ANALYSIS OF FRICTION PERFORMANCE OF LM6-SIC METAL MATRIX COMPOSITE BY USING DESIGN OF EXPERIMENTS

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Abstract: **In the present investigation an attempt has been made on the study of friction performance of LM6 reinforcing with varying SiC content composite for varying process parameters. The composite is prepared by stir casting process in an electric melting furnace. The tribological tests are carried out on LM6 with varying SiC for testing the friction property of the material. The experimental study is performed varying Normal pressure, speed and wt % of SIC. The design of experiment approach was employed to acquire data in controlled way using Taguchi method. An orthogonal array, signal-to-noise ratio and analysis of variance were employed to optimize the wear rate and frictional force of LM6-SiC composite. The mathematical model was obtained to determine the friction performance of Al-SiC composite. It is observed that sliding speed influence the friction behaviour, significantly.**

Keywords: **Anova, Coefficient of friction, stir casting, Taguchi technique.**

1. INTRODUCTION

Aluminum metal matrix composites have been of interest as engineering materials because of their higher stiffness and specific strength, as well as superior wear resistance, compared to Unreinforced aluminum alloys. Aluminium is the most abundant metal and the third most abundant chemical element in the earth's crust, comprising over **8**% of its weight**[1]**. Aluminium alloys are broadly used as a main matrix element in composite materials. The broad use of aluminium alloys is dictated by a very desirable combination of properties, combined with the ease with which they may be produced in a great variety of forms and shapes. 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].**

The industrial application of these materials is increasing mainly in the field of automobile and aeronautics where material cost is not limited. Some main examples are engine systems in automobiles due to low friction and low wear property. In aeronautics it is used for manufacturing of rotor blades due to increased creep resistance. In general these materials are used for their high wear resistance. The aluminium composites exhibit lower friction co-efficient than there base alloys**[7,8**]. Iwai et al [**9]** conducted the study with **2024** Al alloy reinforced with **10%** vol SiC. The friction study showed that initially the friction coefficient value is around **0.6** for both **2024** Al alloy and **2020**Al-**10**%SiC and then gradually decreases to **0.4**. Hassan et al [**10**] concluded from their study of Al-4wt%Mg-**5**wt%SiC and Al-4wt%Mg-10wt%SiC that the friction coefficient value is higher for both the cases than the alloy metal. The composite with **10%** SiC exhibit higher friction coefficient value. Martin et al **[8]** conducted the study on 2618Al alloy with **15**% vol SiC reinforcement. The materials are tested at different temperature ranging from **0** to **2000**C. The friction coefficient value of reinforced material is less than the alloy. The friction coefficient value increases from **0.5** to **1.5** with increase in temperature for both the cases. Rodriguez et al **[11]** conducted the study on Al/Li alloy reinforced with SiC and found that the friction coefficient value of reinforced materials is higher than the alloy. Yalcin and Akbulut [**12]** found that friction coefficient value decreased with increase in volume fraction and applied load.

For the present study LM6 aluminium alloy is used as base metal and silicon carbide is used as reinforcement. The composite is prepared by stir casting process in an electric melting furnace. The tribological tests are carried out on AMC with varying SiC for testing the friction property of the material. The result data is analyzed by Taguchi method. Furthermore, a statistical analysis of variance (ANOVA) is performed to find the statistical significance of process parameters.

2. TAGUCHI TECHNIQUE

The taguchi method was developed by Dr.Genichi Taguchi. He developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic. 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 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.

