ISSN 2250-3153

Study of Dry Sliding Wear Behavior of Aluminium/SiC/Al_2O_3/Graphite Hybrid Metal Matrix Composite Using Taguchi Technique

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ABSTRACT:- The experimental investigation of hybrid metal matrix composites with SiC, Al_2O_3 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, Al_2O_3) 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. The design of experiments (DOE) approach using taguchi method was employed to analyze the wear behaviour of hybrid composites. Signal-to-noise ratio and analysis of variance (ANOVA) were used to investigate the influence of parameters on the wear rate.

Key words- Aluminium Alloy, Graphite, Wear, DOE, Taguchi's orthogonal array, ANOVA, Regression analysis

1. INTRODUCTION

Metal matrix composites (MMCs) have proved their importance to conventional alloys in high strength and stiffness application in industries like auto-mobile, aerospace and mineral processing. To improve the mechanical and tribological properties, reinforcement phase such as hard ceramic particles or fibers are uniformly distributed in the soft matrix phase. The composite materials have emerged as the important class of advanced materials giving engineers the opportunity to tailor the material properties according to their needs. Basically these materials differ from the conventional engineering materials from the viewpoint of homogeneity. Particulate metal matrix composites are most commonly manufactured by melt incorporation and stir casting technique. These properties along with good specific strength, modulus makes them good materials for many engineering situations where sliding contact is expected.

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 to a very soft material such as graphite have been reported to be superior when compared with unreinforced alloys. 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 design of experiments (DOE) approach using Taguchi technique has been successfully used by researchers in the study of wear behaviour of DRAMMCs. The DOE process is made up of three main phases: the planning phase, the conducting phase, and the analysis phase. 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 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. This method was been successfully used by researchers in the study of wear behavior 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/graphite hybrid metal matrix composites using Taguchi technique.

3. Experimental Details

3.1. Material

The matrix material selected was commercially available pure aluminium Al6061T6. The chemical composition of the matrix material is given in the **Table 1**. The reinforcement was SiC and Al_2O_3 average size of 400 µm, and graphite (200µm). 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. Graphite imparts excellent self lubricating property to the hybrid composite.

Table 1- Chemical Composition of Al6061T6 alloy

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

3.2. 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, $Al_2O_3$and graphite particles 10% and 5% 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 liquidus 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.

Fig.1 Stir Casting Setup

Fig.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 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.

3.3. 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.

Table 2: Parameters and their levels

Controllable factors	Load(L) (N)	Sliding Speed(S) (m/s)	Sliding distance(D) (m)
Level 1	24.53	1.5	700
Level 2	29.43	2	1400
Level 3	34.34	2.5	2100

In the present investigation, a L27 orthogonal array was selected and it has 27 rows and 13 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 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:

$$S/N = -10 \log [1/n (\Sigma y2)] \text{ -------(1)}$$

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.

Table 3-Result of L_{27} orthogonal array

Expt. No.	load(N)	speed(m/s)	distance(m)	wear rate	S/N(db)	COF	S/N(db)
1	25	1.5	700	0.003354	49.489	0.4595	6.7537
2	25	1.5	1400	0.003454	49.234	0.4192	7.5523
3	25	1.5	2100	0.0032855	49.668	0.4375	7.1802
4	25	2	700	0.0315548	30.019	0.5268	5.5669
5	25	2	1400	0.021888	33.196	0.5223	5.6412
6	25	2	2100	0.0177563	35.013	0.4783	6.4062
7	25	2.5	700	0.0484922	26.287	0.7372	2.6482
8	25	2.5	1400	0.053598	25.417	0.4086	7.7748
9	25	2.5	2100	0.0404794	27.855	0.3768	8.4787
10	30	1.5	700	0.0058953	44.59	0.4258	7.4168
11	30	1.5	1400	0.0060108	44.421	0.4169	7.5989

12	30	1.5	2100	0.0056569	44.948	0.3197	9.904
13	30	2	700	0.0835952	21.556	0.4992	6.0354
14	30	2	1400	0.0497451	26.065	0.5508	5.1801
15	30	2	2100	0.0363433	28.792	0.4292	7.3477
16	30	2.5	700	0.00565	44.959	0.051	25.854
17	30	2.5	1400	0.0126981	37.925	0.5399	5.3533
18	30	2.5	2100	0.0100904	39.922	0.5369	5.4027
19	35	1.5	700	0.0202996	33.85	0.6395	3.8834
20	35	1.5	1400	0.9852	0.1295	0.5325	5.4736
21	35	1.5	2100	0.09134	20.787	0.4892	6.2103
22	35	2	700	0.1295556	17.751	0.479	6.3927
23	35	2	1400	0.0696936	23.136	0.5111	5.8305
24	35	2	2100	0.0510615	25.838	0.5696	4.8886
25	35	2.5	700	0.05324	25.475	0.5712	4.8642
26	35	2.5	1400	0.0654	23.688	0.5854	4.6509
27	35	2.5	2100	0.07123	22.947	0.5543	5.1251

