Frictional and Wear Characteristics of Stir-Cast Hybrid Composite Aluminium Al6061Reinforced with SiC Particulates

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Abstract
The Aluminium Al6061 alloys are mainly used in the application of automobile and aeronautical applications. An attempt has been made to increase the mechanical and tribological property of Al6061 alloy by adding SiC particulates as reinforcements. The particle size of SiC particles is 400µm. Hybrid metal matrix composite is prepared by Stir casting route and Friction and wear test is done by pin-on-disc method. Al6061T6 hybrid composites are used in automobile components for reliable, long life and high performance. Experiments were conducted based on the plan of experiments generated through Taguchi's technique. A L_9 Orthogonal array was selected for analysis of the data. Purpose of investigation is to find the influence of applied load, sliding speed and sliding distance on wear rate, as well as the coefficient of friction during wearing process was carried out using ANOVA and regression equation. Objective of the model was chosen as "smaller the better" characteristics to analyse the dry sliding wear resistance. Results show that sliding distance has the highest influence on wear rate followed by sliding speed and load. Sliding distance has the highest influence on wear rate followed by load and sliding speed.

Key words: *Hybrid composite, Particulate Reinforcement, Wear, Stir-cast, Pin-on-disc, Orthogonal Array*

1. INTRODUCTION

The demand for good quality materials for automobile and aeronautical applications leads to production of best structural composite materials. From the different materials, Aluminum based composites are achieving better results now days. Basically the hard material is mixed with reinforcement to improve the mechanical and also tribological properties. That composites are very well suitable to automobile components such as engines, brake disc etc. From the literature survey based on aluminum composites, the reinforcements used are SiC or Al_2O_3 to base alloy. These found to improve the wear resistance under sliding and abrasion condition. V.C. Ujaraja studied comparison of Al6063 and Al7075 composites, Al6061 results better in bonding, hardness and tribological properties. G.B. Veeresh Kumar suggests that the Al6061-SiC composites are better compared with Al7075-Al2O3 composites based on mechanical and tribological properties. There is a growing interest worldwide in manufacturing hybrid metal matrix composites [HMMCs] which possesses combined properties of its reinforcements and exhibit improved physical, mechanical and tribological properties. Aluminium matrix composites reinforced silicon carbide was developed using conventional foundry techniques.

2. TAGUCHI METHOD

The Taguchi technique is a powerful design of experiment tool for acquiring the data in a controlled way and to analyze the influence of process variable over some specific variable which is unknown function of these process variables and for the design of high quality systems. Analysis of the experimental results uses a signal to noise ratio to aid in the determination of the best process designs. This method was been successfully used by researchers in the study of wear behaviour of aluminium metal matrix composites. Taguchi creates a standard orthogonal array to accommodate the effect of several factors on the target value and defines the plan of experiment. The experimental results are analyzed using analysis of means and variance to study the influence of parameters. A multiple linear regression model is developed to predict the wear rate of the hybrid composites. The major aim of the present investigation is to analyse the influence of parameters like load, sliding speed and sliding distance on dry sliding wear of aluminium/SiC hybrid metal matrix composites using Taguchi technique by selecting L_9 orthogonal array.

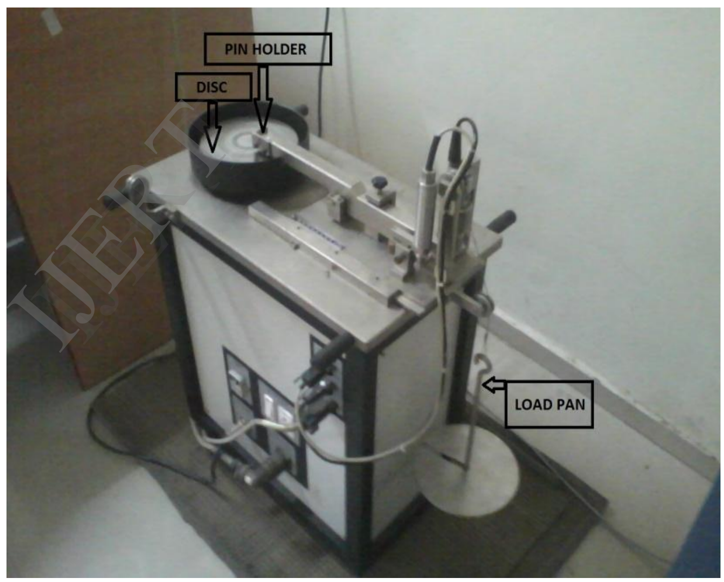
3. EXPERIMENTAL PROCEDURE AND MATERIALS

"Table 1 Nominal composition weight percent of Al6061 matrix material"

