Effect of T6 type heat treatment on dry sliding wear behaviour of LM6/SiCp using Taguchi and ANOVA

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Abstract- In this study, the effects of T6 type heat treatment of LM6 reinforced with SiCp were prepared by stir casting techniques. The LM6 composite reinforced with 5 wt% and 15 wt% of SiCp. Dry sliding wear test is conducted using pin-on-disc testing machine. L9 orthogonal array was selected for the experimental run. The optimum process parameters were determined by using signal-to-noise ratio. S/N ratio and ANOVA were used to investigate the influence of process parameters on the wear rate. The regression analysis employed to find the optimal process parameters levels and to analyze the effect of process parameters on LM6/SiCp.
Keywords: ANOVA, composites, Heat treatment, smaller-the-better, Taguchi Technique.

I. INTRODUCTION

Amid the previous couple of years, materials plan has moved accentuation to pursue light weight, environment friendliness, ease, quality, and performance. Parallel to present trend, metal-matrix composites (MMCs) are attracting growing interest. The requirement for cutting edge engineering materials within the areas of aerospace and automotive industries had led to a fast development of metal matrix composites (MMC)[1-4]. The utilization of various metal matrix composites (MMCs) is continually since they have better physical, mechanical and tribological properties compared to the matrix materials. Aluminium matrix composites (AMCs) reinforced with ceramic particles are gaining wide spread popularity in several technological fields owing to their improved mechanical properties when compared with conventional aluminum alloys[4-10] . They exhibit higher mechanical properties than the unreinforced aluminium alloys and are used as tribological components in some vehicles for years thanks to their high specific strength and better wear resistance[10-15] Rajashekhar et.al[16] Studied on Effect of Heat Treatment on Mechanical Properties of Hybrid Aluminum Matrix Composites hybrid composite materials developed with soft and hard reinforcements subjected to heat treatment for further enhancement of their mechanical properties have shown keen interest in the last few decades. Sridhar Bhat et.al investigated Effect of Heat Treatment on Microstructre and Mechanical Properties of Al-FA-Sic Hybrid MMCS. In this investigation Preheated silicon carbide (SiC) And Fly Ash(FA) was used as the reinforcements, produced by stir casting process. Cut pieces of alloy Al6061 were preheated at 450 °C for 1h before melting. Firstly SiC and Fly Ash particles were heated at 8000C for 2 hrs. before adding preheated SiC and Fly Ash particles in to Al6061 melt, 1Wt% of Mg is added to melt to improve the wettability between matrix and reinforcement. Daljeet Singh et.al investigated Mechanical behavior of Aluminum by adding SiC and Alumina. This work is focused to study the change in behavior of aluminum by adding different %age amount of 'Sic' and 'Al2O3' composites. Vijay Kumar S Maga et.al[17] studied on Mechanical Properties of Aluminium Alloy (Lm6) Reinforced With Fly Ash, Redmud and Silicon Carbide. This deals with fabricating or producing aluminium based metal matrix composite and then studying its microstructure and mechanical properties such as tensile strength, impact strength and wear behavior of produced test specimen. Satpal Kundu et.al[18] investigated of hybrid metal matrix composites with SiC, Al2O3 and graphite reinforced aluminium alloy (Al 6061T6) composites samples, processed by stir casting route are reported. The aluminium alloy was reinforced with 10 wt. % (SiC, Al2O3) and 5 wt. % of graphite to mixture the hybrid composite. Dry Sliding Wear of the hybrid composite were tested it was found that when the wear resistance of the hybrid composites can be increased when compared to Al6061 T6 alloy. The parameters such as load, sliding speed and sliding distance were identified will affecting wear rate.

Hence, Present work is focused on the effect of T6 type heat treatment on the tribological wear behavior of LM6 /SiCp MMC.

II. EXPERIMENTAL METHOD

A. Fabrication Process

Stir casting set up as shown in the Fig.1 consisted of resistance furnace and a stirrer assembly was used to synthesize the composite.

Fig 1: shows the graphical representation of Stir casting and Resistance Furnace

The matrix material used for the present study is LM6 Al-Sic alloy. The chemical composition of matrix material is as shown in Table 1 determined using Atomic Absorption Spectrophotometer (model AA-670, Varian, The Netherlands). SiC particles with size of 150µm and with varying amounts of 0, 5 and 15 wt% are being used as reinforcing material in the preparation of composites. Stir casting technique has been used for the preparation of composites. Initially calculated amount of LM6-alloy was charged into Gr crucible and superheated to a temperature of 750^0C in an electrical resistance furnace.

