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Effect of Heat Treatment on Dry Sliding Wear Behaviour of AA6061-SiC Metal Matrix Composites by Taguchi Techniques

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Abstract: In the present study, metal matrix composites of AA6061 matrix with varying composition of 3%, 6% and 9wt.% SiC were prepared by liquid metallurgy route. The cast composites have been subjected to solutionizing heat treatment at a temperature of $525^0 \pm 2^0$C for 6 hours followed by ageing at a temperature of $175^0 \pm 2^0$C for 4 hours. The wear and frictional properties of metal matrix composites were studied by conducting dry sliding wear test using Pin on Disc machine as per ASTM G-99 standard. The wear tests were carried out by using Taguchi technique. The L9 orthogonal array and analysis of variance approach was employed to study the effect of wear parameters such as load, percentage reinforcement and sliding distance on wear rate of the composites. The effect of wear parameters on wear rate of the composites was studied. The experimental results revealed that applied load (52.70%) had the most significant effect on wear rate of composites than the reinforcement percentage (26.37%) and sliding distance (19.39%). The worn surfaces of samples were examined by using Scanning Electron Microscope (SEM) photographs to analyze the nature of wear mechanism.

Index Terms **- Taguchi technique, Wear, MMC, AA6061, SiC**

I. INTRODUCTION

It is well known that aluminium and its alloys being lightweight materials have huge applications in the area of automotive and aerospace applications. Taking a cue from their low density and moderate strength properties, many researchers across the world have developed composite materials using organic and ceramic based materials as reinforcement [1]. Among the various series of aluminium alloys, the AA6061 is better choice for a matrix material because it has excellent mechanical properties, good formability and the strength of this material can be altered by doing the heat treatment [2]. Most commonly used reinforcements are SiC, Al_2O_3, graphite, TiB_2, TiC, B_4C and carbon nanotubes. The stir casting method is found to be easier and the low cost production method when compared to other processing methods, particularly when discontinuous reinforcements are used [3, 4].

Deuis, et.al [5] reported the influence of volume fraction and particle size on the wear behaviour of aluminium composites. They concluded that the most significant parameter on the wear rate was sliding distance and applied load. Radhika et.al [6] reported that the Taguchi technique is a better technique to deal with responses influenced by multivariable. Dutta and Bourell [7] expounded that accelerated ageing in MMCs can be attributed to an increase in dislocation density in the vicinity of the reinforcements or to the matrix residual stress field near reinforcements. Both mechanisms aid the diffusion of solute atoms, thereby leading to more rapid precipitation.

In a study conducted using the Al /SiC composites, it was found that the presence of SiC particles led to increasing the peak hardness of the alloy [8]. It was suggested that the principal hardening mechanism of the composites is due to the residual dislocations. Other contributions due to grain/sub grain structure, particle strengthening and/or initial work hardening would represent a factor of 0.3 due to the residual dislocations [9-10].

Basavarajappa et.al [11] found that graphite particles addition into aluminiummatrix increases wear resistance of the composite. Most of the studies have been carried out on Al-Gr [12, 13] and Al-SiC [14, 15] composites individually. From the literature survey, not much work has been reported on the effect of heat treatment, applied load, % reinforcement and sliding distance on the drysliding wear behaviour of AA6061-SiCcomposites. In view of the above, an attempt was made to study the effect of these parameters on AA6061-SiC composites using Taguchi design of experiments.

II. TAGUCHI TECHNIQUE

. Taguchi technique is a powerful tool for designing high quality systems based on orthogonal array (OA). It is a reliable and systematic approach to optimize designs for performance, quality and cost [16]. There are several orthogonal arrays based on the process Parameters and their levels. The suitable Orthogonal Array is selected and the experiments are conducted as per the OA specifies. The experimental results are analyzed by signal to noise ratio (S/N) values. The S/N ratios are categorized into three types i.e. lower the better (LB), higher the better (HB) and nominal the best (NB). This will be selected based on the response of the process, since here theresponse is the wear rate and we have to minimize the value of the response so LB characteristics needs to be applied here. The Mathematical equation for smaller is better S/N ratio is represented in equation 1. Furthermore Analysis of Variance (ANOVA) was performed to find out which parameter is significant over the other and to find the percentage of contribution of each parameter on the wear rate. With the help of the S/N ratio and ANOVA analysis, the optimal combination of process parameters can be obtained. At last a confirmation test was performed to verify the optimal process parameters.