Material	Si	Fe	Cu	Mn	Ni	Pb	Zn	Ti	Sn	Mg	Cr	Al
Percentage	0.43	0.7	0.24	0.139	0.05	0.24	0.25	0.15	0.001	0.802	0.25	balance

Metal matrix composites are basically produced either by Liquid Metallurgy Route or Powder Metallurgy. In Liquid Metallurgy Route, the reinforcement's phases are mechanically dispersed in the matrix phase. Stir casting method is mostly used because components at a normal cost. The stir casting technique increases the microstructure and reduces porosity. In this present work, stir casting method was used to develop Al6061 alloy with 20% wt. SiC reinforcement. The experimental sets up were as shown in Fig.1. The stir casting furnace is placed on the bottom floor and the temperature of the furnace is measured and controlled in order to achieve quality composite. Two thermo couple and one PID controller were used for this Purpose. This stirrer was connected to 1HP DC Motor through flexible link and was used to stir the molten metal in semi solid state. The melt was maintained at a temperature between 750-800^{o}C for one hour. Vortex was created by using a mechanical stirrer. The particulate, preheated at 500ºC were added to the melt with constant Stirring for about 5 min at 500 to 650 rpm for all samples to avoid casting defects.

"Fig. 1 Stir Casting Setup"



"Fig. 2 Pin on Disc wear testing machine TR20CH DUCOM"

3.1 Wear Behaviour

A pin on disc test apparatus as shown in above fig. was performed to determine the sliding wear characteristics of the composite. Specimens of size 12 mm diameter and 30 mm length were cut from the cast samples, machined and then polished. The contact surface of the cast sample (pin) has to be flat and will be in contact with the rotating disk. During the test, the pin is held pressed against a rotating EN32 steel disc (hardness of 65HRC) by applying load that acts as counterweight and balances the pin. The track diameter was kept constant 60mm for each batch of experiments and the parameters such as the load, sliding speed and sliding distance were varied in the range given in Table 2. A LVDT (load cell) on the lever arm helps determine the wear at any point of time by monitoring the movement of the arm. Once the surface in contact wears out, the load pushes the arm to remain in contact with the disc. This movement of the arm generates a signal which is used to determine the maximum wear and the coefficient of friction is monitored continuously as wear occurs. Weight loss of each specimen was obtained by weighing the specimen before and after the experiment by a single pan electronic weighing machine with an accuracy of 0.0001g after thorough cleaning with acetone solution.

3.2 Plan of Experiments

The experimental plan was formulated considering three parameters (variables) and three levels based on the Taguchi technique. The three independent variables considered for this study were load, sliding speed and sliding distance. The levels of these variables chosen for experimentation are given in Table 2.

"Table 2 Parameters and their levels"

Controllable factors	Load, L (N)	Sliding speed, S (m/s)	Sliding distance, D(m)
Level 1	20	1.5	1000
Level 2	25	2	1500
Level 3	30	2.5	2000

In the present investigation, a L_9 orthogonal array was selected and it has 9 rows and 3 columns. The selection 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. Each variable and the corresponding interactions were assigned to a column defined by Taguchi method. The first column was assigned to load (L), the second column to sliding speed (S), the third column to sliding distance. The response variables to be studied were wear rate and coefficient of friction. The experiments were conducted based on the run order generated by Taguchi model and the results were obtained. This analysis includes the ranks 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. Analysis of variance of the S/N ratio is performed to identify the statistically significant parameters. The analyses of the experimental data were carried out using MINITAB 15 software, which is specially used for DOE applications. The experimental results were transformed into signal-to-noise (S/N) ratios. 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 wear rate using **'smaller the better'** characteristic, which can be calculated as logarithmic transformation of the loss function, is given as:

$S/N = -10 \log [(\Sigma y^2)*1/n]$ where y is the observed data (wear rate and COF) and n is the number of observations. The above S/N ratio transformation is suitable for minimization of wear rate.