The furnace temperature was controlled to an accuracy of $\pm 50^0$C using a digital temperature controller. Sliding wear test specimens were machined from as-cast samples, to obtain cylindrical pins of diameter 10 mm and length 24 mm. then the samples were subjected to heat treatment (T6 type), where composites have been subjected to solutionizing treatment at 530^0C for 1 h followed by quenching in water. The quenched samples again subjected to artificial aging at 170^0C for 6 h followed by air cooled.

Table1: Composition of LM6 alloy

Elements	**Percentage (%)**
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	Remaining

B. Wear test

Dry sliding wear tests for different number of specimens was conducted by using a pin-on-disc machine (Model: Wear & Friction Monitor TR-20) supplied by DUCOM, was shown in Figure.2.

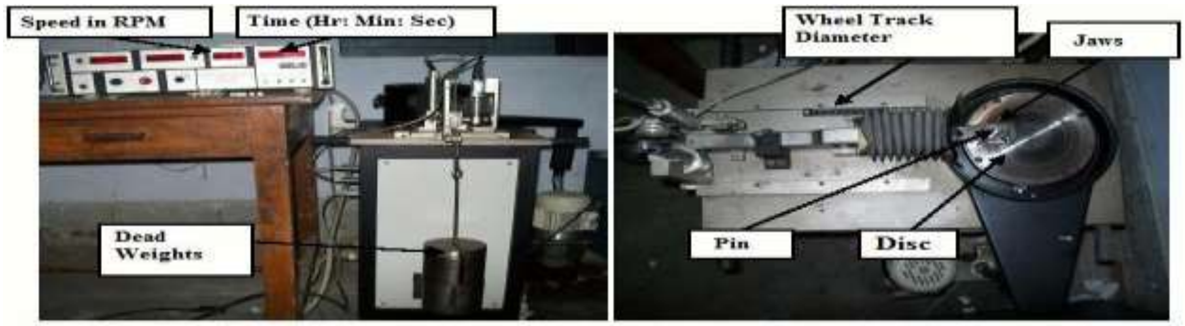

Fig. 2:- Showing Wear Testing Machine

The pin was held against the counter face of a rotating disc (EN32 steel disc) with wear track diameter 80mm. The pin was loaded against the disc through a dead weight loading system. The wear test for all specimens was conducted under the normal load of 1,3 & 5 kg . Wear tests were carried out for a total sliding distance of approximately 1000m under similar conditions as discussed above. The pin samples were 24 mm in length and 8 mm in diameter**.** The surfaces of the pin samples was slides using emery paper (80 grit size) prior to test in ordered to ensure effective contact of fresh and flat surface with the steel disc. The samples and wear track were cleaned with acetone and weighed (up to an accuracy of 0.0001 gm using microbalance) prior to and after each test. The wear rate was calculated from the weight loss technique and expressed in terms of wear volume loss per unit sliding distance.

C. Taguchi Method

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 experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels. This technique is carried out in a three stages 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. Tolerance deign is used to determine and analyze tolerance about the optimum combination suggested by parameter design.

Table 2: Control and Noise Factors

Sl.No.	Process Parameters	Level 1	Level 2	Level 3
1	SiCp (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

D. Design of Experiment

The experimental plan was formulated considering three parameters (variables) and three levels based on the Taguchi technique. % of SiCp (A), Normal Pressure (B) and Sliding Speed (C), these are process parameters are considered for the study. Process parameters setting with the highest S/N ratio always yield the optimum quality with minimum variance. The levels of these variables chosen for experimentation are given in the Table 2.

In the present investigation an L9 orthogonal array was chosen as 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. The S/N ratio for the wear rate and coefficient of friction using 'smaller the better' characteristics, which can be calculated as logarithmic transformation of the loss function is given as

$$S/N = -10 \log_{10} (MSD) \quad \text{------------ (1)}$$

Where MSD = Mean Square Deviation

For the smaller the better characteristic,

$$MSD = (Y_1^{\ 2} + Y_2^{\ 2} + Y_3^{\ 2} + \ldots\ldots\ldots) \times 1/n$$

Where Y1, Y2, Y3 are the responses and 'n' is the number of tests in a trial.

