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Wear Characterization of Aluminium/Sic/Al_2O_3 Hybrid Metal Matrix Composite Using Taguchi Technique

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Abstract:
Aluminium Al6061T6 alloys are mainly used in the application of automobile and aeronautical applications. An attempt has been made to increase the tribological property of an Al6061 alloy by adding SiC and Al_2O_3 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 L27 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. The objective of the model was chosen as "smaller the better" characteristics to analyse the dry sliding wear resistance. Results show that applied load has the highest influence on the wear rate followed by sliding speed and sliding distance. Sliding distance has the highest influence on the wear rate followed by applied load and sliding speed.

Key words: *Aluminium Alloy, Wear, DOE, Taguchi's orthogonal array, ANOVA, Regression analysis*

1. Introduction

Metal matrix composites (MMCs) are the forerunners amongst different classes of composites. Over the past two decades, metal matrix composites (MMCs) have been transformed from a topic of scientific and intellectual interest to a material of broad technological and commercial significance. MMCs offer a unique balance of physical and mechanical properties. Aluminium based MMCs have received increasing attention in recent decades as engineering materials with most of them possessing the advantages of high strength, hardness and wear resistance. The stir casting method is widely used among the different processing techniques available. Stir casting usually involves prolonged liquid-reinforcement contact. We find that the wear and hardness were enhanced by increasing the volume fraction of SiC. Wear is an important property in the selection of discontinuous reinforced Al MMCs. Wear is not an intrinsic material property, but characteristics of the engineering system which depend on load, speed, temperature, hardness, and the environmental conditions. Wear performances of aluminium matrix composites reinforced with various reinforcements ranging from very hard ceramic particulates such as SiC and Al_2O_3. In this present investigation an attempt is to find the influence of wear parameters on dry sliding wear and to establish correlation between sliding speed, load, sliding distance and combined effect of these parameters on dry sliding wear of the aluminium and its composite using Taguchi and analysis of variance techniques

2. Taguchi Method

The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. The Taguchi method was developed by Dr. Genichi Taguchi of Japan who maintained that variation. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. A major step in the DOE process is the determination of the combination of factors and levels which will provide the desired information. Analysis of the experimental results uses a signal to noise ratio to aid in the determination of the best process designs. The Taguchi technique is a powerful design of experiment tool for acquiring the data in a controlled way and to analyse the influence of process variable over some specific variable which is an unknown function of these process variables and for the design of high quality systems. This method was being successfully used by researchers in the study of the 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 analysed 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/Al_2O_3 hybrid metal matrix composites using Taguchi technique.

3. Material

The matrix material selected was commercially available pure aluminium Al6061T6. The chemical composition of the matrix material is given in the **Table 1**. There are sufficient literatures elucidating the improvement in wear properties through the addition of SiC and Al_2O_3. Addition of Silicon carbide and alumina oxide into aluminium base matrix, results into improved wear resistance, high strength, low density, low coefficient of thermal expansion and high thermal conductivity of metal matrix composite.

Element	**Si**	**Fe**	**Mn**	**Mg**	**Cu**	**Zn**	**Ti**	**Cr**	**Al**
Wt%	0.76	0.14	0.29	0.84	0.33	0.004	0.02	0.006	97.61

Table 1: Chemical Composition of Al6061T6 Alloy

3.1. Preparation of the Composite

Liquid metallurgy route was used to synthesise the hybrid composite specimens. The matrix alloy was first superheated above its melting temperature and then the temperature was lowered gradually until the alloy reached a semisolid state. A vortex was created in the melt due to continuous stirring by a stainless steel mechanical stirrer with a rotational speed of 350 rpm. At this stage, the blended mixture of preheated SiC, Al_2O_3 as 15% respectively were introduced into the slurry and the temperature of the composite slurry was increased until it was in a fully liquid state. Small quantities of magnesium were added to the molten metal to enhance wettability of reinforcements with molten aluminium. Stirring was continued for about 5 minutes until the interface between the particle and the matrix promoted wetting and the particles were uniformly dispersed. Then the hybrid composite melt was degassed using hexachloroethane tablets. The melt was then superheated above the liquids temperature and solidified in a cast iron permanent mould to obtain cylindrical samples. Sliding wear test specimens were machined from as-cast samples, to obtain cylindrical pins of diameter 12 mm and length 30 mm. The specimen faces were then metallographically polished on 320 grit size emery paper.