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

Level	load(N)	speed(m/s)	distance(m)
1	36.66	36.19	31.81
2	37.02	25.16	29.25
3	20.24	32.57	32.86
Delta	16.78	11.03	3.62
Rank	1	2	3

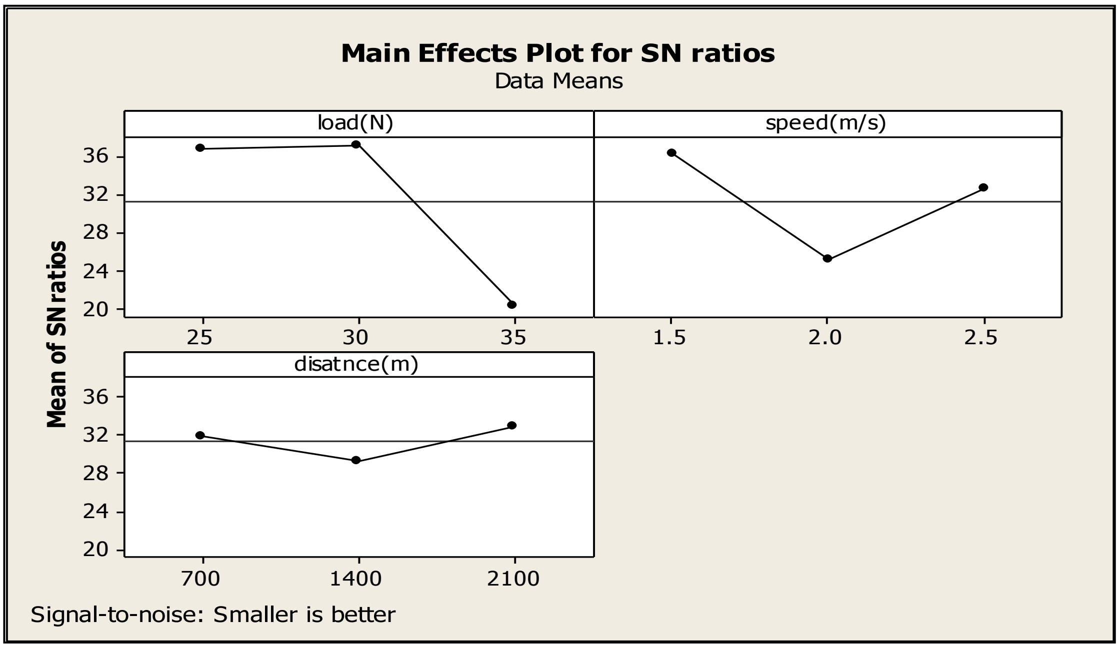

Fig. 3-Main Effects Plot for SN ratios-Wear rate

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

Level	load(N)	speed(m/s)	distance(m)
1	0.02299	0.13107	0.04665
2	0.02397	0.06063	0.14085
3	0.17691	0.3217	0.03636
Delta	0.15392	0.09891	0.10449
Rank	1	3	2