4. RESULTS AND DISCUSSIONS

The experiments were conducted as per orthogonal array and the wear rate results obtained in terms of S/N ratios for various combinations of parameters are shown in Table3. The experimental values were transformed into S/N ratios for measuring the quality characteristics using MINITAB 15.

4.1 S/N Ratio Analysis

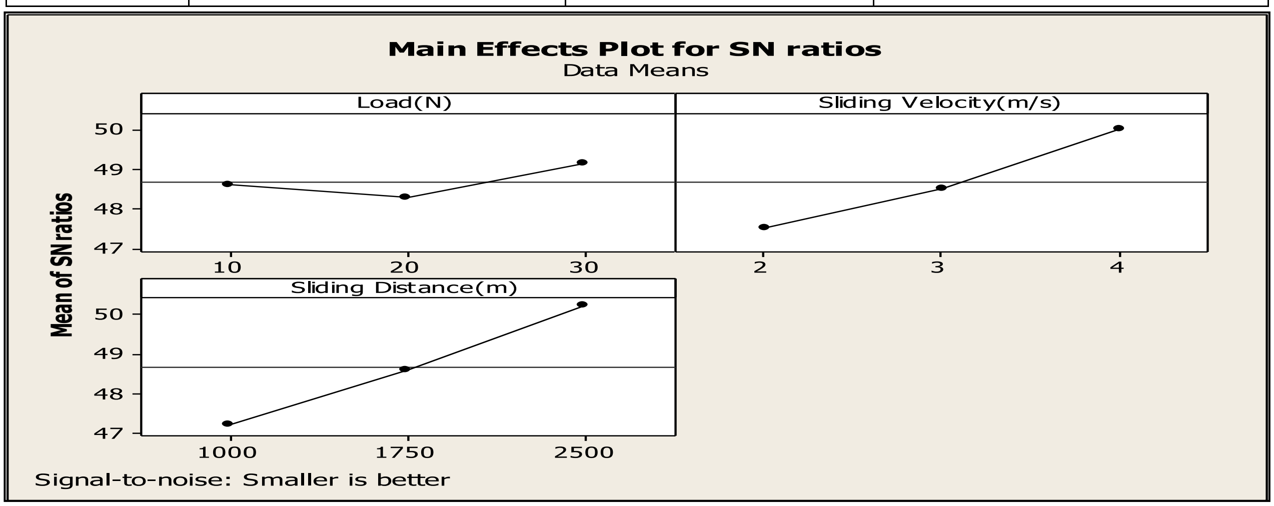
The influence of control parameters such as applied load, sliding speed and sliding distance content on wear rate has been evaluated using S/N ratio response analysis. Process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance. The control parameter with the strongest influence was determined by the difference between the maximum and minimum value of the mean of S/N ratios. Higher the difference between the mean of S/N ratios, the more influential will be the control parameter.

"Table 3 Result of L_9 orthogonal array Al6061/20%SiC"

Load (N)	Sliding Velocity (m/s)	Sliding Distance (m)	COF	S/N ratios(db)	Wear Rate (mm3/m)	S/N ratios(db)
20	1.5	1000	0.421	7.51436	0.004926	46.1501
20	2	1500	0.343	9.29412	0.003916	48.1431
20	2.5	2000	0.2861	10.8696	0.002643	51.5581
25	1.5	1500	0.368	8.68304	0.004421	47.0896
25	2	2000	0.343	9.29412	0.003219	49.8456
25	2.5	1000	0.461	6.72598	0.0040017	47.9551
30	1.5	2000	0.4012	7.93278	0.003428	49.2992
30	2	1000	0.4412	7.10729	0.004185	47.5661
30	2.5	1500	0.38125	8.3758	0.002961	50.5712

