Experimental Investigation and Optimization of Wear Characteristics of Aluminium Metal Matrix Composite Reinforced with Sillimanite (Al2SiO5) by using Taguchi Technique

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Abstract - *In metallurgy wear rate is one of the important mechanical properties for the material selection in manufacturing process. To get the maximum efficiency in machining and product manufacturing, it is important to select the minimum wear rate materials to get the better results. Today minimum wear rate materials are available rather we can form the new minimum wear rate material by the alloy forming using different casting process. This research study project deals with the forming of new minimum wear rate material by adding different proportions of material in to the base material. The base material selected for the study is LM 25 and sillimanite (Al2SiO5) as reinforcement. The properties and wear rate of the material checked by varying the percentage of the reinforcement. Pins were formed by using stir casting method for equal distribution of the reinforcement into base metal. This pins were tested on pin-on-disc machine and then optimization of the result were done by using Taguchi method.*

Key Words: *Aluminium alloy LM25, Sillimanite(Al2SiO5), Wear*

1. INTRODUCTION

Aluminium matrix composites (AMCs) reinforced with ceramic particles have drawn considerable attention in automobile, defence, aerospace, and other structural applications as fuel efficient advanced materials for different tribological applications. These composites provide greater flexibility in tailoring the desired mechanical properties for different engineering applications. Aluminium and its alloys act as a good matrix material for the development of particulate reinforced composites as they possess low density, high specific strength, high corrosion resistance and ease of fabrication with low cost.[1].

PRAMANIK says the effect of reinforcement on the wear mechanism of metal matrix composites (MMCs) was investigated by considering different parameters, such as sliding distance (6 km), pressure (0.14–1.1 MPa) and sliding speed (230–1480 r/min the reinforced particles resist the abrasion and restrict the deformation of MMCs which causes high resistance to wear. These results reveal the roles of the reinforcement particles on the wear resistance of MMCs and provide a useful guide for a better control of their wear.[2] Rama Arora says wear results indicated that the composites containing fine size reinforced particles showed around two times higher wear resistance over a wide range of temperature than the composite-containing coarse particles. A transition in wear mode from mild to severe was observed above 200C. Wear track and wear debris were analysed to understand the nature of wear[3]. The sillimanite particles were added into the matrix melt by creating a vortex with the help of a mechanical stirrer and the melt temperature was maintained between 750 and 8008ºC. The cast composite was characterized in terms of microstructural, mechanical and abrasive wear properties. It was noted that the sillimanite particles were reasonably uniformly distributed within the matrix and exhibited good mechanical bonding with the matrix. The strength of the composite was noted to be marginally lower than that of the base alloy but the hardness and the wear resistance of the composite were found to be signifcantly higher than those of the base alloy[4]. The Sillimanite reinforced metal matrix composite of 5, 10 weight percent was fabricated by vacuum assisted stir casting method and their properties such as density, hardness, tensile and impact strength are reported. For

Figure 1: Stir Casting method for MMC

comparison pure aluminum is taken into consideration and found that the addition of sillimanite reinforcement increase the hardness, tensile, impact strength only in 5 wt. % after that there is no substantial improvement in the mechanical properties.[5] From literature review it is found that sillimanite as reinforcement is used in different aluminium alloy except Lm25 aluminium alloy .So that in this we are concentrating on Aluminium LM25 alloy reinforced with sillimanite and considering parameters like reinforcement, load, sliding distance and temperature.

2. OBJECTIVES OF EXPERIMENT

The objectives of this study are:

1. The primary objective of this study is to improve the wear resistant property of the aluminium alloy as base metal and sillimanite as reinforcement.
2. To fabricate the pins for experiment with even and equal distribution of the reinforcement particles which is varying in order of 3%, 6%, and 9% into the aluminium alloy LM25 base metal by using stir casting technique.
3. To find optimum values of different parameters like load, sliding distance, reinforcement and temperature and to obtain mathematical model with the help of Taguchi technique.

