



Advanced Materials Manufacturing & Characterization

journal home page: www.ijammc-griet.com



Wear Characteristics Optimization of Al-7.5%SiC Metal Matrix Composite Using Taguchi Method

Shouvik Ghosh, Prasanta Sahoo* and Goutam Sutradhar

Department of Mechanical Engineering, Jadavpur University, Kolkata 700032, India.

ARTICLE INFO

Article history:

Received: 26-05-2014

Accepted: 28-05-2014

Keywords:

Al-sic;
Metal matrix composite;
Wear;
Optimization;
Taguchi method.

A B S T R A C T

In the present paper an attempt has been made to optimize the wear behaviour of Al-7.5%SiC metal matrix composite using Taguchi Method. Al-7.5%SiC metal matrix composite is synthesized using LM6 aluminium alloy as matrix metal and Silicon carbide as reinforcement using Stir casting process. Using L_{27} orthogonal array and Taguchi method the optimization of wear behaviour of the composite is carried out. The L_{27} orthogonal array is constructed using three levels of each tribological testing parameter Load (L), Sliding Speed (S) and Time (T). The wear tests are conducted in a Multi-Tribotester (DUCOM TR-25) using a block on roller arrangement at various combinations of the testing parameters. The analysis of the result is carried out using wear depth as system response. Furthermore, ANOVA analysis is carried out to find out the significant test parameters and their interactions affecting the wear behaviour of the composite. Scanning electron microscopy (SEM) is carried out to identify the wear mechanism.

1. Introduction

Metal Matrix Composites (MMC) has gained tremendous interest in industrial application in the recent past. The composite materials show improved toughness, strength, and stiffness than the base metal. There are different types of MMCs based on the base metal, reinforcement type and volume fraction of reinforcement. The composites gain mixed properties of the base metal and reinforcement. In case of Al-SiC MMC the tribological testing is carried out by researchers in different testing conditions such as abrasive wear test, dry sliding wear test etc. Ahlatci et al. [1] carried out abrasive test of Al-8%SiC MMC by abrasive wear tester. Sahin et al. [2] performed abrasive wear test of Al-15%SiC at different loads, sliding distances and reinforcement particles size. They observed that reinforcement particle size has the greatest effect on wear. Ma et al. [3] conducted wear test with block-on-ring configuration for Al-20% SiC and Al-50%SiC. From the tests they reported that wear increases with increase in load and sliding speed, while wear decreases with increase in SiC incorporation. It was also observed that at loads of above 100 N and at sliding speed of 6 m/s severe wear took place. Yalcin and Akbulut [4] observed that

wear rate varies inversely with reinforcement volume fraction. Sharma et al. [5] conducted the dry wear test for SiC reinforcement 0-5 volume fraction range and observed that wear rates decrease with increase in volume fraction of the reinforcement. Ghosh et al. [6] have recently considered friction behavior of Al-5%SiC MMC. Another study conducted by Ghosh et al. [7] on the wear behavior of Al-5%SiC metal matrix composite. Onat [8] investigated the dry wear properties of Al-4.5Cu-3Mg/15 vol. % SiC. The materials were tested on a pin-on-disk apparatus at loads 5, 10 and 15 N and sliding speed of 0.5, 1 and 2 m/s against a steel disk (AISI D2). The wear rate increased with increase in load and sliding speed whereas the friction coefficient decreased for increasing load and sliding speed.

Iwai et al. [9] used SiC whisker reinforcement to study the sliding wear behaviour of the composite material. The composite was produced using 2024 Al alloy as matrix metal and was reinforced with SiC whisker reinforcement with volume fraction ranging from 0-16% by powder metallurgy. All the materials showed transition of severe wear to mild wear with increase in sliding speed. The severe wear rate decreased linearly with increase in volume fraction of reinforcement. In another study, Miyajima and Iwai [10] used different types of reinforcement to study the effect of reinforcement on wear behaviour of Al-SiC composite. The reinforcement used is SiC whiskers\particles. The wear tests