S/N = - 10 log (y12 + y22 + y32 + ...+ yn2)   (1)

Where y1, y2, y3,   yn, are the response of sliding wear, n is the number of observations.

III. MATERIALS, METHODS, PROCESSING AND TESTING OF COMPOSITES

3.1 Materials and Methods

The matrix material selected for the present research study is AA6061. The reinforcing material selected were SiC particles of 10 to 30 µm size. The chemical composition of AA6061 alloy by weight percent Si = 0.72, Mg = 0.89, Cu = 0.21, Fe = 0.23, Cr = 0.22, Zn = 0.10, Ti = 0.01 and Al = Balance. The amount of SiC particles are variedfrom 3 to 9 wt. % in steps of 3wt. %. Stir casting technique has been used to prepare the AA6061-SiC composite.

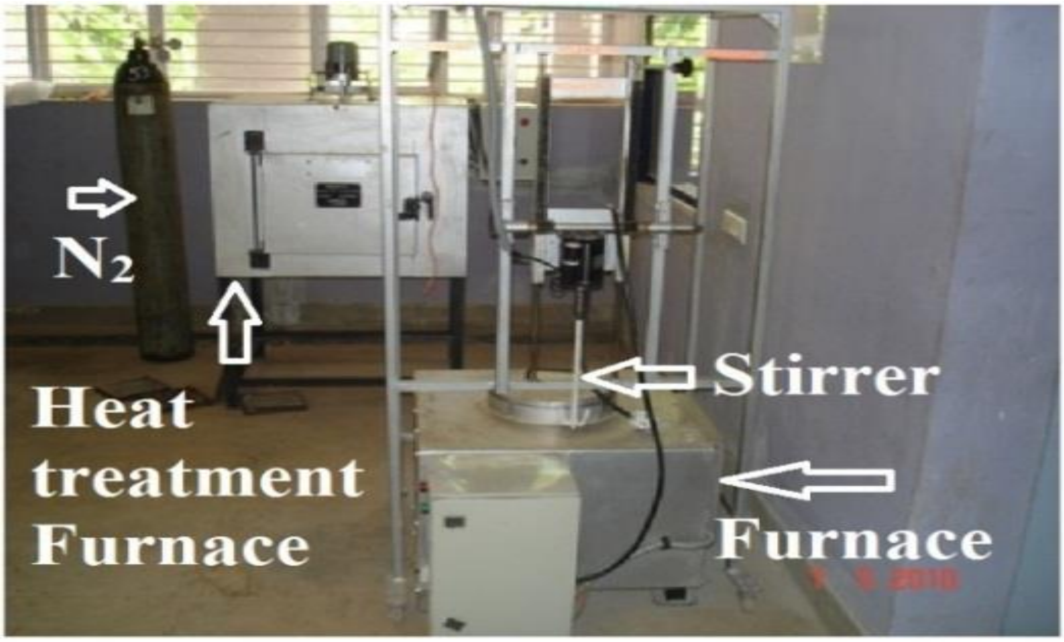

Fig. 1 The Photograph of stir casting setup used to prepare AA6061-SiC composites

