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EFFECT OF WEIGHT PERCENTAGE OF SiC ON COEFFICIENT OF FRICTION AND WEAR BEHAVIOUR OF Al(6351)-SiC METAL MATRIX COMPOSITE

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Abstract

Tribological behavior of aluminum alloy (Al6351-SiC) reinforced with silicon carbide fabricated by stir casting process was investigated. The wear and frictional properties of the metal matrix composites was studied by performing dry sliding wear test using a pin-on-disc wear tester. Experiments were conducted based on the plan of experiments generated through Taguchi's technique. A L9 Orthogonal array was selected for analysis of the data. Investigation 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 for each response were developed for both 7%, 14% & 21% Sic reinforced Al-6351MMCs. Objective of the model was chosen as 'smaller the better' characteristics to analyses the dry sliding wear resistance. Results show that sliding distance has the highest influence followed by load and sliding speed.

Keywords: Metal Matrix Composites; Stir casting; Taguchi's techniques; orthogonal array; Analysis of variance; wear behavior.

1. INTRODUCTION

In the last two decades, research has shifted from monolithic materials to composite materials to meet the global demand for light weight, high performance, environmental friendly, wear and corrosion resistant materials. Metal Matrix Composites (MMCs) are suitable for applications requiring combined strength, thermal conductivity, damping properties and low coefficient of thermal expansion with lower density. These properties of MMCs enhance their usage in automotive and tribological applications. In the field of automobile, MMCs are used for pistons, brake drum and cylinder block because of better corrosion resistance and wear resistance. Fabrication of MMCs has several challenges like porosity formation, poor wet ability and improper distribution of reinforcement. Aluminum based silicon carbide particulate metal matrix composites fabricated using two step mixing method of stir casting technique by varying the volume fraction of SiC (7%,14% and 21%) showed an increasing trend in hardness values with increase in volume fraction of SiC .The tribological properties are considered to be one of the major factors controlling the performance. In this case, the wear rate and coefficient of friction was determined using pin-on-disc type apparatus by varying the applied load from 9.81-29.4N with a different sliding velocity and sliding distance.

A Numerical analysis of pin on disc tests on Al/SiC composites at different loads has been reported.
There is a growing interest worldwide in manufacturing metal matrix composites MMCs which possesses combined properties of its reinforcements and exhibit improved physical, mechanical and tribological properties. Aluminum matrix composites reinforced silicon carbide was developed using conventional foundry techniques. The reinforcements were varied by 7%,14% and 21% by weight. The composite was tested for density, mechanical properties, and dry sliding wear. The results show an increasing trend in all the properties with increase in SiC content, except density which decreased with increase in reinforcements. The tribological properties of MMCs are also increased by increasing reinforcements at all applied conditions.

2. Design of experiments (DOE)

Design of Experiment is one of the important and powerful statistical techniques to study the effect of multiple variables simultaneously and involves a series of steps which must follow a certain sequence for the experiment to yield an improved understanding of process performance. All designed experiments require a certain number of combinations of factors and levels be tested in order to observe the results of those test conditions. Taguchi approach relies on the assignment of factors in specific orthogonal arrays to determine those test combinations. 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. This technique has been successfully used by researchers in the study of dry sliding wear behavior of composites. These methods focus on improving the design of manufacturing processes. In the present work, a plan order for performing the experiments was generated by Taguchi method using orthogonal arrays. This method yields the rank of various parameters with the level of significance of influence of a factor or the interaction of factors on a particular output response.
Quality characteristic of a product under investigation in response to a factor introduced in the experimental design is the ‘signal’ of the desired effect. The effect of external factors (uncontrollable factor) on the outcome of quality characteristics under test is termed as ‘noise’. The S/N Ratio measures the sensitivity of the quality characteristic being investigated in a controlled manner to those of external influencing factors (noise factor) not under control. The S/N Ratio is transformed figure of merit, created from the loss function. S/N Ratio combines both the parameters (the mean level of the quality and the variation around this mean) in a signal metric. The aim in any experiment is always to determine the highest possible ratio for the result (wear rate and frictional force) a high value of S/N Ratio implies the signal is much higher than the random effect of noise factor.

