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STUDY OF FRICTION PERFORMANCE OF Al-10% SiC METAL MATRIX COMPOSITE USING TAGUCHI METHOD

Shouvik Ghosh, Prasanta Sahoo and Goutam Sutradhar

Department of Mechanical Engineering, Jadavpur University, Kolkata, India

ABSTRACT

In the present paper the friction performance of Al-10% SiC for varying operating parameters has been studied. The experimental study is performed varying applied load, sliding speed and time. The friction performance is studied and optimized using Taguchi L_{27} orthogonal array. L_{27} orthogonal array is constructed using three levels of operating parameters (applied load, sliding speed and time). The composite is prepared using stir casting process. Aluminium alloy LM6 mixed with 10 vol% silicon carbide is mixed by stir casting process. The friction behaviour of the casted material is then studied by Multi Tribotester (TR 25, Ducom, India) at various experimental conditions. A confirmation test is carried out to verify the accuracy of the results. Analysis of variance (ANOVA) is performed to observe the significance of process parameters and its interactions on the system response (Co-efficient of friction). The wear tracks are analyzed with the help of scanning electron microscopy.

Keywords: Co-efficient of Friction, Taguchi Method, Metal Matrix Composite.

1. INTRODUCTION

Particle reinforced composites are recognized as a light weight material having enhanced mechanical and tribological properties than the constituent materials. The MMC (metal matrix composite) materials attain the toughness of the alloy matrix and hardness, stiffness and strength of the reinforcement. Mainly different aluminium alloys are used as alloy matrix in synthesis of matrix composite [1-3]. Different types of reinforcement such as particle, whisker and fiber reinforcement are used as reinforcement for fabrication of composites. Some of the reinforcement materials are SiC, Al_2O_3, B_4C, etc. The reinforcements are mixed in volume fractions ranging from a few percent to 60% [4]. But mostly volume fraction ranging from 1% to 20% is considered [5-7]. Some of the major advantages of these materials compared to its base metal components are greater strength, improved stiffness, improved high temperature properties, improved corrosion resistance and improved wear resistance. However, the relatively poor seizure resistance of aluminium alloy has restricted their uses in some engineering application. These materials are good alternative to the traditional materials due to its improved properties. 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 [8, 9]. Some of the major research examples are cited below. Chen et al [3] studied the fretting wear behaviour and found that friction coefficient value increased from 0.16 to 0.45 for change in normal load from 5N to 20N and from 0.25 to 0.45 for heat treated materials. It was also concluded that friction coefficient varies for pre and post heat treated materials at lower load whereas no variation is found at higher load. Chen et al [5] carried out another study with volume fraction range of 0-10%. From the study it was concluded that friction coefficient value increases with increase in volume fraction at lower load and values range from 0.3 to 0.8 with gradual increase in % vol. But at higher load the friction coefficient value of all the material ranges from 0.3 to 0.4. Iwai et al [6] 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 2020Al-10%SiC and then gradually decreases to 0.4. Hassan et al [7] concluded from their study of Al-4wt%Mg-5wt%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 [9] conducted the study on 2618Al alloy with 15% vol SiC reinforcement. The materials are tested at different temperature ranging from 0 to 200^0C. 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. Murthy et al [10] investigated the abrasive wear behaviour of Al-SiC whisker reinforcement of volume fraction ranging from

10-40%. The study showed that friction coefficient value increased gradually with increase in volume fraction, but decreased with increase in sliding distance. Tang et al [11] found that monolithic SiC showed higher value of friction coefficient than the composite. Rodriguez et al [12] 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 [13] found that friction coefficient value decreased with increase in volume fraction and applied load. Ma et al [14] found from his experimentation that friction coefficient value increased with increase in volume fraction. A350 Al alloy showed lower coefficient value than 50% SiC reinforced material. Bai et al [15] found that friction coefficient value increased with increase in sliding time. The variation is higher for high applied load.