"The precast AA6061 alloy ingots were charged into the graphite crucible and melted using electric resistance furnace up to a temperature of 750°C. The molten metal was degassed by passing pure nitrogen for 3-5 minutes. The SiC particles of 10-30µm size were preheated at 600°C for a soaking period of 2 hours to improve wetness and remove moisture, the adsorbed hydroxide and other gases from the surface. The molten metal was agitated by use of mechanical stirrer rotating at a speed of 300 – 400 rpm to create fine vortex. The SiC particles were introduced into the degassed vortex of the molten matrix material AA6061 alloy maintained at 730°C at the rate

of 0.01kg/min. The mechanical mixing of the matrix and the reinforcement were ensured by stirring it for 5 minutes using zirconium coated steel impeller. After this the melts were poured it into the cavity of the pre heated finger mould metal die maintained at 200°C. For AA6061-SiC system, the SiC content was varied from 3 - 9 wt% in the steps of 3 wt%. Further molten composite was poured and solidified in the steel mould in the form of cylinders of 20mm x 200mm".

3.2 Processing of Composites

The cast composites have been subjected to solutionizing heat treatment at a temperature of $525^0 \pm 2^0$C for 6 hours, followed by ageing at a temperature of $175^0 \pm 2^0$C for 4 hours. The microstructural study revealed that,the distributions of reinforcements in the matrix are fairly uniform. The detailed microstructural analysis and hardness of composites have been explained in our earlier paper [17].

3.3 Plan of Experiments

The L9 orthogonal array was used to conduct the experiment. The wear parameters chosen in this experimentalstudy were (i) Applied Load, (ii) Sliding Distance and (iii) Percentage Reinforcement and the response studied was the wear rate. Table 1, indicates the level and their factors. The experiment consists of 9 tests and each parameter was varied for three levels.

Table 1: process parameters and levels

Level	% Reinforcement	Sliding Distance, D (m)	Applied load, L (N)
1	3	500	9.81
2	6	1000	19.62
3	9	1500	29.43

3.4 Dry Sliding Wear Test

Dry sliding wear test were conducted by using a pin on disc wear test machine. Test specimens as per ASTM G- 99 standard of size 8mm diameter and 30mm length were cut from the cast samples. The surface of the specimen was polished by fine emery paper. A single pan digital weighing machine with the least count of 0.0001gram was used for measuring the initial weight of the specimen. The wear test was conducted at room temperature. During the test the track diameter was set for 100 mm the specimen was mounted in between the grippers and pressed against a rotating EN 32 steel disc of hardness 65 HRC by applying the load. After the test, the specimen was removed and cleaned with acetone. The final weight of the specimen was measured. The difference in the weight of specimen before and after the test gives the amount of material removed from the surface of the composite.

IV. Results and discussion

4.1 Statistical Analysis of Experiments

The experiments were conducted as per L9 orthogonal array and the obtained results of wear rate and S/N ratio for various combinations of parameters are shown in the Table 2

The wear rate is obtained by, W R = [δv/ D)] mm^3/m, where δv is the wear volume in mm^3 and D is the sliding distance in m.