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

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

Expt Run	Process Parameters			Volumetric Wear rate (mm^3/m)	S/N ratio for Vol. Wear rate (db)	COF (N)	S/N ratio for COF (db)
	% of SiCp	Nr. Pressure (MPa)	Sliding speed (m/s)				
01	0	0.19	1	8.92857E-5	80.9844	0.34659	9.2037
02	0	0.59	3	4.01786E-4	67.9201	0.35338	9.0352
03	0	0.990	5	6.69643E-4	63.4831	0.4159	7.6202
04	5	0.19	3	2.67857E-4	71.4419	0.22426	12.9850
05	5	0.59	5	4.91071E-5	86.1771	0.49269	6.1485
06	5	0.990	1	9.375E-4	60.5606	0.33843	9.4106
07	15	0.19	5	2.23214E-4	73.0256	0.42813	7.3685
08	15	0.59	1	5.35714E-5	85.4213	0.36697	8.7074
09	15	0.990	2	9.82143E-4	60.1565	0.58308	4.6854

III. RESULTS AND DISCUSSION

The experiments were conducted as per the orthogonal array and the volumetric wear rate for various combinations of process parameters. The experimental values were remodelled into S/N quantitative measuring for measure the standard characteristics using MINITAB 16.

A. Analysis of S/N Ratio

In Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristics and the term 'noise' represents the undesirable value for the output characteristics. Taguchi uses S/N ratio to measure the quality characteristics deviating from the desired value. The volumetric wear rate and COF readings are shown in Table 4. The influence of control parameters such as Normal pressure, Sliding speed and wt% of reinforcement content has been analyzed and the rank of involved factors like wear rate of composite materials which supports S/N ratio response is given in the table 5 & 6 and for COF is given in the table 7 & 8. It is evident from the table that among these process parameters, normal pressure is a dominant factor on the wear rate. The influence of controlled process parameters on wear rate are graphically represented in figures 3 and 4 and for COF are graphically represented in figures 5 and 6. The response tables 3, 4 and 5, 6 shows the average value of each response characteristics (S/N ratios, means) for each level of each factor for volumetric wear rate and COF of LM6-SiCp composites. The table indicates ranks based on Delta statistics, which compare the relative magnitude of effects of all the parameters. The Delta statistic is the highest minus the lowest average of S/N ratio and mean for each factor. Minitab 16 assigns ranks based on Delta values; rank 1 indicates highest Delta value, rank 2 second highest, and so on.

Table 5: Response Table of volumetric wear rate for S/N Ratio Smaller is better

Level	% of SiCp	Nr. Pressure	Sliding speed
1	70.80	75.15	75.66
2	72.73	79.84	66.51
3	72.87	61.40	74.23
Delta	2.07	18.44	9.15
Rank	3	1	2

Table 6: Response Table of volumetric wear rate for mean

Level	% of SiCp	Nr. Pressure	Sliding speed
1	0.000387	0.000193	0.000360
2	0.000418	0.000168	0.000551
3	0.000420	0.000863	0.000314
Delta	0.000033	0.000695	0.000237
Rank	3	1	2

Table 7: Response Table of COF for S/N Ratio (Smaller is better)

Level	% of SiCp	Nr.Pressure	Sliding speed
1	8.620	9.852	9.107
2	9.515	7.964	8.902
3	6.920	7.239	7.046
Delta	2.594	2.614	2.061
Rank	2	1	3

Table 8: Response Table of COF for mean

Level	% of SiCp	Nr.Pressure	Sliding Speed
1	0.3720	0.3330	0.3507
2	0.3518	0.4043	0.3869
3	0.4594	0.4458	0.4456
Delta	0.1076	0.1128	0.0949
Rank	2	1	3

In the experimental run our goal was to minimize the volumetric wear rate and COF of LM6-SiCp composites. In Taguchi experiments, we always want to maximize the S/N ratio. The S/N ratios with high values in the response tables 5 and 7 shows that the S/N ratios can be maximized at these levels and wear can be minimized at these levels.