- Corresponding author: Prasanta Sahoo
- E-mail address: psjume@gmail.com
- Doi: <http://dx.doi.org/10.11127/ijammc.2014.08.03>

reveal less volume loss for particle reinforced composite than whisker reinforced composite. Venkataraman and Sundararajan [11, 12] studied the sliding wear behaviour of Al-SiC. The study was conducted in two parts; the wear rate and friction coefficient behaviour of the material was studied followed by subsurface deformation due to the wear was studied. The friction test results indicated increase in friction coefficient value with increase in volume fraction of SiC. The wear rates decreased with increase in volume fraction. The effect of matrix hardness on wear behaviour of 6061 aluminium alloy reinforced with 20 vol % Al₂O₃ was investigated by Straffellini et al. [13]. The extruded materials were heat treated at T6 condition (530°C for 1 h, water quenched and aged at 175°C for 16 h). The wear rates increased with T6 heat treatment and forging treatment. The wear rate of the heat treated and forged materials changed from mild wear to severe wear at loads greater than 200N. Straffellini et al. [14] studied the effect of load and temperature on the wear behaviour of the composite Al-SiC. The friction coefficient value for both the material decreased with increase in load with Al-10%SiC exhibiting lower value than Al-20%SiC at higher loads. The microstructure study of the wear tracks showed presence of grooves which indicated abrasive wear effect on the material.

The purpose of the present study is to optimize wear behavior of Al-7.5%SiC MMC. Aluminum LM6 and Silicon Carbide (SiC) are mixed by stir casting process in an electric melting furnace for the synthesis of the metal matrix composite. Wear tests are carried out on Al-SiC for testing the wear behavior of the material. The result is analyzed by Taguchi method. Furthermore, a statistical analysis of variance (ANOVA) is performed to find the statistical significance of test parameters. Finally a confirmation test is carried out to verify the optimal test parameters obtained from the parameter design. The microstructure study is done with the help of SEM to judge the wear mode of the material.

Taguchi method

Taguchi method [15-17] is a powerful tool for designing high quality systems based on Orthogonal Array (OA) experiments that provide much reduced variance for the experiments with an optimum setting of process control parameters. It introduces an integrated approach that is simple and efficient to find the best range of designs for quality, performance and computational cost. This method achieves the integration of Design of Experiments (DOE) [18] with the parametric optimization of the process yielding the desired results. The traditional experimental design procedures focus on the average process performance characteristics. But the Taguchi method concentrates on the effect of variation on the process quality characteristics rather than on its averages. That is, the Taguchi approach makes the process performance insensitive (robust) to variation in uncontrolled or noise factors. Taguchi recommends that this can be done by the proper design of parameters during the "parameter design" phase of off-line quality control. He designed certain standard OAs by which simultaneous and independent valuation of two or more parameters for their ability to affect the variability of a particular product or process characteristic can be done in a minimum number of tests. 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 OA requires a set of well- balanced (minimum experimental runs) experiments. The Taguchi method uses a statistical measure of performance called (S/N) ratios, which are logarithmic functions of desired output to serve as objective functions for optimization. The S/N ratio takes both the mean and the variability into account and is defined as the ratio of the mean (signal) to the standard deviation (noise). The ratio depends on the quality characteristics of the product/process to be optimized. The three categories of S/N ratios are used: Lower the Better (LB), Higher the Better (HB) and Nominal the Best (NB). The parameter level combination that maximizes the appropriate S/N ratio is the optimal setting. For the case of minimization of wear, LB characteristic needs to be used. Furthermore, a statistical Analysis of Variance (ANOVA) is performed to find which process parameters are statistically significant. With the S/N ratio and ANOVA analyses, the optimal combination of the process parameters can be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design.

Experimental detail

3.1 Fabrication process

Metal matrix composite is fabricated in the Metal Forming Lab at Jadavpur University. The alloy matrix used for fabrication is LM6 aluminum alloy and reinforcement is silicon carbide of 400 mesh size. The chemical composition of the matrix material (LM6) and the thermo physical properties of SiCp & LM6 are given in Table 1 & Table 2. The fabrication process chosen for this purpose is liquid metal stir casting technique. The LM6 aluminium is heated and liquefied in an electric melting furnace at 760°C. The layout of the electric melting furnace is shown in fig 1. The melt is mechanically stirred by using an impeller after addition of the pre-heated silicon carbide particle at about 1000°C The mixture is stirred to incorporate the reinforcement in the alloy metal at 750°C and 600 rpm speed. The mixture is then poured in the sand casting and after cooling the casting is cut properly and machined to prepare the samples (20mm x 20mm x 8 mm) suitable for tribological experimentation.

