mesh (37 µm) size. The reinforcement silicon carbide (SiC) is pre-heated at 850-900°C in a box furnace. The mould is prepared by mixing sand, coal dust and bentonite. The reinforcement is then added to the molten metal and the mixture is stirred at a suitable stirring speed. The stirring system used for this purpose is a mechanical stirring system driven by motor. The melt is then poured at a temperature of 690°C into the sand mould. After cooling the casting is properly cut and machined to prepare the samples of suitable size (20mm x 20mm x 8mm). These samples are then used for the tribological experimentation.

2.2. Design of Experiment

Taguchi technique is a powerful tool for design of high quality systems. It introduces an integrated approach to find the best range of designs for quality, performance and computational cost in a simple and efficient manner. This method has been utilized widely in engineering analysis to optimize performance characteristics within the combination of design parameters because of its proven success in greatly improving industrial product quality. In this optimization technique, the process or product should be carried out in a three-stage approach such as system design, parameter design and tolerance design. System design reveals the usage of scientific and engineering information required for producing a part. The parameter design is used to obtain the optimum levels of process parameters for developing the quality characteristics and to determine the product parameter values depending on optimum process parameter values. Tolerance design is required if the reduced variation obtained by the parameter design does not reach the required performance.

The present work aims to study and optimize the friction characteristics of Al-SiC metal matrix composites by varying the controllable factors. In this study the controllable factors are the tribological testing parameters. Three levels, having equal spacing, within the operating range of the parameters were selected for each of the factors. Selection of three levels enables to study the curvature or non-linearity effects, if any. The tribological testing parameters include volume fraction (V), applied load (L) and sliding speed (S). The interaction effects of these parameters (V, L and S) are also considered. Table 1 shows the design parameters and their levels.

Table 1. Design factors and their levels.

Design Factors	Unit	Levels		
		1	2	3
Volume Fraction (V)	Wt %	5	7.5[i]	10
Applied Load (L)	N	50	75[i]	100
Sliding Speed (S)	RPM	180	200[i]	220
i – initial condition				

2.3. Friction Test

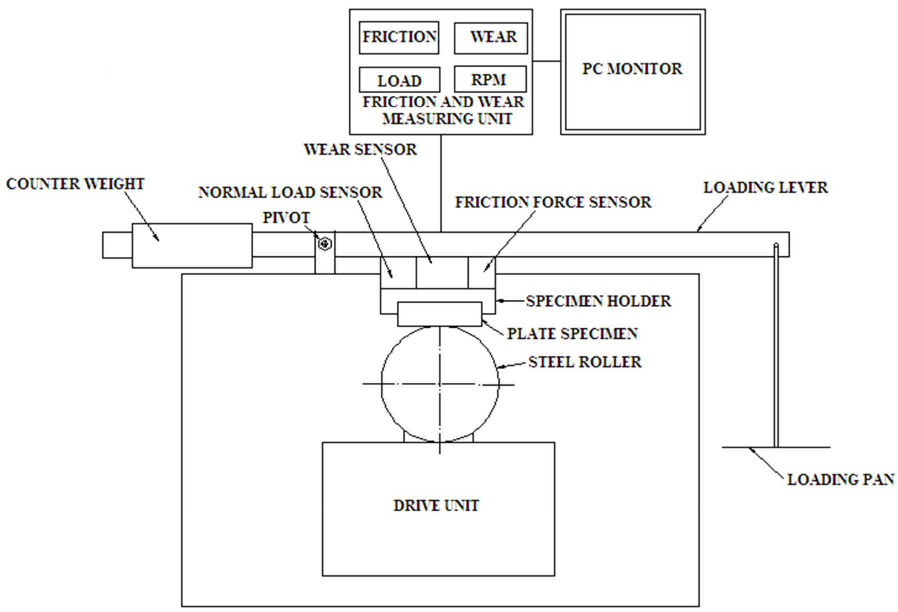

Fig. 1. Layout of Multi tribotester.