For the present experimental 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 Al-10%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. Finally, a confirmation test is carried out to verify the optimal process parameters obtained from the parameter design. The microstructure study is done with the help of SEM to judge the wear mode of the material.

2. TAGUCHI METHOD

Dr Genechi Taguchi's standardized version of DOE (Design of Experiment) is known as Taguchi Method [16, 17] which is a powerful tool for design of high quality systems. This optimization technique is 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. 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 used to determine and analyze tolerance about the optimum combinations suggested by parameter design. In the present study, parameter design is used to optimize the friction behaviour of Al-10%SiC.

Using Taguchi method and based on orthogonal arrays the number of experiments required for the purpose is reduced. Thus the time required and cost of experimentation is decreased. Taguchi method uses S/N (Signal/Noise) ratio to identify the quality characteristics. The three categories of quality characteristics are (i) Smaller-the-better, (ii) Higher-the-better and (iii) Nominal-the-best. For the present study of friction, where friction is minimized the smaller-the-better criterion is used. Furthermore, a statistical analysis of variance (ANOVA) is performed. With the use of both S/N ratio and ANOVA analysis, the optimal combination of tribo testing parameters is predicted.

3. EXPERIMENTAL DETAILS

3.1 Fabrication Process

The material is fabricated by stir casting process. The stir casting process is both simple and less expensive, so the process is chosen for the fabrication of Al-SiC composite. In stir casting process aluminium LM6 alloy (base metal) is heated and liquefied in an electric melting furnace. The reinforcement silicon carbide is pre heated and then added to the liquefied metal. After addition of SiC the mixture is stirred with the help of stirrer to incorporate the reinforcement into the metal to fabricate the composite. Finally the mixture is poured in the sand casting and after cooling the casting is cut properly and machined to prepare samples (20mm x 20mm x 8mm) suitable for tribological testing.

3.2 Design of Experiments

Design factors or control factors are those which are varied during the experimental tests. There are a number of control factors that can affect friction behaviour of Al-10%SiC. For this case the control factors chosen are load, speed and time. Table 1 shows the design factors with their levels. The present study considers the friction characteristics of Al-10%SiC coefficient of friction is taken as the response variable.

The design of experiment is a powerful statistical technique introduced by R.A. Fisher [18]. It basically refers to the process of planning, designing and analyzing the experiment so that valid and objective conclusion can be drawn effectively and efficiently. Based on Taguchi method an orthogonal array (OA) is considered to reduce the number of experiments required to determine the optimal friction for Al-10%SiC metal matrix composite. To choose an orthogonal array the total number of degrees of freedom is to be chosen. For this experimental purpose L_{27} orthogonal array is chosen. This L_{27} OA has 27 rows corresponding to the number of tests and the degree of freedom is 26. The degree of freedom of each design factor is 2 and for two way interaction of the factors the dof is 4. So, the total degree of freedom for the conducted experiment is (2x3 = 6 + 4 x3 = 12 = 18). So, the L_{27} OA is chosen for the experimental purpose. The 1st column is assigned to load (L), 2nd column is assigned to speed (S) and the third column is assigned to time (T). The rest of the columns are assigned to the two way interactions of the factors and error terms. Table 2 shows the orthogonal array.

Table 1: Design Factors and its Levels

Design Factors	Unit	Levels		
		1	2	3
Load (L)	N	50	75^{i}	100
Speed(S)	RPM	180	200^{i}	220
Time (T)	MIN	20	30^{i}	40