3. EXPERIMENTAL SETUP

3.1 Speciman Details

Aluminium alloy LM25 with Sillimanite was selected as a composite material mainly used in friction brakes, disc brakes of the vehicle which are subjected to wear. Sillimanite(Al_2SiO_5) is selected as a reinforcement material because of it's chemical stability, low friction coefficient, and good mechanical properties. Sillimanite(Al_2SiO_5) is added into the base metal in order of 3%,6%,and 9% with the help of stir casting method.

Figure 2: Pin produced after machining

The chemical composition of the Aluminium alloy LM25 material is shown in Table 1.

Table 1: Chemical Composition of Brass material

Sr. No.	Element	Percentage
1	Si	7.11
2	Mg	0.51
3	Mn	0.2
4	Fe	0.12
5	Cu	0.2

6	Ni	0.04
7	Zn	0.08
8	Ti	0.01
9	Al	Balanced

3.2 Microstructure

Microstructure of developed composite was analyzed through electron microscope in order to identify the distriburion of reinforcement particles in metal matrix. SEM was done at Dr. Babasaheb Ambedkar Marathwda University, Aurangabad.

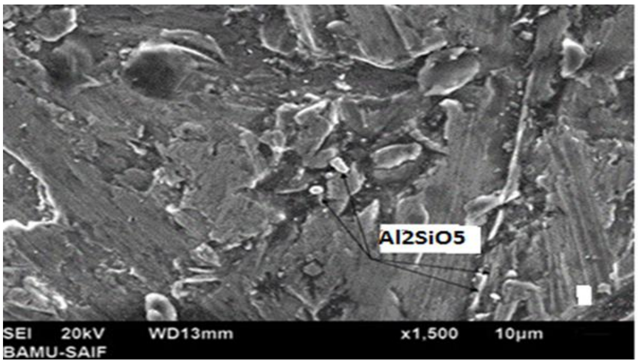

Figure 3: Aluminium LM25+3% Al2SiO5

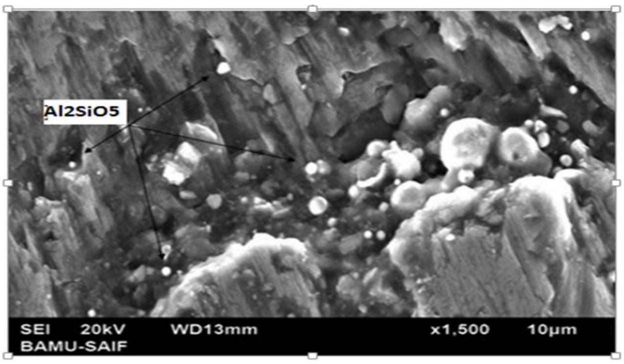

Figure 4: Aluminium LM25+6% Al2SiO5

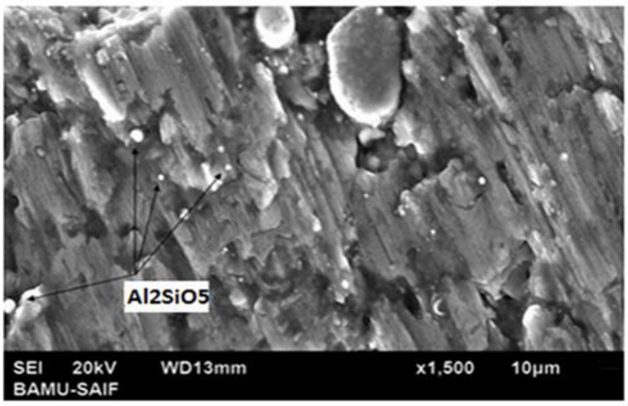

Figure 5: Aluminium LM25+9% Al2SiO5

From the images of Scanning Electron Microscope it was clear that there is a presence of Al2SiO5 reinforcement particles in Aluminium alloy LM25 metal matrix composite. The distribution of reinforcement Al2SiO5 particle was homogeneous and uniform.