Friction tests for the present work are performed in a multi tribotester apparatus (TR-25, DUCOM) (Fig. 1). The tests are carried out in dry condition (without any lubrication) using block-on-roller geometry. The ambient temperature is about 28ºC with a relative humidity at 85%. During the test, composite specimens are held stationary with the help of the attachment and made to slide against the rotating counter face roller (EN8). The speed of the roller and the duration of tests can be controlled via a computer attached to the tribotester. Loads can be applied by placing dead weights on the loading pan which is attached to a loading lever. A beam type load cell (1000 N capacity) is used by the frictional force sensor to measure the frictional force which is plotted in real time on the computer screen.

2.4. Microstructure Study

The microstructure study is conducted using scanning electron microscope SEM (JEOL, JSM-6360). The wear tracks are monitored to study the wear phenomenon occurring on the composite.

3. Results and Discussion

The friction behaviour of sand cast Al-SiC metal matrix composite is studied and optimized. Co-efficient of friction (COF) is taken as the response variable for optimization analysis. The coefficient of friction values are collected from the multi tribotester via friction force sensor. The frictional force values are then divided by normal load to obtain the co-efficient of friction values. The S/N ratio calculations are performed using smaller-the-better criterion since friction is to be minimized. The response table for S/N ratio for friction analysis is given in Table 2. The significance of each parameter is determined from the inclination of the main effects plot shown in Fig. 2. A parameter for which the line has the highest inclination will have the most significant effect. It is very much clear from the main effects plot that parameter V (volume fraction) is the most significant parameter followed by parameter L (applied load) while parameter S (sliding speed) also has some significant effect. Thus from the present analysis it is clear that the volume fraction (V) is the most influencing parameter for friction characteristics of sand cast Al-SiC metal matrix composites. The optimal process parameter combination is the one that yields maximum mean S/N ratio and thus the same for minimum friction coefficient is found to be V3L2S3, i.e. highest level of volume fraction, mid level of load and highest level of sliding speed.

Table 2. Response table for S/N ratio for friction.

Level	Volume Fraction (%)	Applied Load (N)	Sliding Speed (rpm)
1	8.825	8.283	8.781
2	8.255	9.105	8.672
3	9.289	8.98	8.915
Delta	1.034	0.823	0.243
Rank	1	2	3

Total mean S/N ratio: 8.7894 dB

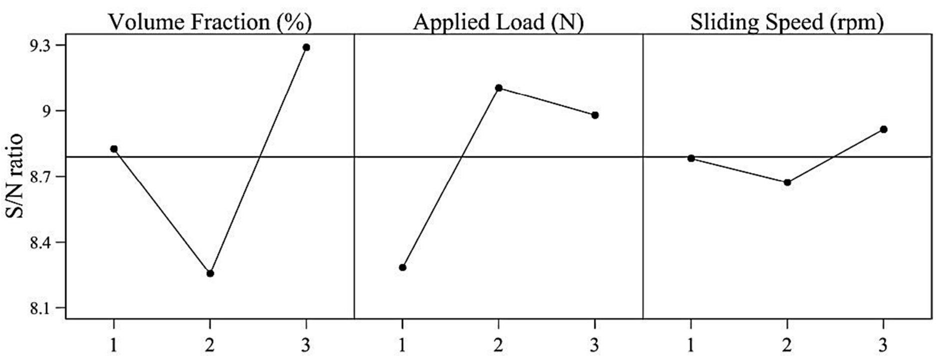

Fig. 2. Main effects plot for S/N ratio for friction.

3.1. Analysis of Variance (ANOVA)

ANOVA is performed to determine which parameter and interaction significantly affect the performance characteristics. The result of analysis of variance (ANOVA) is given in Table 3. The ANOVA table shows the percentage contribution of each parameter. From the table it can be observed that volume fraction is the most effective parameter at 95% confidence level, affecting the friction performance of the composite material and parameter applied load being less significant at 90% confidence level. The interactions V vs. L and V vs. S are the most significant interactions at 85% confidence level. The contribution of volume fraction is highest at 18% followed by applied load having a contribution of 13%.