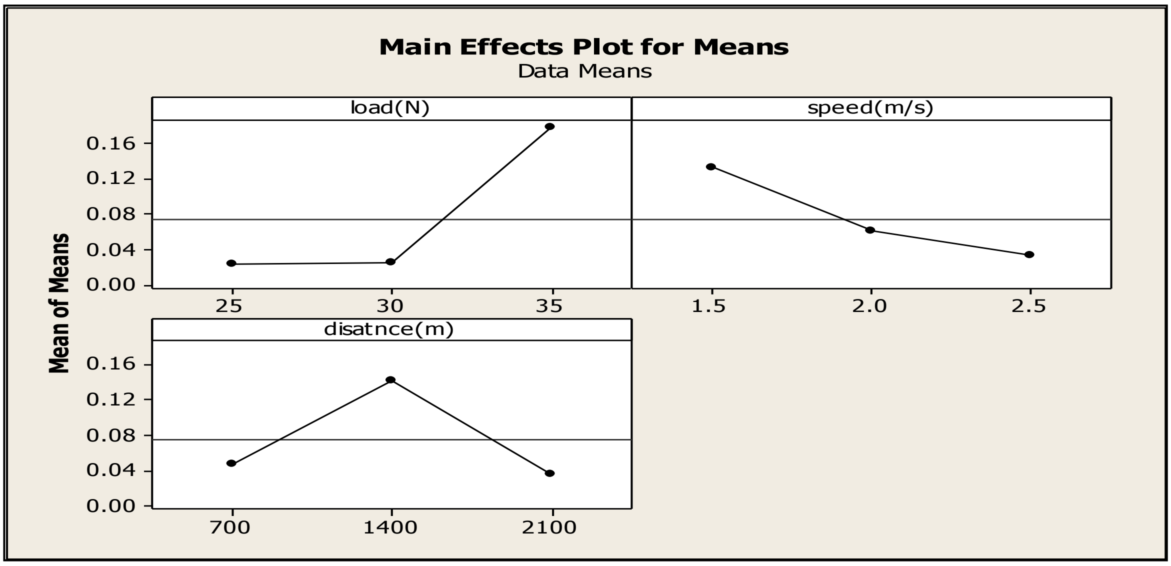

Fig. 4- Main Effects Plot for Means-Wear rate

Table 6- Response Table for SN Ratios- Smaller is better (Coefficient of friction)

Level	load(N)	speed(m/s)	distance(m)
1	6.445	6.886	7.713
2	8.899	5.921	6.117
3	5.258	7.795	6.772
Delta	3.642	1.874	1.596
Rank	1	2	3

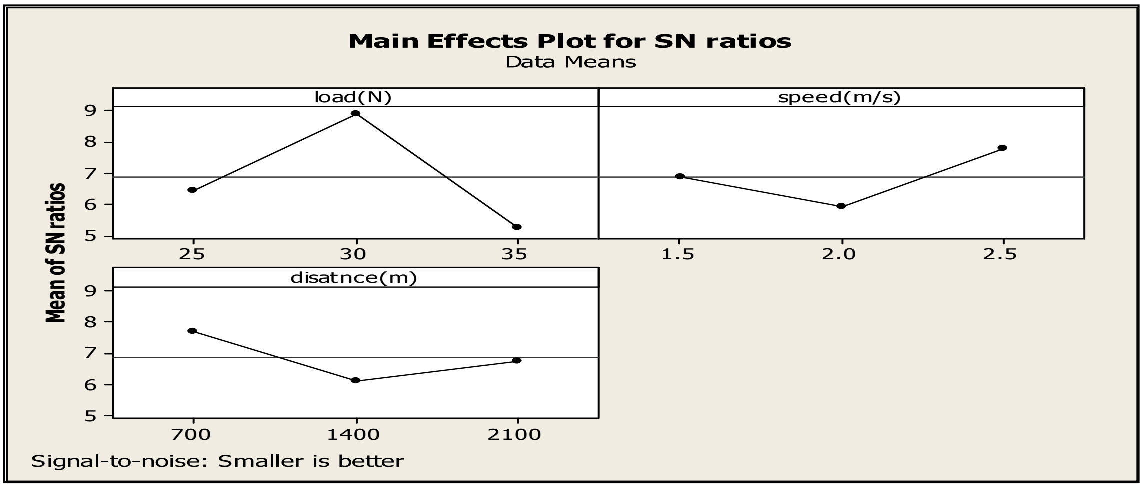

Fig.5-Main Effects Plot for SN ratios-coefficient of friction

Table 7- Response Table for Means- Smaller is better (Coefficient of friction)

Level	load(N)	speed(m/s)	distance(m)
1	0.4851	0.46	0.4877
2	0.4188	0.5074	0.4985
3	0.548	0.4846	0.4657
Delta	0.1292	0.0474	0.0328
Rank	1	2	3