Table 2: Taguchi orthogonal array Result of AA6061-SiC composites for wear rate

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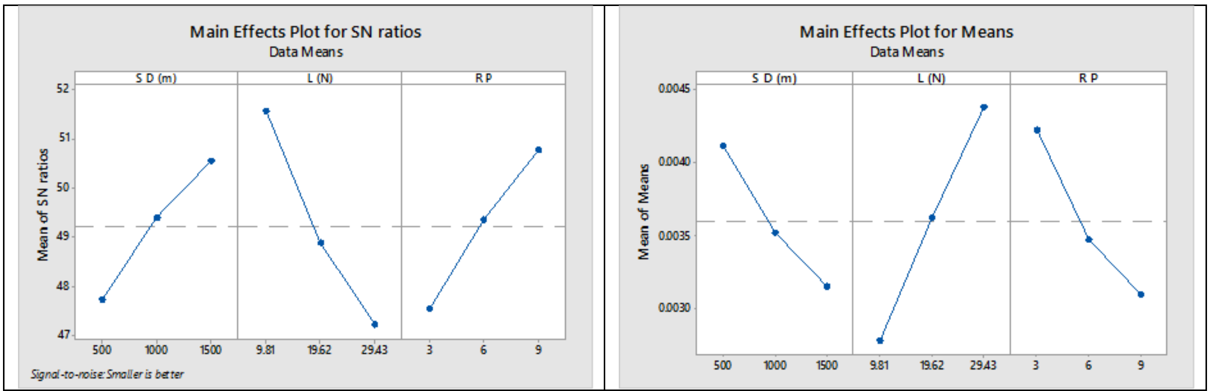
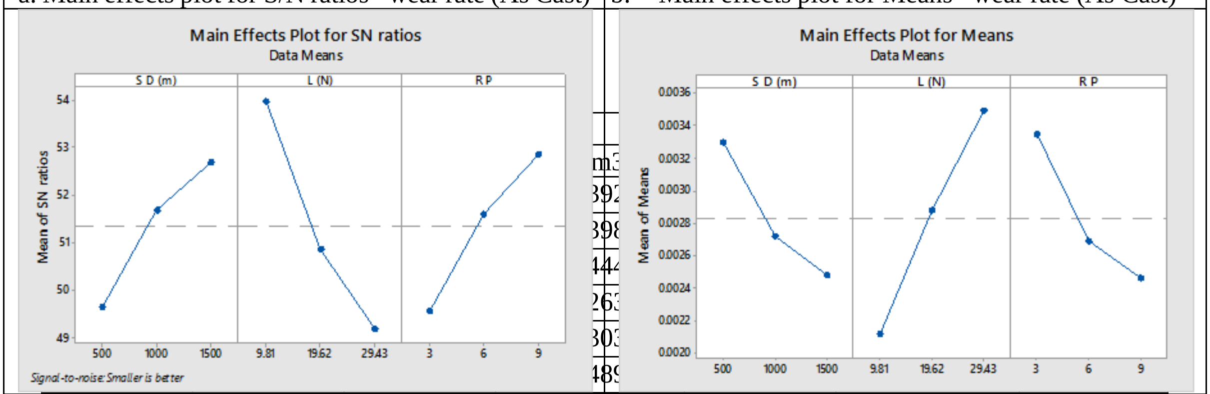
The experiments were conducted as per L9 orthogonal array and the obtained results of wear rate and S/N ratio for various combinations of parameters are shown in the table 2. The measured results were analyzed using the software MINITAB 17. The influence of process parameters such as applied load, sliding distance and percentage reinforcement on wear rate has been analyzed using signal to noise ratio. The response table obtained for this process is shown in the table 3. This table is clearly indicating that the applied load is a dominant parameter on the wear rate followed by reinforcement percentage and sliding distance. Figure 2 shows the influence of process parameters on wear rate graphically. The optimum condition for wear rate which is shown in Figure 2 is D3, L1 and R3.

Table 3: Response table for signal to noise ratios for wear rate (smaller is better)

Level	As Cast			Heat Treated		
	S D (m)	L (N)	R P	S D (m)	L (N)	R P
1	47.72	51.55	47.54	49.66	53.99	49.55
2	49.39	48.88	49.34	51.68	50.87	51.61
3	50.54	47.22	50.77	52.70	49.18	52.87
Delta	2.82	4.33	3.23	3.04	4.81	3.32
Rank	3	1	2	3	1	2



a. Main effects plot for S/N ratios –wear rate (As Cast) b. Main effects plot for Means –wear rate (As Cast)



c. Main effects plot for S/N ratios –wear rate (Heat Treated) d. Main effects plot for Means –wear rate (Heat Treated)

1500	9.81	9	0.001795	54.9187	0.001340	57.4579
1500	19.62	3	0.003854	48.2818	0.003100	50.1728
1500	29.43	6	0.003795	48.4158	0.003000	50.4576

Fig.2 Main effects plots for S/N ratios and Means- Wear Rate

Table 4(a): Analysis of Variance for wear rate (As Cast)