Using OA, the Taguchi method explores the entire design space through a small number of experiments in order to determine all of the parameter effects and several of the interactions. These data are then used to predict the optimum combination of the design parameters that will minimize the objective function and satisfy all the constraints. In addition to locating a near optimum objective function, the Taguchi method provides information on parameter trends and noise sensitivities thereby enabling a robust design. The parameter design phase of the Taguchi method generally includes the following steps: **(1)** identifying the objective of the experiment; **(2)** identifying the quality characteristic (performance measure) and its measurement systems; **(3)** identifying the factors that may influence the quality characteristic, their levels, and possible interactions; **(4)** select the appropriate OA and assign the factors at their levels to the OA; **(5)** conducting the test described by the trials in the OA; (**6**) analyzing the experimental data using the signal-to- noise **(S/N)** ratio, factor effects, and the analyzing variance (ANOVA) to see which factors are statistically significant and to and the optimum levels of factor

3. EXPERIMENTAL DETAILS

3.1 Materials and Methods

For the fabrication process aluminium alloy**, LM6** is used as matrix metal that has been reinforced with SiC particles of **400** mesh size (size ~ **37** μm). The reinforcement percentage (herein termed as volume fraction of reinforcement) is varied in the range **5**% - **15**% by weight. The chemical composition of the matrix material **(LM6**) is given in table **1.**

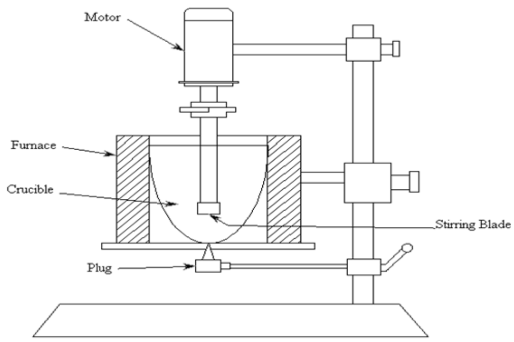

Fig. 1: Line diagram of the stir casting process.

The fabrication of LM6-SiC composites were carried out by stir casting process. The line diagram of the experimental set up used for making of these composites was shown in figure 1. Silicon carbide particles were preheated at around 850^{0}C to 900^{0}C for 2-3 hrs to make their surfaces oxidized. LM6 Al alloy ingots were taken into a graphite crucible and melted in an electrical furnace. They were then slightly cooled to below the liquids, to maintain the slurry in the semi-solid state. The preheated silicon carbide particulates were added and mixed manually. The composite slurry was then reheated to a fully liquid state and mechanical mixing was carried out about 20 min at an average mixing speed of 400-500 rpm. The final temperature was controlled to be around 750^{0}C. The melt is then poured into a green silica sand mould. The material is then cooled and samples for wear testing are prepared by different machining processes.

3.2 Design of experiments

Design of Experiment is the powerful tool to study the effect of multiple variables simultaneously all designed experiments require a certain number of combinations of factors and levels be tested in order to observe the results of those test conditions. The experimental plan was formulated considering three parameters (variables) and three levels based on the Taguchi technique. SiC wt% (A), Normal Pressure (B) and Sliding Speed(C), these are process parameters is considered for the study. Process parameters setting with the highest S/N ratio always yield the optimum quality with minimum variance**[9].** The levels of these variables chosen for experimentation are given in the Table **2.**

Based on Taguchi method an orthogonal array (OA) is considered to reduce the number of experiments required to determine the optimal friction for Al-SiC. To choose an orthogonal array the total number of degrees of freedom is to be chosen. For this experimental purpose L9 orthogonal array is chosen is shown in Table **3.** The selected of the orthogonal array is based on the condition that the degrees of freedom for the orthogonal array should be greater than, or equal to, the sum of the variables. The experiments were conducted based on the run order generated by Taguchi model and the results were obtained. This analysis includes the rank based on the delta statistics, which compares the relative value of the effects. S/N ratio is a response which consolidates repetitions and the effect of noise levels into one data point. The experimental results were transformed into signal-to-noise ratio (S/N) ratios. An S/N ratio is defined as the ratio of the mean of the signal to the standard deviation of the noise. The S/N ratio indicates the degree of the predictable performance of a product or process in the presence of noise factors.

Table 1: Composition of LM6 alloy

Elements	Si	Cu	Mg	Fe	Mn	Ni	Zn	Pb	Sb	Ti	Al
(%)	10-13.0	0.1	0.1	0.6	0.5	0.1	0.1	0.1	0.05	0.2	Bal.