i = initial condition

Table 2: L_{27} Orthogonal Array with design factors and results

	Column													Results	
Trial No.	**1 (L)**	**2 (S)**	**3 (L×S)**	**4 (L×S)**	**5 (T)**	**6 (L×T)**	**7 (L×T)**	**8 (S×T)**	**9 -**	**10 -**	**11 (S×T)**	**12 -**	**13 -**	**COF**	**S/N Ratio**
1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.353	9.0445
2	1	1	1	1	2	2	2	2	2	2	2	2	2	0.356	8.9710
3	1	1	1	1	3	3	3	3	3	3	3	3	3	0.344	9.2688
4	1	2	2	2	1	1	1	2	2	2	3	3	3	0.392	8.1343
5	1	2	2	2	2	2	2	3	3	3	1	1	1	0.371	8.6125
6	1	2	2	2	3	3	3	1	1	1	2	2	2	0.383	8.3360
7	1	3	3	3	1	1	1	3	3	3	2	2	2	0.350	9.1186
8	1	3	3	3	2	2	2	1	1	1	3	3	3	0.369	8.6595
9	1	3	3	3	3	3	3	2	2	2	1	1	1	0.394	8.0901
10	2	1	2	3	1	2	3	1	2	3	1	2	3	0.314	10.061
11	2	1	2	3	2	3	1	2	3	1	2	3	1	0.322	9.8429
12	2	1	2	3	3	1	2	3	1	2	3	1	2	0.328	9.6825
13	2	2	3	1	1	2	3	2	3	1	3	1	2	0.331	9.6034
14	2	2	3	1	2	3	1	3	1	2	1	2	3	0.348	9.1684
15	2	2	3	1	3	1	2	1	2	3	2	3	1	0.366	8.7304
16	2	3	1	2	1	2	3	3	1	2	2	3	1	0.399	7.9805
17	2	3	1	2	2	3	1	1	2	3	3	1	2	0.386	8.2683
18	2	3	1	2	3	1	2	2	3	1	1	2	3	0.395	8.0681
19	3	1	3	2	1	3	2	1	3	2	1	3	2	0.258	11.768
20	3	1	3	2	2	1	3	2	1	3	2	1	3	0.318	9.9515
21	3	1	3	2	3	2	1	3	2	1	3	2	1	0.333	9.5511
22	3	2	1	3	1	3	2	2	1	3	3	2	1	0.271	11.341
23	3	2	1	3	2	1	3	3	2	1	1	3	2	0.320	9.8970
24	3	2	1	3	3	2	1	1	3	2	2	1	3	0.284	10.934
25	3	3	2	1	1	3	2	3	2	1	2	1	3	0.275	11.213
26	3	3	2	1	2	1	3	1	3	2	3	2	1	0.308	10.229
27	3	3	2	1	3	2	1	2	1	3	1	3	2	0.284	10.934

3.3 Tribological Test

The tribological tests are carried out in a Multi-tribotester TR25 (Ducom, India) (Fig 1). It is used to measure the friction of Al-5%SiC under dry non lubricated condition and at ambient temperature (28^0C). It is a block-on-roller apparatus where EN8 steel roller is used. The load is applied by placing dead weight in a loading pan which is connected by a lever. The experimental data is recorded by a computer attached with the apparatus. The frictional force is measured by a frictional force sensor. The friction tests are carried out at different load and speed for different interval of time as mentioned in Table 1.

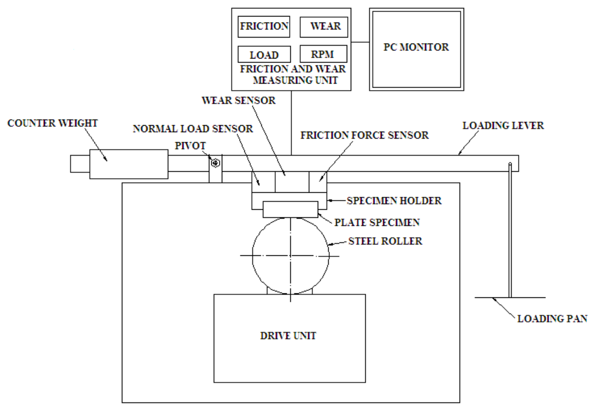

Fig 1. Multi Tribotester

3.4 Microstructure Study

After friction tests scanning electron microscope (SEM) is done to evaluate the microstructure of the specimens. The microstructure study is conducted to know the nature of the wear tracks. Scanning Electron Microscope (JEOL, JSM - 6360) is used for the microstructure study of the material.