"Table 4 Response Table for Signal to Noise ratios- Smaller is better (Wear rate)"

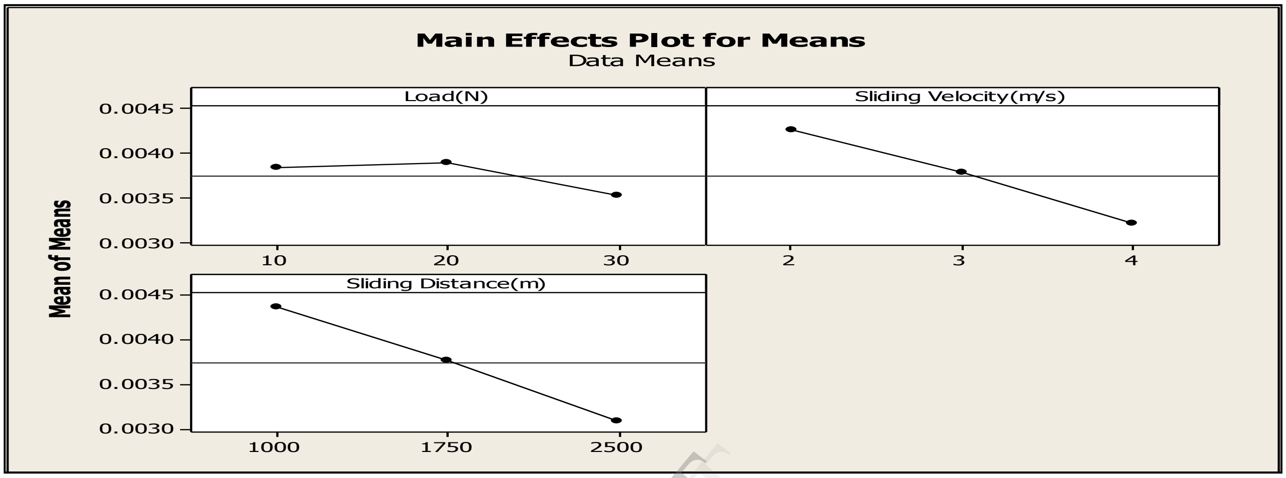
Level	Load(N)	Speed(m/s)	Distance(m)
1	48.62	47.51	47.22
2	48.3	48.52	48.6
3	49.15	50.03	50.23
Delta	0.85	2.52	3.01
Rank	3	2	1



"Fig. 3 Main Effects Plot for SN ratios- Smaller is better Wear rate"

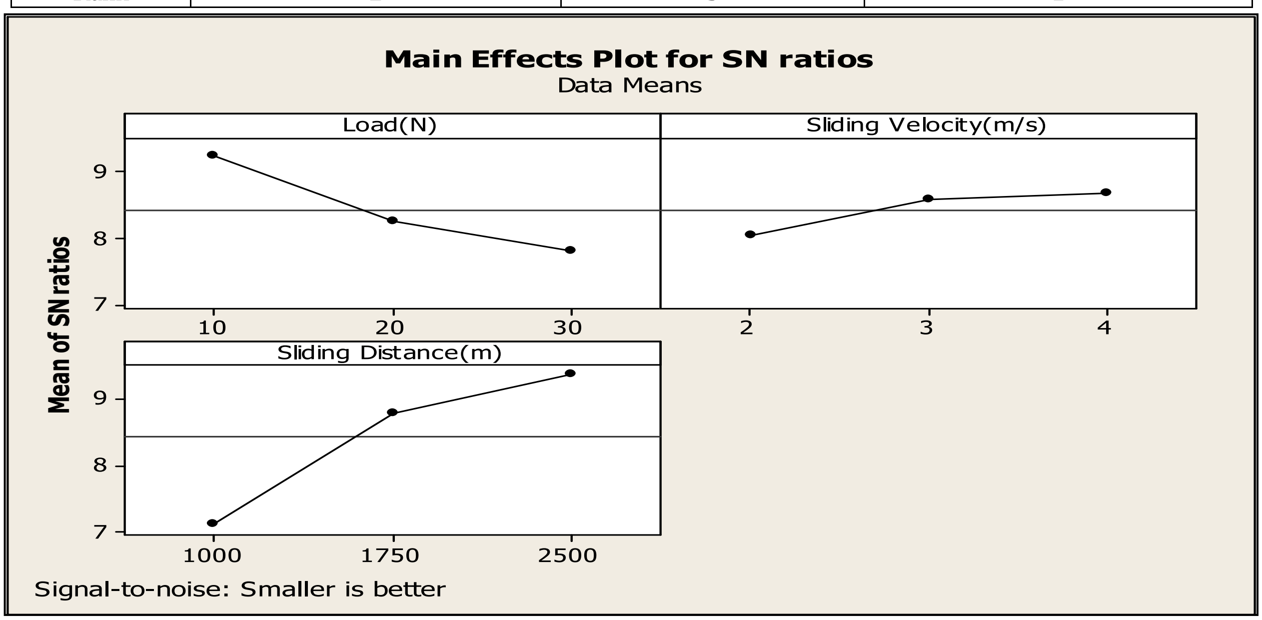
"Table 5 Response Table for Means- Smaller is better wear rate"