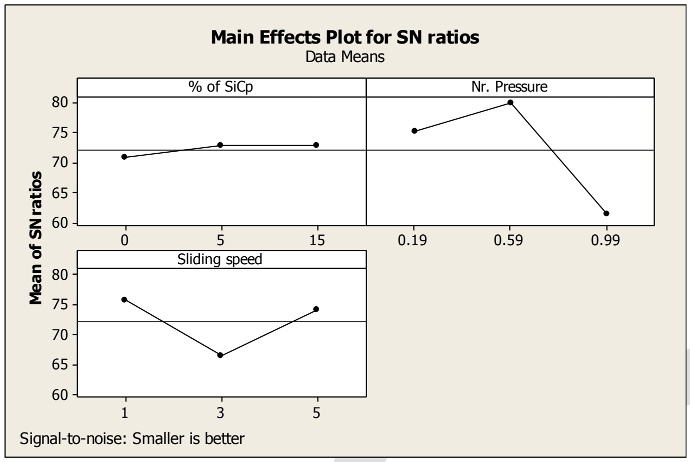

Fig 3: Main Effects Plot for SN ratios – volumetric wear rate

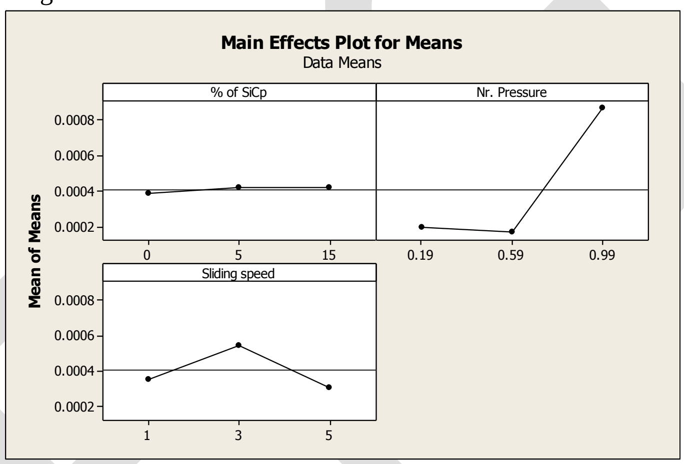

Fig 4: Main Effects Plot for Means- volumetric wear rate

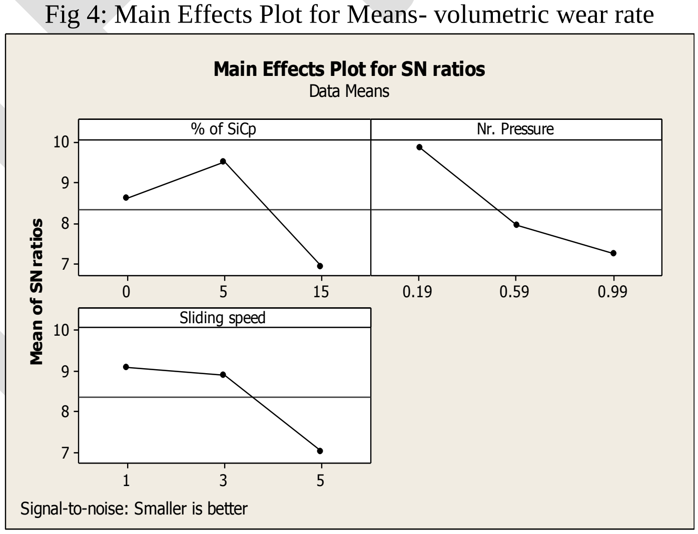

Fig 5: Main Effects Plot for SN ratios – COF

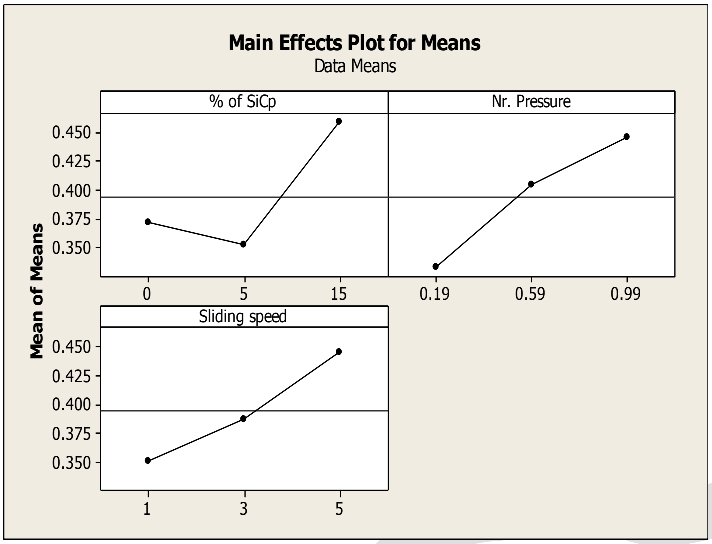

Fig 6: Main Effects Plot for Means- COF

Main effects plot is a plot of the means at each level of a factor. One can use these plots to compare the magnitudes of the various main effects and compare the relative strength of the effects across factors. However it is important to be sure to evaluate significance by looking at the effects in the analysis of variable table.