Table 3. ANOVA table for friction.

Source	DF	Seq SS	Adj MS	F ratio	Contribution (%)
V	2	4.8309	2.4154	4.64*	18.10
L	2	3.5341	1.7671	3.39#	13.24
S	2	0.2663	0.1331	0.26	1.00
V vs. L	4	5.7837	1.4459	2.78^	21.67
V vs. S	4	5.1136	1.2784	2.46^	19.16
L vs. S	4	2.9995	0.7499	1.44	11.24
Error	8	4.1652	0.5207		15.60
Total	26	26.6932			100

(F ratio values: $^{*}F_{0.05,2,8}$ – 4.45, $^{\#}F_{0.10,2,8}$ – 3.11, $^{\wedge}F_{0.15,4,8}$ – 2.27)

3.2. Confirmation Test

Table 4 shows the comparison of estimated S/N ratio with the actual S/N ratio using the optimal parameter combination. The increase in S/N ratio from the initial to final combination is found to be 1.386 dB which indicates that co-efficient of friction reduced by nearly 15%. This result shows that the aim for this study i.e. minimization of friction is attained by optimizing the process parameters and at optimal combination friction coefficient is reduced.

Table 4. Confirmation test for friction analysis.

	Initial parameters	Optimal Parameters	
		Theoretical	Experimental
Level	V2L2S2	V3L2S3	V3L2S3
COF	0.373		0.318
S/N ratio (dB)	8.566	9.731	9.952

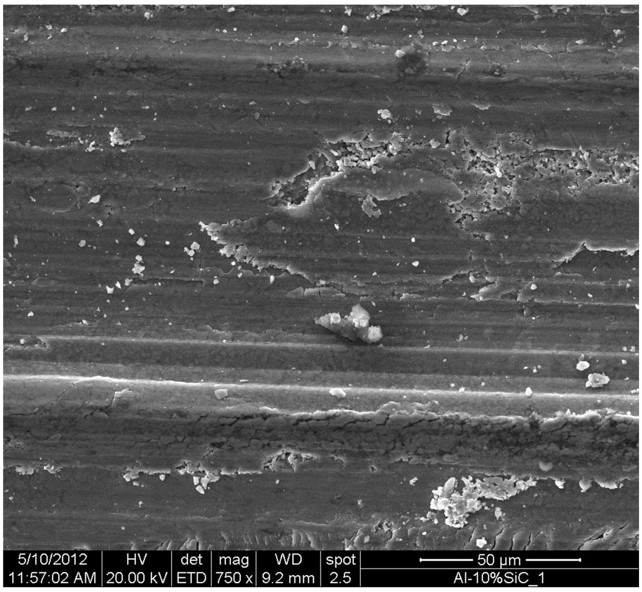

Fig. 3. SEM image of wear track.

3.3. Microstructure Study

The microstructure study of composites is carried out after the wear testing is completed. The wear tracks are analysed by scanning electron microscopy to study the wear mechanism. Figure 3 shows a SEM image of wear track of Al-SiC composite. The SEM image exhibits longitudinal grooves and partial irregular pits that indicate adhesive wear. Some traces of micro-cutting and micro-ploughing effect are also noticed that suggest abrasive wear mechanism. Thus it can be concluded that both abrasive and adhesive wear mechanisms are observed with abrasive wear being predominant in nature.

4. Conclusions

The optimization study of friction performance using Taguchi method revealed that volume fraction of reinforcement is the most important parameter controlling friction property of the composite. The optimal combination of process parameters is V3L2S3, i.e. highest level of volume fraction, mid level of load and highest level of sliding speed. From ANOVA analysis it is concluded that interaction between parameters volume fraction and applied load is the most effective interaction. The microstructure study of the wear tracks of the composites revealed that wear mechanism is abrasive in nature with traces of adhesive wear mechanism.

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