Level	Load(N)	Speed(m/s)	Distance(m)
1	0.003828	0.004258	0.00437
2	0.003881	0.003773	0.00377
3	0.003525	0.003202	0.0031
Delta	0.000356	0.001056	0.00127
Rank	3	2	1



"Table 6 Response Table for SN ratios- Smaller is better Coefficient of Friction"

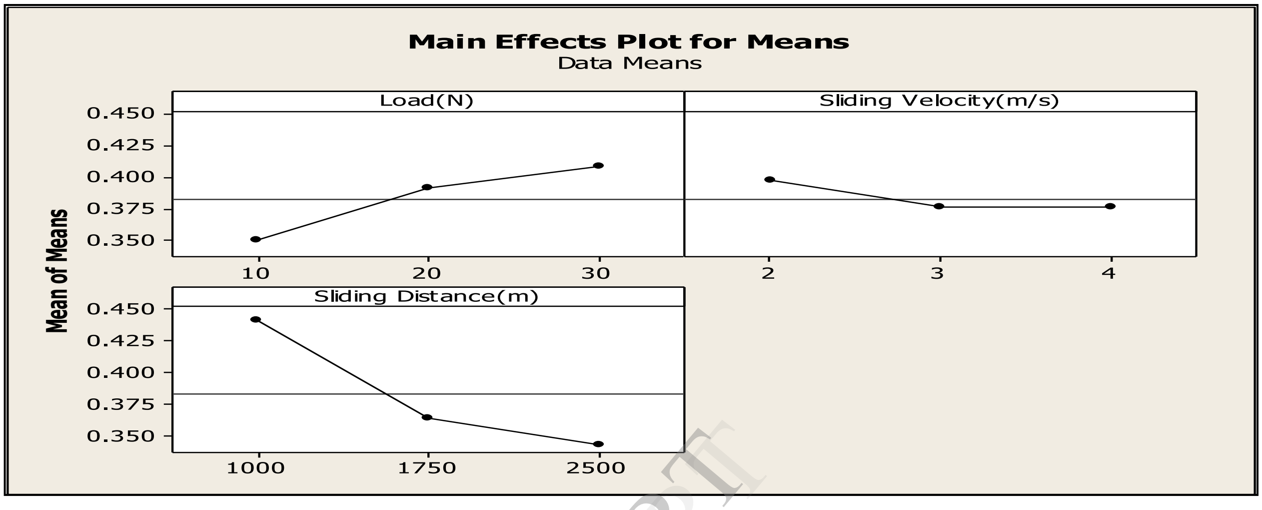
Level	Load(N)	Speed(m/s)	Distance(m)
1	9.226	8.043	7.116
2	8.234	8.565	8.784
3	7.805	8.657	9.366
Delta	1.421	0.614	2.25
Rank	2	3	1



"Fig.5 Main Effects Plot for SN ratios-Coefficient of Friction"