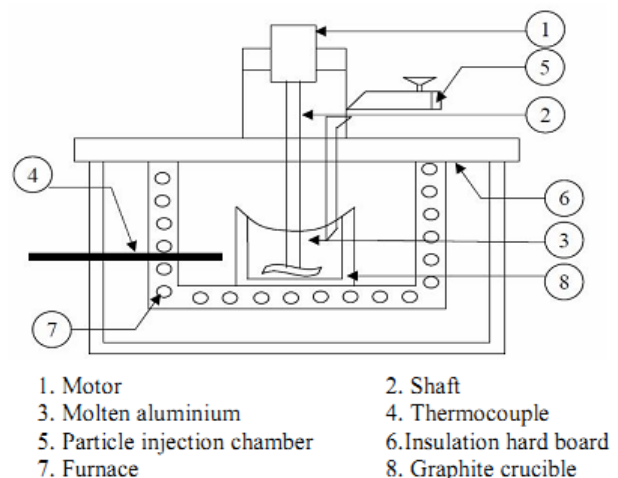


Fig. 1. Layout of electric melting furnace

Table 1. Chemical Composition of LM6

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

Table 2. Thermal and Physical Properties of SiC and LM6

Properties	SiC	LM6
Density(gm/cm ²)	3.2	2.66
Average Particle size (mesh)	400	-
Thermal Conductivity (W/m/K)	100	155
Specific Heat (J/Kg/K)	1300	960

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 the wear behavior of Al-7.5%SiC. For this case the control factors chosen are load, speed and time since these are the significant ones [19]. Table 3 shows the design factors with their levels. The present study considers the wear characteristics of Al-7.5%SiC as the response variable.

Table 3. Design factors used in experiment

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 testing condition

The design of experiment is a powerful statistical technique introduced by Fisher [20]. 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 wear for Al-7.5%SiC metal matrix composite. To choose an orthogonal array the total number of degrees of freedom is to be chosen.

For this experimental purpose L₂₇ orthogonal array is chosen. This L₂₇ 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 + 4x3 = 18). So, the L₂₇ 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 4 shows the orthogonal array.

3.3 Wear test

Wear tests are carried out in a Multi-Tribotester TR25 (Ducom, India) (Fig. 2) under dry non lubricated condition and at ambient temperature (280C). It uses a block-on-roller configuration where EN32 steel roller of hardness 65 HRC is used. The load is

applied by placing dead weight in a loading pan which is connected by a 1:5 ratio loading lever. The Al-SiC samples of dimension 20mm x 20mm x 8mm is placed in the sample holder and pressed against the steel roller. The experimental data is recorded by a computer attached with the apparatus. The wear is measured in terms of wear depth (microns). The wear tests are carried out at different load and speed for different interval of time as mentioned in Table 3.

Table 4. L₂₇ Orthogonal Array with Design Factors

Trial No.	Column												
	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
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	1	2	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

3.4 Microstructure analysis

After wear tests scanning electron microscopy (JEOL, JSM-6360) is done to evaluate the microstructure of the specimens and to know the nature of the wear tracks.

Table 5. Experimental Results

Exp No	Wear	S/N ratio
1	60.07	-35.573
2	71.84	-37.127
3	85.24	-38.613
4	79.44	-38.001
5	94.89	-39.544
6	107.9	-40.66
7	50.14	-34.004
8	69.63	-36.856
9	86.03	-38.693
10	50.63	-34.088
11	61.39	-35.762
12	77.16	-37.748
13	64.45	-36.184
14	82.24	-38.302
15	96.24	-39.667
16	71.07	-37.034
17	89.68	-39.054
18	106.2	-40.522
19	57.24	-35.154
20	67.93	-36.641
21	83.21	-38.404
22	59.24	-35.452
23	67.93	-36.641
24	83.21	-38.404
25	65.58	-36.335
26	89.09	-38.997
27	113.77	-41.121

Table 6. Response Table for Wear

Level	Load (L)	Speed (S)	Time (T)
1	-37.67	-36.57	-35.76
2	-37.6	-38.1	-37.66
3	-37.46	-38.07	-39.31
Delta	0.21	1.53	3.56
Rank	3	2	1