3.3 Wear test

Tribological tests under dry condition was carried out on Pin ON Disc machine according to American Society of Testing Materials (ASTM) G99 standards. The wear test samples was machined with pin dimension 12 mm diameter and 29 mm length. The connterface surface is made up of EN31 steel with hardness 62 HRC. The readings were taken for constant 100mm track diameter and 10 min. of testing time. To remove debris and impurities the disc and pin were clean with aceton after each test.

The weight loss was measured by using weighing machine having least count of 0.0001g. Percentage Reinforcement, Load, temperature, sliding velocity were taken as input parameter and readings of wear rate were obtained.

Figure 6: Schematic Setup of Pin ON Disc Machine

Wear rate calculations:

$$Specific\ Wear\ Rate = \frac{(M1 - M2)X10\text{^}3}{\rho FL}$$

Wear rate calculations:

Wear rate in mm3/N-m

M1-M2= Mass loss in grams

ρ: Density of Brass in gm/cc

L: Sliding distance in the meter.
F: Load in Newton.

3.4 Design of Experiment

Important objective of Taguchi design is to minimize the number of experiments, which gives information about all the effect of input parameters on output responses. The arrangement of levels of input parameters in systematic way knows as orthogonal array. In Taguchi design the response was normalized in form of Signal to Noise ratios. S/N ratios with 'Smaller is better' is selected and calculated as follows.

$$SN\ ratio = -10 \times \log(\sum((wear_1^2 + wear_2^2 + wear_3^2) \div 3)$$

Table 2: Layout of Orthogonal Array

Run	Al2SiO5	Load(N)	SV	Temperature
1	3	15	2.5	100
2	3	20	3.5	125
3	3	25	4.5	150
4	6	20	2.5	150
5	6	25	3.5	100
6	6	15	4.5	125
7	9	25	2.5	125
8	9	15	3.5	150
9	9	20	4.5	100

3.5 Anova

ANOVA technique is a Statistical tool which shows the degree of adequacy for number of different variables. -The results were carried out for 95% level of confidence i.e., P values are less than 0.05. It also shows the percentage contribution of each factor and it's variation which influence on the result is most.

4. RESULTS AND DISCUSSION

4.1 Analysis of Process parameters

SN ration is used to normaliszed the experimental data in specific range. SN ratios were calculated and the response for SN ratio smaller is better selected.

SN ratio for one trial

$$SN\ ratio = -10 \times \log(\sum((0.4841^2 + 0.4829^2 + 0.4631^2) \div 3)$$

SN ratio=6.20366

Similarly, Signal to Noise ratio values can be obtained for other experimental runs in orthogonal array.

Table 3: Cumulative data for SN ratio Aluminium Composite Wear

SR NO.	% Al2SiO5	Load	SV	Temperature	Specific Wear Rate (10^{-3}) ($mm^3/N.m$)	S/N RATIO
1	3	15	2.5	100	0.4632	6.20366
2	3	20	3.5	125	0.4919	6.41566
3	3	25	4.5	150	0.5152	6.47795
4	6	15	3.5	150	0.4722	6.60548
5	6	20	4.5	100	0.4606	6.39071
6	6	25	2.5	125	0.5015	6.10058
7	9	15	4.5	125	0.4671	6.38180
8	9	20	2.5	150	0.4856	6.40843
9	9	25	3.5	100	0.4707	6.36952

Main Effect Plots for SN ratios

The graph 4 show the Main Effect plot for S/N ratio for Brass composite with Al2SiO5. The level of a factor which having highest SN ratio is selected as optimum respond measured. The optimum parameter for wear rate were 9% percentage Al2SiO5 (level 3),15N of load (level 1), 100◦C temperature (level 1), 3.5 m/s sliding velocity (level 2).