4. RESULTS AND DISCUSSION

4.1 Friction Study

The aim of the present study is to minimize friction of Al-10%SiC by optimizing the tribo testing parameters with the help of Taguchi method. The influence of tribological testing parameters like applied load, sliding speed and sliding duration together with their interactions on the friction behavior of Al-10% SiC is studied. Since the study is related to friction, coefficient of friction is taken as system response. Accordingly the effect of the tribo testing conditions on the friction behavior of Al-5% SiC is studied.

4.2 Analysis of Signal-to-Noise Ratio

As the present case is also a minimization problem the lower-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

Table 3: Response table for mean S/N Ratio

Level	Load	Speed	Time
1	8.693	9.793	9.807
2	9.045	9.417	9.289
3	10.646	9.173	9.288
Rank	1	2	3
Delta	1.954	0.620	0.519

Total mean S/N Ratio = 9.461 dB

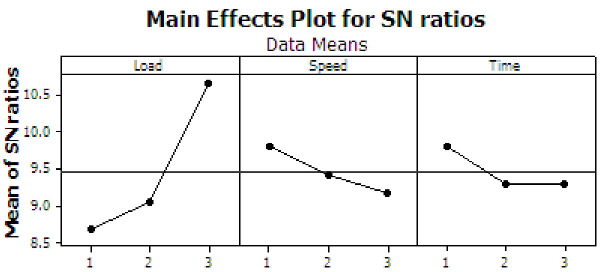

Fig 2. Main effects plot

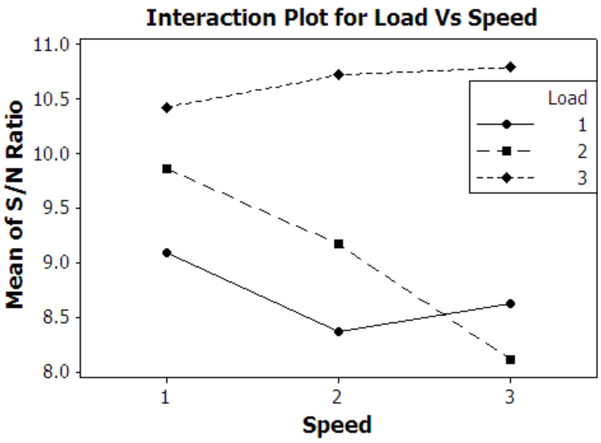

Fig 3(a). Interaction Plot Load vs. Speed

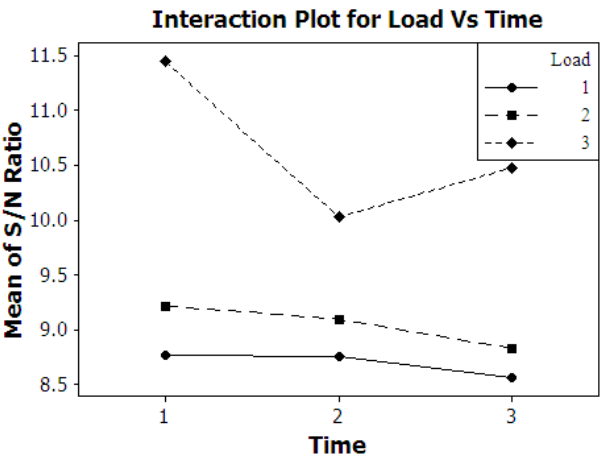

Fig 3(b). Interaction Plot Load vs. Time

2. The mean S/N ratio for each level is summarized in Table 3. Analysis of the influence of each control factor (L, S and T) on the friction characteristics is obtained from the response table of mean S/N ratio. It is clear from Figure 1 that the S/N ratio is higher at level 3 for parameter L, at level 1 for parameter S and at level 1 for parameter T respectively. So, from Figure 2 considering the interactions between the factors, the optimum conditions for tribo testing parameters for friction is found to be **L3S1T1**. The interaction plots are shown in Figs 3(a), 3(b), 3(c).