Figure 1: Stir Casting Setup *Figure 2: Pin on Disc wear testing machine TR20CH DUCOM*

3.2. Wear Behaviour

A pin on disc test apparatus was performed to determine the sliding wear characteristics of the composite. Specimens of size 12 mm diameters 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.

3.3. 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.

Controllable factors	Load(L) (N)	Sliding Speed(S) (m/s)	Sliding distance(D) (m)
Level 1	25	2.0	100
Level 2	30	2.25	1500
Level 3	35	2.5	2000

Table 2: Parameters and Their Levels

In the present investigation, a L27 orthogonal array was selected and it has 27 rows and 13 columns. The first column was assigned to load (L), the second column to sliding speed (S), the fifth column to sliding distance, and the remaining columns were assigned to their interactions. 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 [1/n (Σy2)] ---------------------------------- (1)

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 Discussion

The experiments were conducted as per orthogonal array and the wear rate results obtained for various combinations of parameters are shown in Table 3. The experimental values were transformed into S/N ratios for measuring the quality characteristics using MINITAB 15. The S/N ratio obtained for all the experiments are shown in Table 3.

4.1. S/N Ratio Analysis

The influence of control parameters such as load, sliding speed and fly ash 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.

Expt. No.	Load(N)	Speed(m/s)	Distance(m)	Wear rate (mm^3/m)	S/N Ratios (db)	COF	S/N Ratios (db)
1	25	2	1000	0.0046913	46.5741	0.5382	5.38082
2	25	2	1500	0.00440023	47.1305	0.4417	7.09647
3	25	2	2000	0.004812	46.3535	0.33556	9.4846
4	25	2.25	1000	0.00414315	47.6534	0.58024	4.72785
5	25	2.25	1500	0.0046665	46.6202	0.4989	6.03973
6	25	2.25	2000	0.00381376	48.3729	0.4761	6.44604
7	25	2.5	1000	0.00528966	45.5314	0.59632	4.49041
8	25	2.5	1500	0.00446022	47.0129	0.5633	4.9852
9	25	2.5	2000	0.00379	48.4272	0.5128	5.80104
10	30	2	1000	0.00442461	47.0825	0.6512365	3.72523
11	30	2	1500	0.00385247	48.2852	0.49652	6.08127
12	30	2	2000	0.00460907	46.7277	0.4032	7.88959

Expt. No.	Load(N)	Speed(m/s)	Distance(m)	Wear rate (mm^3/m)	S/N Ratios (db)	COF	S/N Ratios (db)
13	30	2.25	1000	0.0048302	46.3207	0.4617	6.7128
14	30	2.25	1500	0.0042141	47.5059	0.38426	8.3075
15	30	2.25	2000	0.00369873	48.6389	0.307894	10.232
16	30	2.5	1000	0.003953	48.0615	0.58237	4.69602
17	30	2.5	1500	0.0026812	51.4334	0.50692	5.90121
18	30	2.5	2000	0.0033974	49.3771	0.48031456	6.36948
19	35	2	1000	0.00378058	48.4488	0.4913134	6.17283
20	35	2	1500	0.00324542	49.7746	0.428434	7.36232
21	35	2	2000	0.00253019	51.9369	0.40924	7.76044
22	35	2.25	1000	0.00402	47.9155	0.492243	6.15641
23	35	2.25	1500	0.00426109	47.4096	0.44652	7.00318
24	35	2.25	2000	0.0037879	48.432	0.3825	8.34737
25	35	2.5	1000	0.00440482	47.1214	0.5006143	6.00993
26	35	2.5	1500	0.004048	47.8552	0.47872	6.39837
27	35	2.5	2000	0.0042178	47.4983	0.4635	6.67901

Table 3: Results of L_{27} Orthogonal Array for Al6061T6/15%Sic/15%Al_2O_3

Level	load(N)	speed(m/s)	distance(m)
1	47.08	48.03	47.19
2	48.16	47.65	49.91
3	48.49	48.04	48.42
Delta	1.41	0.38	1.23
Rank	1	3	2