Table 2: Control and Noise Factors

Sl.No.	**Process Parameters**	**Level 1**	**Level 2**	**Level 3**
1	SIC (wt%),A	0	5	15
2	Normal Pressure (MPa),B	0.19	0.59	0.990
3	Sliding Speed (m/s.), C	1	3	5

Table 3: L9 Orthogonal Array

	(OA)		
SI No.	**A**	**B**	**C**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

3.3 wear test

Wear test were performed using a pin on disk type apparatus (Fig 2). Before the wear test, each specimen was finished up to **1200** grade abrasive papers, making sure that that the wear surface was in complete contact with the surface of the abrasive papers. Dry sliding wear test was carried out using wear and friction monitor manufactured by DUCOM, Bangalore was used. Weight loss of pin was recorded using an electronic balance at the end of the experiment. Tests were carried out at loads of **1, 3**& **5** kgs, Sliding speed of **1, 3** &**5** m/s.

Fig. 2 Wear Testing Machine

4. RESULT AND DISCUSSION

4.1 Friction Study

The aim of the present study is to minimize friction of Al-SiC by optimizing the tribological parameters with the help of Taguchi method. The influence of tribological testing parameters like Nr. pressure, sliding speed and % of SiC together with their interactions on the friction behavior of Al- SiC is studied. Since the study is related to friction, coefficient of friction is taken as system response. The result obtained for various combinations of parameters was obtained and was shown in table **4.**

Table 4: Combination of parameters in (L9) Orthogonal Array

SL.No.	Process Parameters			COF	S/N Ratio
	SiC (Wt %)	Normal Pressure (MPa)	Sliding Speed (m/s)		
1	0	0.19	1	0.42813	7.3685
2	0	0.58	3	0.43153	7.2998
3	0	0.97	5	0.76249	2.3553
4	5	0.19	3	0.10194	19.8331
5	5	0.58	5	0.61502	4.2222
6	5	0.97	1	0.41794	7.5777
7	15	0.19	5	0.60143	4.4163
8	15	0.58	1	0.41454	7.6487
9	15	0.97	3	0.69929	3.1069

4.2 Analysis of Signal-to-Noise Ratio

As the present case is a minimization problem the smaller-the-better quality criterion is considered. The experimental plan and the results of the friction characteristics with the S/N ratio are represented in Table **4**. The mean S/N ratio for each level is summarized in Table **5**. Analysis of the influence of each control factor (A, B and C) on the friction characteristics is obtained from the response table of mean S/N ratio. It is clear from Figure 3 that the S/N ratio is higher at level **2** for parameter A, at level **1** for parameter B and at level **2** for parameter C respectively.

Table 5: Response Table for Signal to Noise Ratios

Level	SiC (wt %)	Nr. Pressure	Sliding speed
1	5.675	10.539	7.532
2	10.544	6.390	10.080
3	5.057	4.347	3.665
Delta	5.487	6.193	6.415
Rank	3	2	1