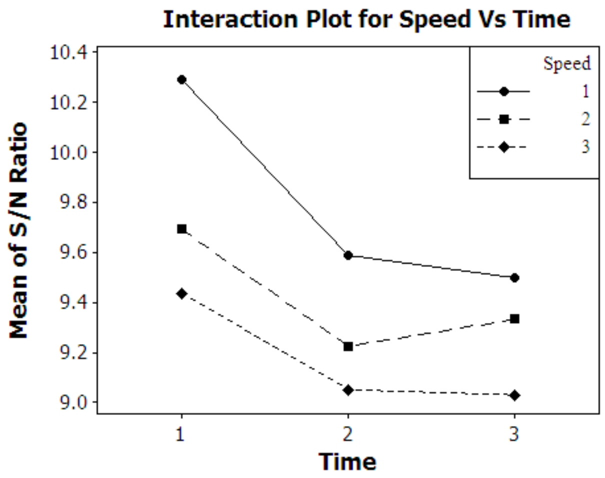

Fig 3(c). Interaction Plot Speed vs. Time

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. This is accomplished by separating the total variability of the S/N ratio, which is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the design parameters and the error. The percentage contributions of variance can be calculated by using the following equations:

The total sum of square deviations SS_T from the total mean of the S/N ratio (η_n) can be evaluated as follows:

$SS_T = SS_d + SS_e,$

$$SS_T = \sum_{i=1}^{m} (\eta_i - \eta_n)^2 = \sum_{i=1}^{m} \eta_i^2 - \frac{1}{m}\left[\sum_{i=1}^{m} \eta_i\right]^2 \quad (1)$$

Where, m is the number of experiments in the orthogonal array and η_i is the mean S/N ratio for the ith experiments. The percentage of contributions ρ can be calculated as follows:

$$\rho = \frac{SS_d}{SS_T} \quad (2)$$

Where, SS_d is the sum of the square deviations and SS_e is the sum of squared error. In the statistical analysis, F - tests are carried out to see which design parameters have a significant effect on the response characteristics. To conduct the F – test, the mean of the square deviations SS_m due to each design parameter need to be calculated.

SS_m=

$$SS_m = \frac{\text{Sum of squared deviations}(SS_d)}{\text{Number of degrees of freedom of each parameters}}$$

F-value can be found out with following equation:

$$\text{F-value} = \frac{\text{Mean squared deviation}(SS_m)}{\text{Mean squared error}(SS_e)}$$

F ratio in calculation of three process parameters is analyzed from the table as $F_{0.01, 2, 8} = 8.65$, $F_{0.05, 4, 8} = 3.84$, $F_{0.10, 4, 8} = 2.81$. Usually, when $F_{calculated} > F_{tabulated}$, that means the parameter has a significance effect on the quality characteristics. Generally when F value increases the significant of the parameter also increases.

From the analysis of variance table (Table 4) it is clear that factor L is the most significant parameters for the resulting friction of the Al-10%SiC metal matrix composite. The interaction between L and S is also significant. It may be observed from the ANOVA table that the load (contribution % = 63.20) and the interaction L*S (contribution % = 12.96) have great significance on the friction of the Al-10% SiC MMC. On the other hand, the factor S and T that is the Speed and Time and the interactions between L*T and S*T represent less significant percentages of contribution.