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

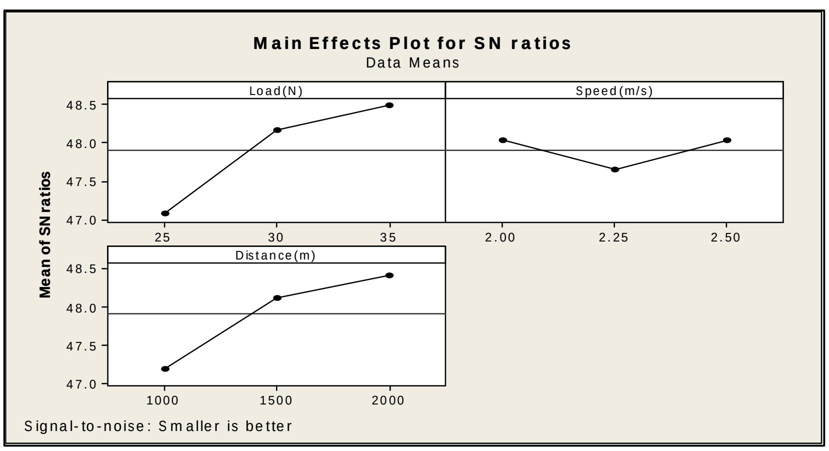

Figure 3: Main Effects Plot for SN ratios-Wear rate

Level	Load(N)	Speed(M/S)	Distance(M)
1	0.004452	0.004038	0.004393
2	0.003962	0.004159	0.003981
3	0.003811	0.004027	0.003851
Delta	0.000641	0.000133	0.000542
Rank	1	3	2

Table 5: Response Table for Means- Smaller Is Better Coefficient of Friction

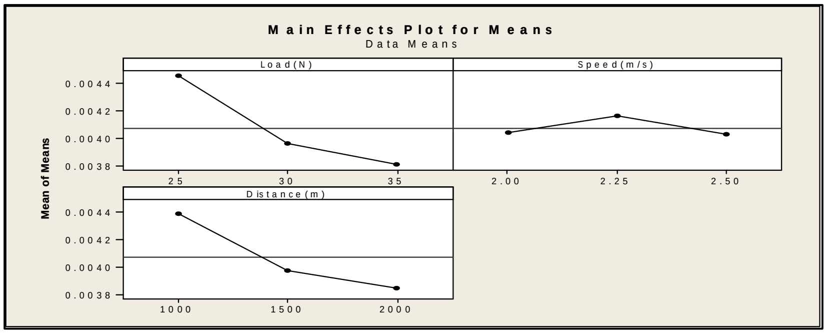

Figure 4: Main Effects Plot for Means-Wear Rate

Level	Load(N)	Speed(S)	Distance(D)
1	6.05	6.773	5.341
2	6.657	7.108	6.575
3	6.877	5.703	7.668
Delta	0.826	1.405	2.326
Rank	3	2	1

Table 6: Response Table for Signal to Noise Ratios Smaller Is Better (Coefficient of Friction)

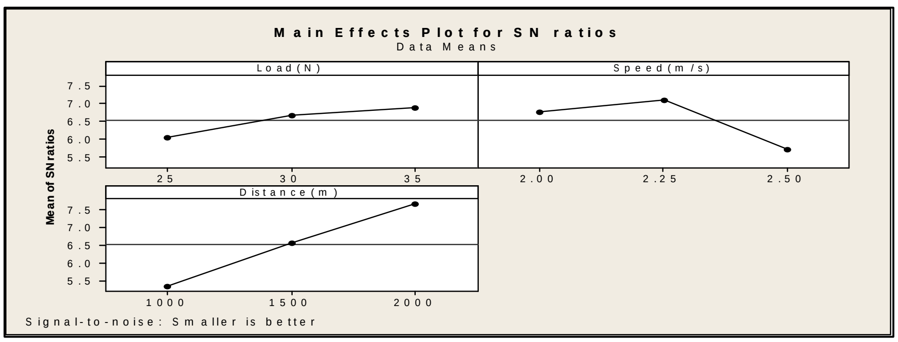

Figure 5: Main Effects Plot for SN Ratios-Coefficient of Friction

Level	Load(N)	Speed(M/S)	Distance(M)
1	0.5048	0.4662	0.5438
2	0.4749	0.4478	0.47
3	0.4548	0.5205	0.49
Delta	0.05	0.0727	0.1248
Rank	3	2	1

Table 7: Response Table for Signal to Noise Ratios Smaller Is Better (Coefficient of Friction)