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. When % of SiCp is 15, Nr. Pressure 0.59 MPa and sliding speed is 1m/s for LM6-SiCp composite the volumetric wear is minimum. Similarly, when % of SiCp is 10, Nr. Pressure 0.19 MPa and sliding speed is 1m/s for LM6-SiCp composite the COF is minimum. Examining the main effects plots and interaction plots confirms the above results.

B. Analysis of variance

Analysis of 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 purpose of ANOVA is to investigate the percentage of contribution of variance over the response parameter and to find the influence of wear parameters. The ANOVA is also needed for estimating the error of variance and variance of the prediction error. The table 4.6 shows analysis of variance for volumetric wear rate of the composite material. From the table 9, it is observed that the normal pressure, sliding speed and wt% of reinforcement have the influence on wear of composite material. The last column of the table 9 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 normal pressure (75.01) was the most significant parameter on the dry sliding wear of composites followed by sliding speed (08.33) and SiCp wt% (08.33). It can be observed from the ANOVA Table 10 that the SiCp wt% (23.46) was the most significant parameter on the COF of composites followed by Nr. pressure (23.35) and sliding speed (16.44). 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 08.33% for volumetric wear rate and 36.75% for COF. This approach gives the variation of means and variance to absolute values considered in the experiment and not the unit value of the variable.

Table 9: Analysis of Variance for volumetric wear rate (mm^3/m)

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% of contribution
% of SiCp	2	0.0000001	0.0000001	0.0000001	0.03	0.967	08.33
Nr. Pressure	2	0.0000009	0.0000009	0.0000005	15.57	0.060	75.01
Sliding speed	2	0.0000001	0.0000001	0.0000000	1.58	0.388	08.33
Error	2	0.0000001	0.0000001	0.0000000			08.33

Total	8	0.0000012					100

Table 10: Analysis of Variance for COF

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% of contribution
% of SiCp	2	0.01963	0.01963	0.00981	0.64	0.610	23.46
Nr. Pressure	2	0.01954	0.01954	0.00977	0.64	0.611	23.35
Sliding speed	2	0.01376	0.01376	0.00688	0.45	0.691	16.44
Error	2	0.03073	0.03073	0.01537			36.75
Total	8	0.08366					100

C. Multiple Linear Regression Models

Statistical software MINITAB R16 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 volumetric wear rate is,

Volumetric Wear rate = -6.36427e-005 + 1.892e-006 % of SiCp + 0.000837054 Nr. Pressure - 1.15327e-005 Sliding speed ------------ (2)

R-Sq = 94.50%

The regression equation developed for COF is,

Regression Equation

COF = 0.196444 + 0.00653352 % of SiCp + 0.141013 Nr. Pressure + 0.0237275 Sliding speed ------------ (3)

R-Sq = 63.26%

IV. CONCLUSION

LM6/SiCp composites can be made in an open atmosphere by stir casting using fabrication scheme derived from the literature review and mentioned in the experimental.

Based on the above analysis the following conclusions are drawn from the present study.

1. In this study, hardness and analysis of mechanical characteristics of Al-SiC reinforced with 0, 5 and 15 wt% of SiC was examined with and without heat treatment. With the increase in reinforcement ratio, the impact strength and hardness of the aluminium silicon carbide metal matrix composite material is increased.
2. Taguchi method provides a systematic and efficient methodology for the design and optimization of volumetric wear rate parameters with far less effort than would be required for most optimization techniques.
3. For LM6-SiCp the optimal tribological testing combination for minimum volumetric wear rate is found to be when % of SiCp is 15, Nr. Pressure 0.59 MPa and sliding speed is 1m/s and minimum COF is found to be when % of SiCp is 5, Nr. Pressure 0.19 MPa and sliding speed is 1m/. All the factors % of SiC (A), Nr. Pressure (B) and sliding speed(C) are found to affect the friction significantly.
4. The analysis of variance shows that the Normal pressure (75.01%) is the wear factor that has the highest statistical influence on the dry sliding wear of composites followed by sliding speed (8.33%) and reinforcement (8.33%) and and reinforcement (23.46%) is the COF that has the highest statistical influence on the dry sliding wear of composites followed by sliding speed (16.44%) and Normal pressure (23.35%).
5. The pooled error associated with the ANOVA analysis was 8.33% for wear rate and 36.75% for COF for the factors and the correlation between the wear parameters was obtained by multiple linear regression models.

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