Source	DF	Adj SS	Adj MS	F-Value	P-Value	P (%)
S D (m)	1	0.000001	0.000001	27.95	0.003	19.36
L (N)	1	0.000003	0.000003	78.83	0.000	54.63
R P	1	0.000001	0.000001	32.54	0.002	22.55
Error	5	0.000000	0.000000			03.46

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Total	8	0.000005				100

Table 4(b): Analysis of Variance for wear rate (Heat Treated)

Source	DF	Adj SS	Adj MS	F-Value	P-Value	P (%)
S D (m)	1	0.000001	0.000001	62.97	0.001	19.39
L (N)	1	0.000004	0.000004	171.25	0.000	52.70
R P	1	0.000002	0.000002	85.68	0.000	26.37
Error	5	0.000000	0.000000			01.54
Total	8	0.000007				100

Model Summary for wear rate

As Cast			Heat Treated		
R-sq	R-sq(adj)	R-sq(pred)	R-sq	R-sq(adj)	R-sq(pred)
98.46%	97.54%	94.49%	96.54%	94.46%	87.81%

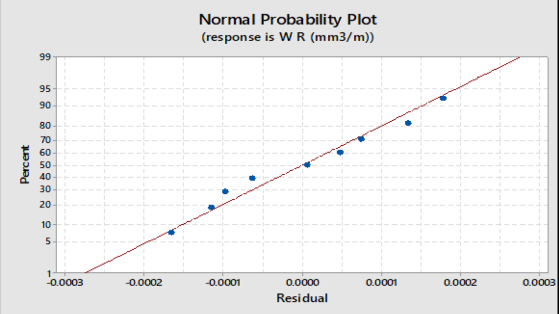
4.2 Multiple linear regression models (MLRM)

The statistical tool MINITAB 17 was used to develop the MLRM. The relation between independent variable and the response variable from the observed data in the form of linear equation was obtained by this model.

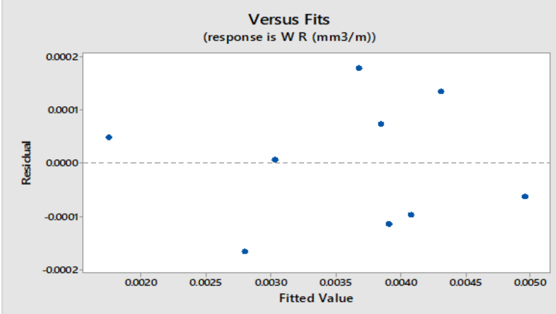
The regression equation developed for wear rate is

W R (As Cast) (mm^3/m) = 0.004097 - 0.000001 S D (m) + 0.000081 L (N) - 0.000188 R P -- (1)

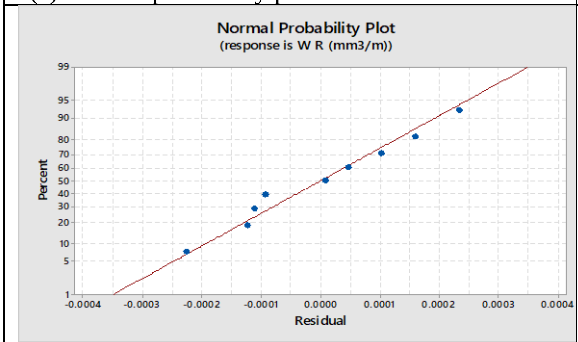
W R (Heat Treated) (mm^3/m) = 0.003160 - 0.000001 S D (m) + 0.000070 L (N) - 0.000147 R P-- (2)



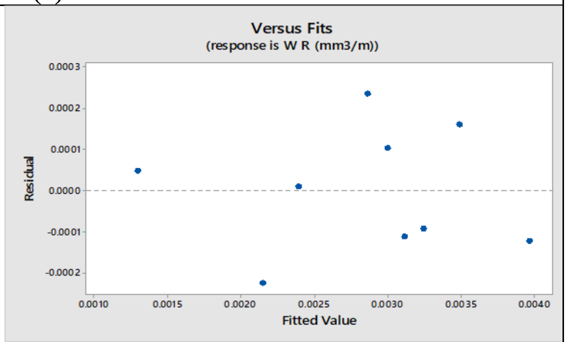
(a) Normal probability plot of Residuals -As Cast