4. Results and discussion

4.1 Analysis of signal to noise ratio

To study wear behaviour, lower the better quality characteristics has been considered and accordingly the signal to noise ratios has been calculated. The expression for lower the better criterion is given in equation (1)

$$S/N = -10\log (\Sigma y^2/n) \tag{1}$$

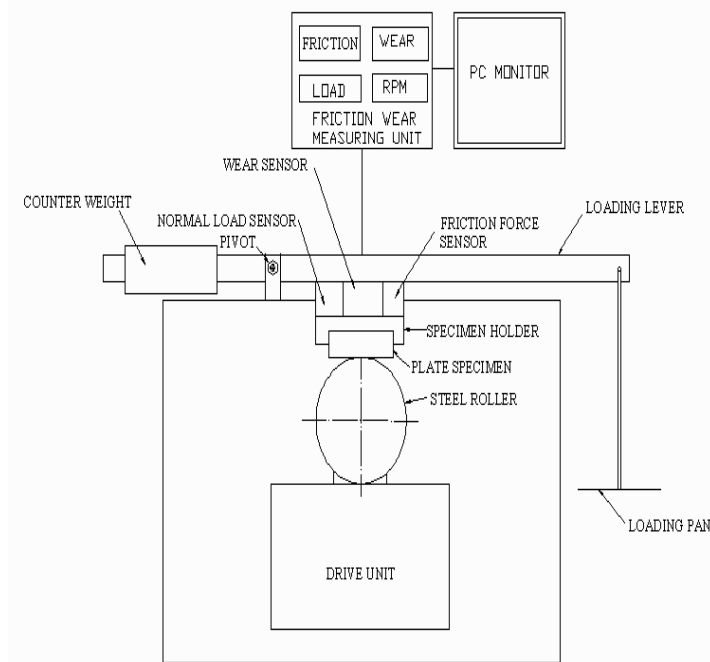


Fig. 2. Layout of multi tribotester

Here, 'y' is the experimental result obtained from the wear testing and 'n' is the number of experiments performed. The experiment is conducted by using three parameters applied load (L), sliding speed (S) and time (T) at three different levels. Table 4 shows the experimental plan and the results of wear with calculated S/N ratios are shown in Table 5. The experimental design being orthogonal, it is possible to separate out the effect of each control factor at different levels. As an example, the mean S/N ratio for factor Load at levels 1, 2 and 3 can be calculated by averaging the S/N ratios for the experiments 1 - 9, 10 - 18 and 19 - 27 respectively. The mean S/N ratio for the other factors at different levels can be calculated in similar manner. Analysis of the influence of each control factor (L, S and T) on wear is obtained from the response table of mean S/N ratio. All the analytical calculations are performed by MINITAB software [21]. The response table is presented in Table 6.

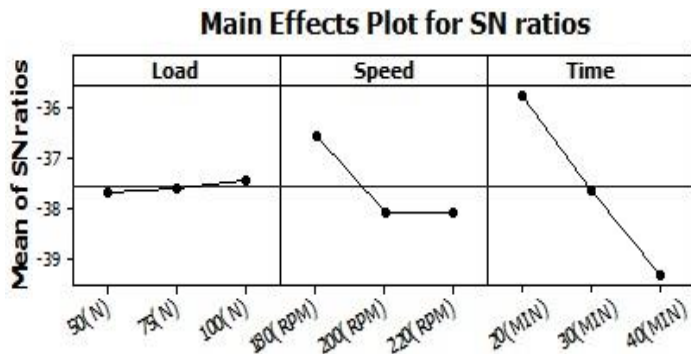
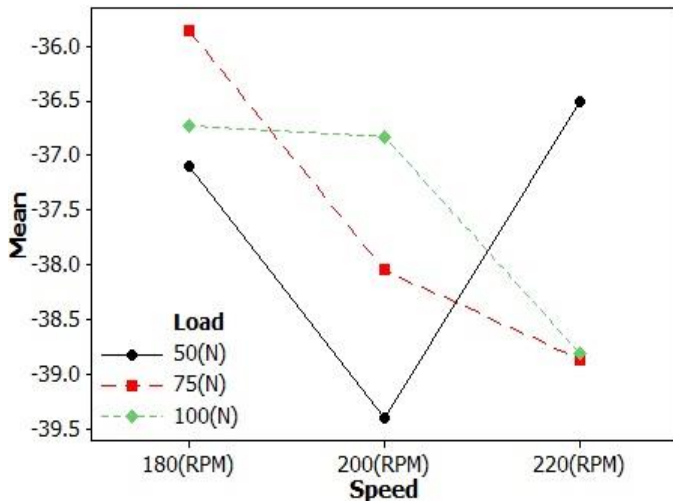