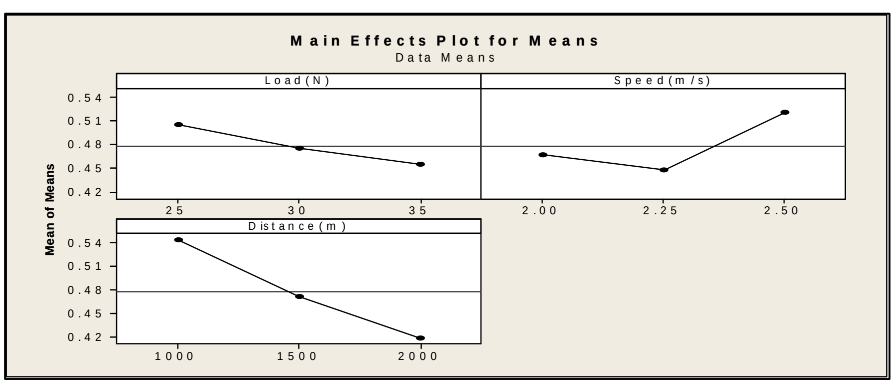

Figure 6: Main Effects Plot for Means-Coefficient of Friction

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P	%
Load(N)	2	9.8391	9.8391	4.9195	4.74	0.044	17.94723
Speed(m/s)	2	0.8801	0.8801	0.4401	0.42	0.668	1.605366
Distance(m)	2	7.3667	7.3667	3.6834	3.55	0.079	13.43739
Load(N)*speed(m/s)	4	21.2477	21.2477	5.3119	5.3119	0.024	38.75733
Load(N)*distance(m)	4	3.5151	3.5151	0.8788	0.85	0.534	6.411795
Speed(m/s)*distance(m)	4	3.6688	3.6688	0.9174	0.88	0.515	6.692155
Residual Error	8	2.3039	2.3039	1.038			4.202479
Total	26	54.8224					

Table 8: Analysis of Variance for SN Ratios –Wear Rate

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P	%
Load(N)	2	3.299	3.299	1.6493	7.57	0.014	5.729121
Speed(m/s)	2	9.687	9.687	4.8433	22.22	0.001	16.82267
Distance(m)	2	24.384	24.384	12.1918	55.94	0	42.34583
Load(N)*speed(m/s)	4	13.429	13.429	3.3573	15.41	0.001	23.32112
Load(N)*distance(m)	4	2.045	2.045	0.5112	2.35	0.142	3.551395
Speed(m/s)*distance(m)	4	3.267	3.267	0.8167	3.75	0.053	5.673549
Residual Error	8	1.743	1.743	0.2179			3.026935
Total	26	57.583					

Table 9: Analysis of Variance for SN Ratios –Coefficient of Friction

4.2. ANOVA and Regression Analysis for Wear Rate and Coefficient of Friction

For Wear Rate such as applied load [17.95%], sliding distance [13.43%] and sliding speed [1.60%], which are influencing wear rate of Al6061 T6/15%SiC/15% Al_2O_3 metal matrix composite. Wear rate is highly influenced by applied load, sliding distance and sliding speed respectively. Interaction term L*S (Load*Speed) [38.75%] is highly associated with wear rate of composite material and most influencing term among different interaction parameters.

For COF such as sliding distance [42.35%], sliding speed [16.82%] and applied load [5.7%] which are influencing coefficient of friction of Al6061 T6/15%SiC/15%Al_2O_3 metal matrix composite. Coefficient of friction is highly influenced by sliding distance, sliding speed and applied load respectively. Interaction term L*S (Load*Speed) [23.32%] is highly associated with coefficient of friction of composite material and most influencing term among different interaction parameters.

Wear Rate = 0.00686 - 0.000064 Load (N) - 0.000023 Speed (m/s) - 0.000001 Distance (m)

COF = 0.571 - 0.00500 Load (N) + 0.109 Speed (m/s) - 0.000125 Distance (m)

Wear rate of composite is inversely proportional to applied load, sliding speed and sliding distance. Coefficient of friction is directly proportional to sliding speed and inversely proportional to load and sliding distance.

5. Conclusion

- Wear rate (Al6061T6/15%SiC/15% Al_2O_3 MMC) was highly influenced by applied load, sliding distance and sliding speed respectively and interaction term L*S (Load*Speed) [37.75%] was found most predominant among different interaction parameters.
- Coefficient of friction(Al6061T6/15%SiC/15% Al_2O_3 MMC) was highly influenced by sliding distance, sliding speed and applied load respectively and interaction term L*D (Load*Distance) [23.32%] was found most influencing term among different interaction parameters.
- From the regression equations for wear rate and coefficient of friction(Al6061T6/15%SiC/15% Al_2O_3 MMC), we found that wear rate of composite is inversely proportional to applied load, sliding speed and sliding distance and Coefficient of friction is directly proportional to sliding speed and inversely proportional to applied load, sliding distance.

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