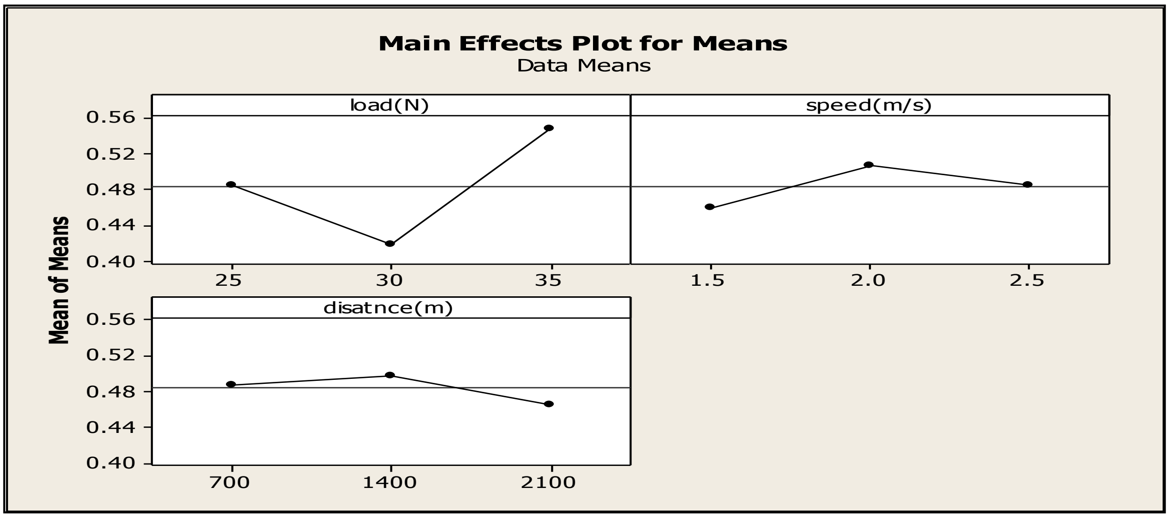

Fig.6-Main Effects Plot for Means-coefficient of friction

4.2. Analysis of Variance

Table8- Analysis of Variance for SN ratios- Wear rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%
Load(N)	2	1652.76	1652.76	826.38	20.08	0	45.5596
Speed(m/s)	2	569.21	569.21	284	9.67	0.007	15.6907
Distance(m)	2	62.33	62.33	31.16	1.06	0.391	1.71817
Load(N)*speed(m/s)	4	982.68	982.68	245.67	8.35	0.006	27.0883
Load(N)*distance(m)	4	43.49	43.49	10.87	0.37	0.824	1.19884
Speed(m/s)*distance(m)	4	81.75	81.75	20.44	0.69	0.617	2.2535
Residual Error	8	238.48	238.48	29.43			6.57388
Total	26	3627.69					

Table 9- Analysis of Variance for SN ratios- coefficient of friction

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%
Load(N)	2	62.08	62.08	31.041	1.43	0.296	14.356413
Speed(m/s)	2	15.8	15.8	7.901	0.36	0.707	3.653855
Distance(m)	2	11.58	11.58	5.79	0.27	0.773	2.677952
Load(N)*speed(m/s)	4	43.69	43.69	10.923	0.5	0.736	10.103603
Load(N)*distance(m)	4	81.26	81.26	20.314	0.93	0.491	18.791915
Speed(m/s)*distance(m)	4	43.76	43.76	10.94	0.5	0.736	10.119791
Residual Error	8	54.25	54.25	21.781			12.545673
Total	26	432.42					

ANOVA was used to determine the design parameters significantly influencing the wear rate (response). Table 8 and Table 9shows 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 L was the most significant parameter having the highest statistical influence (45.55%) on the dry sliding wear of composites followed by S (15.6%) and D (1.7%).When the P-value for this model was less than 0.05, then the parameter or interaction can be considered as statistically significant. This is desirable as it demonstrates that the parameter or interaction in the model has a significant effect on the response. From an analysis of the results obtained in Table 8, it is observed that the interaction effect L*S (18.78%) is significant model terms influencing wear rate of composites. Coefficient of friction was highly influenced by L (14.3%), S (3.6%) and D (2.6%) respectively and interaction term L*D (18.7%) was found most influencing term among different interaction parameters. The coefficient of determination (R2) is defined as the ratio of the explained variation to the total variation. It is a measure of the degree of fit. When R2 approaches unity, a better response model results and it fits the actual data. The value of R2 calculated for this model was 0.9611, i.e., reasonably close to unity, and thus acceptable. It demonstrates that 96.11% of the variability in the data can be explained by this model. Thus, it is confirmed that this model provides reasonably good explanation of the relationship between the independent factors and the response.

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 MINITAB 15. A regression equation thus generated establishes correlation between the significant terms obtained from ANOVA, namely, load, sliding speed, sliding distance and their interactions. The regression equation developed for wear rate is:
Wear rate(mm^3/m) = - 0.179 + 0.0154 load(N) - 0.0989 speed(m/s) - 0.000007 distance(m) **-(1)**

COF = 0.268 + 0.00628 load(N) + 0.0246 speed(m/s) - 0.000016 distance(m) **-(2)**

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 above regression equations for wear rate and coefficient of friction, we found that wear rate of composite is directly proportional to applied load and inversely proportional to speed and distance and Coefficient of friction is directly proportional to applied load and sliding speed. The coefficient of friction and wear rate associated with load (L) in the regression equation (2) is positive and it indicates that as the load increases, wear rate of the composite also increases.

5. Conclusions

1) Wear rate (Al6061T6/10%Sic/10% Al_2O_3/5% Graphite MMC) was highly influenced by applied load, sliding speed and sliding distance respectively and interaction term L*S (Load*Speed) [27.08%] was found most predominant among different interaction parameters.
2) Coefficient of friction(Al6061T6/10%Sic/10% Al_2O_3/5% Graphite MMC) was highly influenced by applied load, sliding speed and sliding distance respectively and interaction term L*D (Load*Distance) [18.78%] was found most influencing term among different interaction parameters.
3) From the regression equations for wear rate and coefficient of friction(Al6061T6/10%Sic/10% Al_2O_3/5% Graphite MMC), we found that wear rate of composite is directly proportional to applied load and inversely proportional to speed and distance and Coefficient of friction is directly proportional to applied load and sliding speed.

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