Fig 3. Main effects plot for S/N ratio

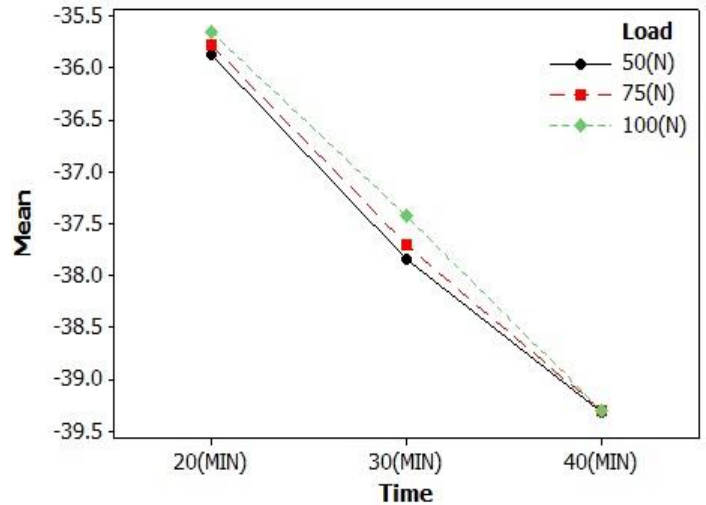
It is clear from Fig. 3 that the S/N ratio is higher at level 3 for parameter L, at level 1 for parameter S and at level 1 for parameter T respectively. Fig. 4(a),(b) and (c) shows the optimum performance at those levels. So, from the figures considering the interactions between the factors the optimal testing parameters combination for minimum wear is found to be L3S1T1. Interaction plots are given in Figs 4(a), (b) and (c). It can be seen from these interaction plots that there is strong interaction between load and speed while there is moderate interaction between speed and time.

4.2 Analysis of variance (ANOVA)

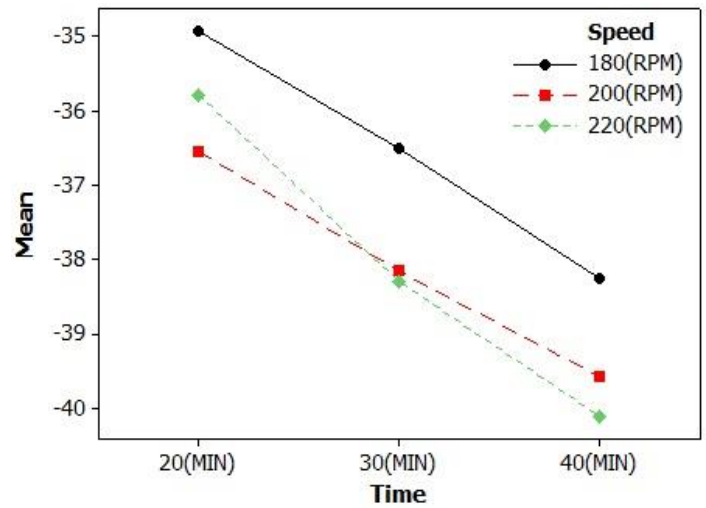
The idea of the analysis of variance is to find out the significance of process parameters and also the percentage contributions of the factors and the interactions in affecting the response. This is accomplished by separating the total variability of the S/N ratio, which is measured by the sum of the 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.



(a)



(b)



(c)

Fig 4 Interaction Plots for (a) Load vs Speed, (b) Load Vs Time & (c) Speed Vs Time

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

$$SS_T = SS_d + SS_e$$

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

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:

$$\rho = \frac{SS_d}{SS_T} \quad (3)$$

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.

$$SS_m = \frac{\text{Sum of squared deviation}(SS_d)}{\text{Number of degrees of freedom of each parameters}} \quad (4)$$

F-value can be found out with following equation:

$$F\text{-value} = \frac{\text{Mean squared deviation}(SS_m)}{\text{Mean squared error}(SS_e)} \quad (5)$$

Table 7. ANOVA table for wear

Source	DF	SS	MS	F	Contribution (%)
L	2	0.21	0.11	0.97	0.21
S	2	13.75	6.88	63.55#	14.25
T	2	56.99	28.50	263.34#	59.07
L*S	4	22.95	5.74	53.02*	23.79
L*T	4	0.13	0.032	0.3	0.13
S*T	4	1.57	0.39	3.63^	1.62
Error	8	0.87	0.11		0.89
Total	26	96.48			100

Significant parameters and interactions (# $F_{0.01, 2, 8} = 8.65$; * $F_{0.05, 4, 8} = 3.84$; ^ $F_{0.10, 4, 8} = 2.81$)

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 $F_{\text{calculated}} > F_{\text{tabulated}}$, that means the parameter has a significance effect on the quality characteristics. Generally when F value increases the significant of the parameter also increases.