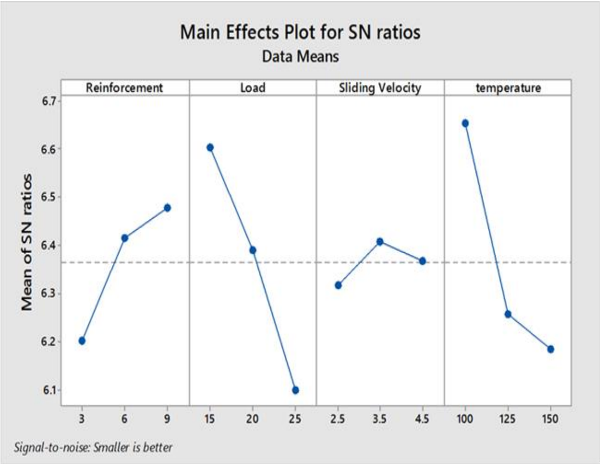

Figure 7: Effect of various parameters on mean of S/N ratios for specific wear rate

4.2 Analysis of Variance

Table 4 shows the ANOVA result of wear for Aluminium alloy Lm25 with Sillimanite composite. It is clear from the table that Applied Load (33.63%),) has great influence on lowering the wear rate followed by Reinforcement (44.92%), temperature (12.2%) and sliding velocity (5.17%) which indicates that there is appreciable increase in wear rate by increasing load and sliding velocity of the experimentation

Table 4: ANOVA result of Aluminium alloy LM25 Composite for Wear

Source	DOF	Adj SS	Adj MS	F-Value	P-Value	%Contribution
%Al2SiO5	2	0.71549	0.357747	49.64	0.012	44.92%
Load	2	0.53576	0.267878	37.17	0.037	33.63%
SV	2	0.06644	0.033222	4.61	0.32	5.17%
Temperature	2	0.21050	0.105250	14.61	0.046	12.2%
Residual Error	9	0.064486	0.007206			4.04%
Total	17	1.59305				100%

R-Sq	R-Sq (adj)	R-sq (Pred)
95.93%	92.31%	83.71%

4.3 Regression Model

To estabish the relationship between input parameter Load, % reinforcement, temperature and sliding velocity with output parameter wear rate, linear regression model for best fitting curve is used. The equation obtained using MINITAB 17.0 is given below.

4.4 Confirmation Test

Regression Equation:

Specific Wear Rate = 0.39550 - 0.00643 Al2SiO5% + 0.00283 load + 0.00047 sv + 0.00025 temp........(1)

Substituting the values of different variables in above equation we can get the value of specific wear rate in equ(1).

The confirmation test is carried out by to test the accuracy of the model by selecting different variables. The results obtained by comparing the equation correlate the evaluation of wear rate in the composite with the degree of approximation. It can be observed from table 6 that the calculated error varies 4.77 % for wear.

Table 5: Optimum level of parameters for aluminium composite

Sr. No.	Parameter	Optimum level
1	%Al2SiO5	9%
2	Load	15 N
3	Sliding Velocity	2.5 m/sec
4	Temperature	100◦C

Table 6: Confirmation experiment result of Aluminium composite

Parameter	Predicted value	Experimental value	Error %
Wear rate	0.4819	0.4589	4.77%

5. CONCLUSIONS

1. The composite with 3%, 6% and 9% of sillimanite as reinforcement was fabricated through stir casting technique.
2. Taguchi optimization technique obtaines optimum parameter for wear rate were 9% percentage of sillimanite (level 3), 15N of load (level 1),100◦C temperature(level 1), 3.5 m/s sliding velocity (level 2).
3. ANOVA analysis results percentage contibution of each parameter load with (33.63%), and %reinforcement (44.92%), temperature (12.2%), sliding velocity (5.17%).
4. The Multiple Linear Regression equation is obtained from MINITAB 17.0 correlate the evaluation of wear rate in the composite.
5. It can be observed from table 6 that the calculated error varies 4.77% for wear.

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