Table 4: ANOVA table for Co-efficient of friction

Source	**DF**	**SS**	**MS**	**F**	**Contribution (%)**
L	2	19.51	9.76	39.61#	63.20
S	2	1.76	0.86	3.56*	5.69
T	2	1.61	0.81	3.28*	5.23
L*S	4	4.01	1.01	4.06^	12.96
L*T	4	1.83	0.46	1.86	5.94
S*T	4	0.19	0.05	0.19	0.60
Error	8	1.98	0.25		6.38
Total	26	30.89			100

Significant parameters and interactions ($^{\#}F_{0.01, 2, 8} = 8.65$; $^{*}F_{0.10, 2, 8} = 3.11$; $^{\wedge}F_{0.05, 4, 8} = 3.84$)

4.4 Confirmation Test

After the optimal level of testing parameters have been found, it is necessary that verification tests are carried out in order to evaluate the accuracy of the analysis and to validate the experimental results. The estimated S/N ratio $\hat{\eta}$, using the optimal level of the testing parameters can be calculated as:

$$\hat{\eta} = \eta_m + \sum_{i=1}^{o} (\overline{\eta_i} - \eta_m)$$

Where, η_m is the total mean S/N ratio, $\overline{\eta_i}$ is the mean S/N ratio at the optimal testing parameter level and o is the number of main design process parameters that significantly affect the friction performance of Al-10% SiC.

Table 5: Confirmation result table

	Initial parameter	**Optimal parameter**	
		Predicted	**Experimental**
Level	L2S2T2	L3S1T1	L3S1T1
COF	0.348		0.258
S/N ratio (dB)	9.1684	11.3243	11.7676

Improvement of S/N ratio = 2.5992 dB

Table 5 shows the comparison of the estimated friction coefficient with the actual friction coefficient using the optimal condition. Good agreement seems to take place between the estimated and actual friction coefficient. The improvement of S/N ratio from initial to optimal condition is 2.5992 dB which means there is an improvement of 28% in friction of Al-SiC MMC.

4.5 Microstructure Study

Figure 4 show the SEM micrographs of the worn surface of the Al-10%SiC MMC. The SEM micrographs exhibit longitudinal grooves and partial irregular pits which indicates adhesive wear. Some traces of micro-cutting and micro-ploughing effect are also noticed which suggests abrasive wear mechanism. Hence the wear phenomenon encountered in case of Al-SiC is predominantly abrasive in nature.

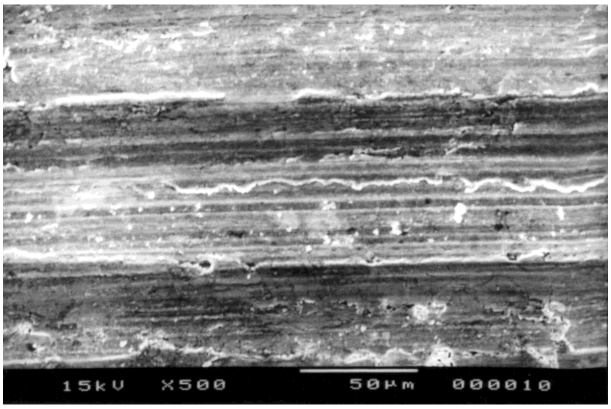

Fig 4. SEM image of Al-10%SiC

5. CONCLUSIONS

From the present study the following conclusions are drawn.

(1) For Al-10% SiC the optimal tribological testing combination for minimum friction is found to be L3S1T1. All the factors applied load (L), speed (S) and time (T) are found to affect the friction significantly. But the factor load (L) is the most important factor with a contribution of 63.20%. The interaction between load and speed (L×S) is found to be the most significant interaction.

(2) From the confirmation test it is found that the improvement of S/N ratio from initial to optimal testing condition for optimization of coefficient of friction is 2.5992 dB which means there is a decrease of 28% for co-efficient of friction.

(3) From the microstructure study of the wear tracks it is observed that mostly abrasive wear phenomenon is encountered.

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7. MAILING ADDRESS

Shouvik Ghosh
Department of Mechanical Engineering,
Jadavpur University, Kolkata – 700032
E-mail: shouvikghosh.1986@gmail.com