(b) Plot of Residuals v/s fitted values -As Cast



(c) Normal probability plot of Residuals-Heat treated



(d) Plot of Residuals v/s fitted values- Heat Treated

Figure 3: Normal probability plot of Residuals and Fits for Wear Rate

Figure 3 shows the normal probability plot of residuals and Fits for wear rate. From the figure 3, it is observed that the data points are close to the normal probability line. It shows that the residuals are normally distributed over the line and the model is best fit to forecast the wear.

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4.3 Confirmation Test : Wear Rate

The obtained results of wear rate were confirmed by conducting the confirmation test. The experimental parameters used for the test was shown in the table 5(a). The results of confirmation test and comparison between the experimental values and computed values developed from the regression model is recorded in the table 5(b). The experimental value of wear rate for heat treated samples is found to vary from the regression equation in the range of 3.50% to 4.81%. The wear rate obtained from the regression model and the experimentation was found to match with least error.

Table 5 (a): Confirmation Experiment for wear rate

Expt. No	Sliding Distance, S D (m)	Applied load, L (N)	% Reinforcement Percentage
1	600	14	3
2	900	24	6
3	1200	34	9

Table5 (b): Result of Confirmation Experiment for Wear Rate and their comparison with regression model

Expt. No	Expt. WR (mm3/m)	Reg. model W R (mm3/m)	%Error
1	0.003108	0.002999	3.50
2	0.003033	0.002887	4.81
3	0.002883	0.002775	3.74

As Cast

a) Distance=500, Load=29.43N, AA606-6wt.%SiC

b) Distance=1000, Load=29.43N, AA6061-6wt.%SiC

c) Distance=1500, Load= 29.43 N, AA6061-6wt.%SiC

Heat treated

a) Load=9.81N, Distance=1000, AA6061-3wt.%SiC

b) Load=19.62N, Distance=1000 AA6061-3wt.%SiC

c) Load= 29.43 N, Distance=1000, AA6061-3wt.%SiC

Fig. 4 SEM Analysis of worn surfaces of AA6061- SiC Composites

Fig. 4 Shows the SEM micrographs of AA6061-SiC composites processed under different conditions at different applied load and sliding distance. It can be seen that for as cast conditions with the increase in the load the width of grove formation is increasing. The groove formation is mainly due to delamination of the matrix material by hard asperities of counter surface disc. So we can observe that from lower to higher load in case of as cast composites there is transition of mild wear to severe wear along with the oxidative wear. In case of heat treated composites we can observe that same phenomena as that of as cast composites. The width of groove formation is increasing at higher loads for 3wt. % SiC, due to deep penetration of asperities of hard counter surface leading higher delamination of the composite surface. For 9wt. % SiC, the amount of delamination is less due higher hardness of the composite material. Further the presence of oxides on the worn surface clearly indicates oxidative wear along with delamination [18].

V. Conclusions

The following conclusions are drawn from the present investigation:

1. Stir casting method was successfully adopted in the preparation of AA6061- (3-9wt.%) SiC composites.
2. The heat treatment has a profound effect on increase in the wear resistance of the composites
3. Incorporation of SiC particles into AA6061 matrix increases the wear resistance of the composite.
4. The Applied load (52.70%) has the highest influence on wear rate of the hybrid composite followed by sliding distance (26.37%) and percentage reinforcement (19.39%).
5. Regression equation generated for AA6061-(3-9) wt. % SiC composite has been used to predict the wear rate for the intermediate conditions with reasonable accuracy.
6. SEM Microstructural study reveals that the uniform dispersion of hard SiC particles strengthens the AA6061 base material and increases the wear resistance of composite material.

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