“Table 7 Response Table for SN Ratios- Smaller is better (Coefficient of friction)”

Level	Load(N)	Speed(m/s)	Distance(m)
1	0.35	0.3967	0.4411
2	0.3907	0.3757	0.3641
3	0.4079	0.3761	0.3434
Delta	0.0579	0.021	0.0976
Rank	2	3	1



“Fig.6 Main Effects Plot for Means - Smaller is better Coefficient of Friction”

4.2 Analysis of Variance

“Table 8 Analysis of Variance for SN ratios- Wear rate (Al6061/20%SiC)”

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P	%
Load(N)	2	1.102	1.102	0.5511	4.6	0.179	4.48226
Speed(m/s)	2	9.164	9.164	4.8082	40.09	0.024	37.2735
Distance(m)	2	13.6273	13.6273	6.8137	56.81	0.017	55.4275
Residual Error	2	0.2399	0.2399				0.97577
Total	8	24.5858					

“Table 9 Analysis of Variance for SN ratios- coefficient of friction (Al6061/20%SiC)”

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P	%
Load(N)	2	3.186	3.186	1.593	2.6	0.278	24.0444
Speed(m/s)	2	0.6574	0.6574	0.3287	0.54	0.651	4.96132
Distance(m)	2	8.1824	8.1824	4.0912	6.68	0.13	61.7516
Residual Error	2	1.2247	1.2247	0.6124			9.24267
Total	8	13.2505					

ANOVA was used to determine the design parameters significantly influencing the wear rate (response). Table 8 and Table 9 show the results of ANOVA for wear rate and COF. This analysis was evaluated for a confidence level of 95%, that is for significance level of α=0.05. The last column of Table 8 and Table 9 shows the percentage of contribution (P %) of each parameter on the response, indicating the degree of influence on the result. It can be observed from the results obtained that sliding distance[55.42%], sliding speed[37.27%] and applied load[4.48%] which are influencing wear rate of Al6061/20%SiC MMC. Wear rate is highly influenced by sliding distance, sliding speed and applied load respectively. Parameters like sliding distance [61.75%],applied load [24.04%] and sliding speed [4.96%] which are influencing coefficient of friction of Al6061/20%SiC MMC. Coefficient of friction is highly influenced by sliding distance, applied load and sliding speed respectively.

4.3 Multiple Linear Regression Model Analysis

A multiple linear regression analysis attempts to model the relationship between two or more predictor variables and a response variable by fitting a linear equation to the observed data. Based on the experimental results, a multiple linear regression model was developed using MINITAB15. A regression equation thus generated establishes correlation between the significant terms obtained from ANOVA such as load, sliding speed, sliding distance. The regression equation developed for wear rate and coefficient of friction is

Wear Rate = 0.00712 + 0.000015 Load(N) - 0.000528 Sliding Velocity(m/s) - 0.000001 Sliding Distance(m)

COF = 0.470 + 0.00289 Load(N) + 0.0103 Sliding Velocity(m/s) -0.000065 Sliding distance(m)

The above equation can be used to predict the wear rate of the hybrid composites. The constant in the equation is the residue. The regression coefficient obtained for the model was 0.964 and this indicates that wear data was not scattered.From the regression equations for wear rate, we can conclude that wear rate of composite is directly proportional to applied load and inversely proportional to speed and distance. From the regression equations for coefficient of friction, we can conclude that coefficient of friction is directly proportional to applied load and sliding speed.

5. CONCLUSIONS

1) Wear rate (Al6061/20%SiC MMC) was highly influenced by sliding distance, sliding speed and applied load respectively.

2) Coefficient of friction (Al6061/20%SiC MMC) was highly influenced by sliding distance, applied load and sliding speed respectively.

3) The regression equations for wear rate (Al6061/20%SiC MMC) implies that wear rate of composite is directly proportional to applied load and inversely proportional to sliding speed and sliding distance.

4) The regression equations for Coefficient of friction (Al6061/20%SiC MMC) implies that Coefficient of friction is directly proportional to applied load and sliding speed and inversely proportional to sliding distance.

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