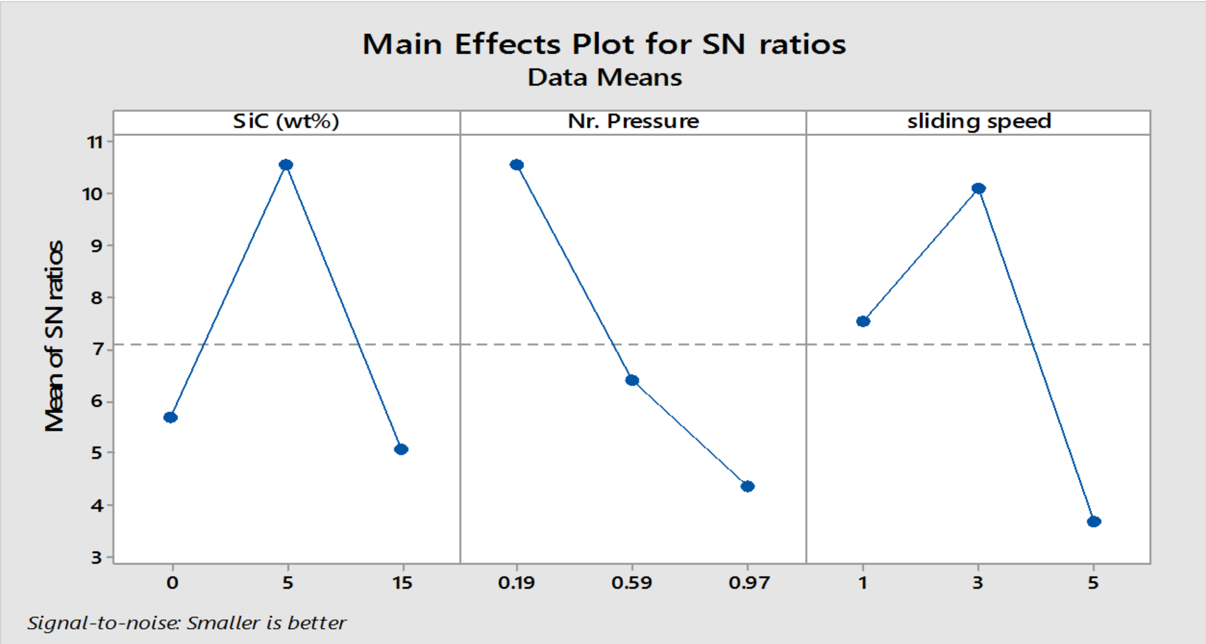

Fig 3: Main Effects Plot for SN ratios for COF

Table 6: ANOVA table for Co-efficient of friction

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P- Value	% of Contribution
SiC (wt%)	2	0.06477	0.06477	0.03238	1.77	0.361	20.60%
Nr. Pressure	2	0.09375	0.09375	0.04687	2.56	0.281	29.82%
Sliding speed	2	0.11928	0.11928	0.05964	3.26	0.235	37.94%
Error	2	0.03660	0.03660	0.01830			11.64%
Total	8	0.31439					100.00%

4.3 Analysis of Variance (ANOVA)

The idea of the analysis of variance is to find out the significance of process parameters and also the percentage contributions of the factors and the interactions in affecting the response.

Analysis o variance (ANOVA) was introduced by Sir Ronald Fisher. This analysis was carried out for a level of significance of 5%, i.e., for 95% level of confidence. The table 6 shows analysis of variance for wear rate of the composite material. From the table 6, it is observed that the normal pressure, sliding speed and wt% of reinforcement have the influence on COF of composite material. The last column of the table 6 indicates the percentage contribution of each other on the total variation indicating their degree of influence on the result. It can be observed from the ANOVA table that the sliding speed (37.94%) was the most significant parameter on the COF of composites followed by Nr. pressure (29.82%) and SiC wt% (20.60%). When the P-value for this model was less than 0.05, then the parameter can be considered as statistically significant. The pooled error associated in the ANOVA table was approximately about 11.64%. This approach gives the variation of means and variance to absolute values considered in the experiment and not the unit value of the variable

4.4 Multiple Linear Regression Models

Statistical software MINITAB R17 is used for developing a multiple linear regression equation. This developed model gives the relationship between independent/predictor variable and a response variable using by fitting a linear equation to the measured data.

The regression equation developed for COF is,

COF = 0.4969 - 0.1186 A - 0.1198 B - 0.0860 C ----- (1)

R-sq = 88.36%

5. CONCLUSIONS

From the present investigation the following conclusions are drawn.

- For Al-SiC the optimal tribological testing combination for minimum friction is found to be A2B1C2. All the factors % of SiC (A), Nr. Pressure (B) and sliding speed(C) are found to affect the friction significantly. But the factor sliding speed (C) is the most important factor with a contribution of **37.94%.**
- The pooled error associated with the ANOVA analysis was **11.64%** for the factors and the correlation between the wear parameters was obtained by multiple linear regression models.

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