The ANOVA table for the wear characteristics of Al-SiC 7.5 wt. % MMC is shown in Table 7. ANOVA table shows the percentage contribution of each parameter. Here the most significant parameter is T (Time) while parameter S (Speed) is also very much significant. It may be observed from the ANOVA table that Speed (% contribution = 14.25) and the time (% contribution = 59.07) and the interaction between L*S (% contribution = 23.79) have great significance on the wear behavior. On the other hand, the interactions between L*T and S*T represent less significant percentages of contribution on the wear behavior of Al-7.5% SiC MMC.

4.3 Confirmation test

After the optimal level of testing parameters have been found, it is necessary that verification test is 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:

$$\hat{\eta} = \eta_m + \sum_{i=1}^o (\bar{\eta}_i - \eta_m) \quad (6)$$

Where, η_m is the total mean S/N ratio, $\bar{\eta}_i$ 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 wear performance of Al-7.5%SiC MMC. Table 8 shows that the comparisons of the estimated and actual wear using the optimal

parameters combination. The improvement of S/N ratio from initial to optimal condition is -3.148 dB which means the wear is decreased by 30%.

Table 8. Result of the confirmation experiment for wear

	Initial parameter	Optimal parameter	Experimental
Level	L2S2T2	L3S1T1	L3S1T1
Wear (μm)	82.24		57.24
S/N ratio (dB)	-38.302	-34.6344	-35.154

Improvement of S/N ratio = -3.148 dB

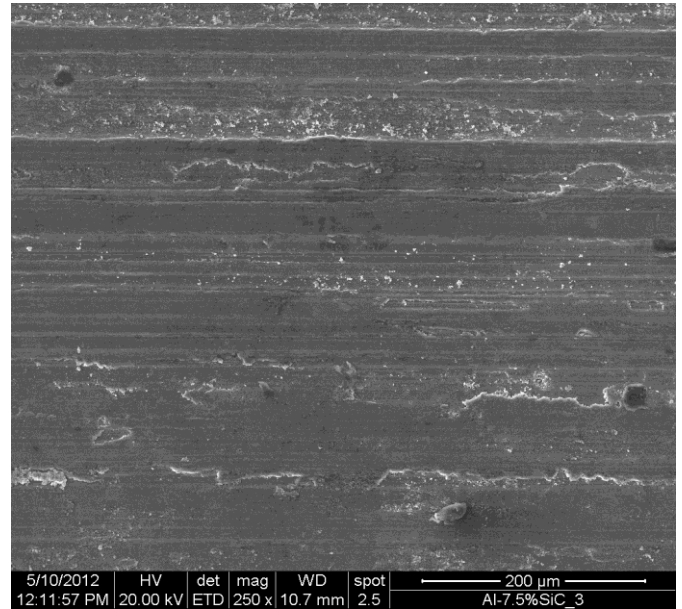


Fig. 5. SEM image of Al-7.5%SiC after wear test

4.4 Analysis of microstructure

Fig 5 shows the SEM micrograph of worn surface of Al-7.5%SiC. From the SEM micrograph it is observed that the worn surface is mainly composed of longitudinal grooves and partial irregular pits along the sliding direction. The presence of grooves indicates the micro-cutting and micro-ploughing effect, whereas pits or rows are indicative of adhesive wear failure of Al-SiC MMC. Micro-cutting and micro-ploughing effect shows that Al-SiC MMC undergoes abrasive wear. Hence the wear phenomenon encountered in case of Al-SiC is predominantly abrasive in nature.

Conclusion

The present paper deals with the tribological performance of Al-7.5% SiC. Optimization of the tribological testing parameters is done with the help of Taguchi's L27 orthogonal array design. Both the main effects as well as interaction effects of the parameters are studied. Also the significance of the design parameters and their interactions considered in this particular study is obtained through ANOVA. The optimal tribological

testing parameter combination for wear for Al-7.5%SiC is found to be L3S1T1. The factors i.e. speed (S) and time (T) are significant parameters affecting the wear behavior, but the factor speed (S) is less significant. The interaction between load and speed (L×S) is the significant interaction. The microstructure study of the wear tracks revealed that mostly abrasive wear phenomenon is encountered.

References

1. H. Ahlatci, E. Candan and H Cimenoglu: *Abrasive wear behavior and mechanical properties of Al-Si/SiC composites*, Wear, Vol. 257, 2004, pp. 625-632.
2. Y Sahin: *Abrasive wear behavior of SiC/2014 aluminum composite*, Tribology International, Vol. 43, , 2010, pp. 939-943.
3. T. Ma, H. Yamaura, D.A. Koss and R.C. Voigt: *Dry sliding wear behavior of cast SiC-reinforced Al MMCs*, Materials Science and Engineering A, Vol. 360, 2003, pp. 116-125.
4. Y. Yalcin and H. Akbulut: *Dry wear properties of A356-SiC particle reinforced MMCs produced by two melting routes*, Materials and Design, Vol. 27, 2006, pp. 872-881.
5. S.C. Sharma, B.M. Girish, R Kamath and B.M. Satish: *Effect of SiC particle reinforcement on the unlubricated sliding wear behavior of ZA-27 alloy composites*, Wear, Vol. 213, 1997, pp. 33-40.
6. S. Ghosh, R. Behera, G. Sutradhar and P. Sahoo,: *Optimization of friction performance of Al-5%SiC metal matrix composite using Taguchi method*, Journal of Tribology Research, Vol. 1, No. 2, 2010, pp. 83-89.
7. S. Ghosh, G. Sutradhar, P. Sahoo: *Wear performance of Al-5% SiC metal matrix composite using Taguchi method*, Journal of Tribology Research, Vol. 2, No. 1, 2011, pp. 33-40.
8. A. Onat: *Mechanical and dry sliding wear properties of silicon carbide particulate reinforced aluminium-copper alloy matrix composites produced by direct squeeze casting method*, Journal of Alloys and Compounds, Vol. 489, 2010, pp. 119-124.
9. Y. Iwai, H. Yoneda, T. Honda: *Sliding wear behavior of SiC whisker-reinforced aluminum composite*, Wear, Vol. 181(183),1995, pp. 594-602.
10. T. Miyajima, Y. Iwai: *Effects of reinforcements on sliding wear behavior of aluminum matrix composites*, Wear, Vol. 255, 2003, pp. 606-616.
11. B. Venkataraman, G. Sundararajan: *The sliding wear behaviour of Al-SiC particulate composite-I Macro behaviour*, Acta mater, Vol. 44, No. 2,1996, pp. 451-460.
12. B. Venkataraman, G. Sundararajan: *The sliding wear behaviour of Al-SiC particulate composite - II The characterization of Subsurface Deformation and Correlation with wear behaviour*, Acta Mater, Vol. 44, No. 2,1996, pp. 461-473.
13. G. Straffelini, F. Bonollo, A. Molinari, A. Tiziani: *Influence of matrix hardness on the dry sliding behaviour of 20 vol.% Al₂O₃-particulate-reinforced 6061 Al metal matrix composite*, Wear, Vol. 211, 1997, pp. 192-197.
14. G. Straffelini, M. Pellizzari, A. Molinari: *Influence of load and temperature on the dry sliding behaviour of Al-based metal-matrix-composites against friction material*, Wear, Vol. 256, , 2004, pp. 754-763.
15. G. Taguchi: *Introduction to Quality Engineering*, Tokyo: Asian Productivity Organization, 1990.
16. J. Ross: *Taguchi Technique for Quality Engineering*, 2nd Edition, McGraw Hill, New York, 1996.
17. R. K. Roy: *A Primer on Taguchi Method*, New York: Van Nostrand Reinhold, 1990.
18. D. C. Montgomery: *Design and Analysis of Experiments*, John Wiley Sons, New York, 2001.
19. P. Sahoo: *Engineering Tribology*, New Delhi: Prentice Hall of India, 2005.
20. R. A. Fisher: *Design of Experiments*, Edinburgh: Oliver & Boyd, 1951.
21. Minitab User Manual, *Making Data Analysis Easier*, Minitab Inc., Pennsylvania State University, Pennsylvania, 2001.