3. Material selection

In the present investigation, Al-Sic alloy was chosen as the base matrix since its properties can be tailored through heat treatment process. The reinforcement was sic, average size of 150 to 160 microns, and there are sufficient literatures elucidating the improvement in wear properties through the addition of Sic. Due to the property of high hardness and high thermal conductivity, Sic after accommodation in soft ductile aluminum base matrix, enhance the wear resisting behavior of the MMC. Al-SiC composites are suitable replacements for copper-molybdenum (CuMo) and copper-tungsten (CuW) alloys; they have about 1/3 the weight of copper, 1/5 of CuMo, and 1/6 of CuW, making them suitable for weight-sensitive applications; they are also stronger and stiffer than copper. They are stiff, lightweight, and strong. They can be used as heat sinks, substrates for power electronics (e.g. IGBTs and high-power LEDs), heat spreaders, housings for electronics, and lids for chips, e.g. microprocessors and ASICs. Metal and ceramic inserts and channels for a coolant can be integrated into the parts during manufacture. Al-SiC composites can be produced relatively inexpensively (USD 2-4/lb in large series); the dedicated tooling however causes large up-front expenses, making Al-SiC more suitable for mature designs. Heat pipes can be embedded into Al-SiC, raising effective heat conductivity to 500–800 W/m K. Al-SiC parts are typically manufactured by near net shape approach, by creating a SiC perform by metal injection molding of an SiC-binder slurry, fired to remove the binder, then infiltrated under pressure with molten aluminum. Parts can be made with sufficiently low tolerances to not require further machining. The material is fully dense, without voids, and is hermetic. High stiffness and low density appears making larger parts with thin wall, and manufacturing large fins for heat dissipation. Al-SiC can be plated with nickel and nickel-gold, or by other metals by thermal spraying. Ceramic and metal insets can be inserted into the perform before aluminum infiltration, resulting in a hermetic seal. Al-SiC can be also prepared by mechanical alloying. When lower degree of SiC content is used, parts can be stamped from Al-SiC sheets.

3.1 Composite preparation

In order to achieve high level of mechanical properties in the composite, a good interfacial bonding (wetting) between the dispersed phase and the liquid matrix has to be obtained. Stir-casting technique is one such simplest and cost effective method to fabricate metal matrix composites which has been adopted by many researchers. This method is most economical to fabricate composites with discontinuous fibers and particulates and was used in this work to obtain the as cast specimens. Care was taken to maintain an optimum casting parameter of

Pouring temperature (700°C) and stirring time (8 min).show below in fig 1& 2.

Fig. 1 melting of aluminum.

Fig. 2 pouring of the molten metal into mould

The reinforcements were preheated prior to their addition in the aluminum alloy melt. Degassing agent (hexachord ethane) was used to reduce gas porosities. The molten metal was then poured into a permanent cast iron mould of diameter 18mm and length 300mm. The die was released after 30 minutes and the cast specimens were taken out. show in fig 3.

Fig. 3composite specimen from mould.

3.2 Wear behavior

The aim of the experimental plan is to find the important factors and combination of factors influencing the wear process to achieve the minimum wear rate and coefficient of friction. The experiments were developed based on an orthogonal array, with the aim of relating the influence of sliding speed, applied load and sliding distance. These design parameters are distinct and intrinsic feature of the process that influence and determine the composite performance. Taguchi recommends analyzing the S/N ratio using conceptual approach that involves graphing the effects and visually identifying the significant factors.

The above mentioned pin on disc test apparatus was used to determine the sliding wear characteristics of the composite. Specimens of size 6 mm diameter and 22 mm length were cut from the cast samples, and then machined. Show in fig.4.

Fig. 4 Specimens

The contact surface of the cast sample (pin) was made flat so that it should be in contact with the rotating disk. During the test, the pin was held pressed against a rotating EN31 carbon steel disc (hardness of 65HRC) by applying load that acts as counterweight and balances the pin. The track diameter was varied for each batch of experiments in the range of 50 mm to 100 mm and the parameters such as the load, sliding speed and sliding distance were varied in the range given in Table1. 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 and time was monitored for all the specimens i.e., 7%, 14% and 21%. The results for various combinations of parameters were obtained by conducting the experiment as per the orthogonal array and show the Table 2. The measured results were analyzed using the commercial software MINITAB 15 specifically used for design of experiment applications. Table 3, 4& 5 shows the experimental results average of two repetitions for wear rate and coefficient of friction.

To measure the quality characteristics, the experimental values are transformed into signal to noise ratio. The influence of control parameters such as load, sliding speed, and sliding distance on wear rate and coefficient of friction has been analyzed using signal to noise response table. The ranking of process parameters using signal to noise ratios obtained for different parameter levels for wear rate and coefficient of friction are given in Table 3.1, 3.2, 4.1,4.2 5.1, 5.2and Table 3.3, 3.4, 4.3, 4.4, 5.3, 5.4 respectively. The control factors are statistically significant in the signal to noise ratio and it could be observed that the sliding distance is a dominant parameter on the wear rate and coefficient of friction followed by applied load and sliding speed. Figure (5-7) shows the influence of process parameters on wear rate and coefficient of friction graphically. The analysis of these experimental results using S/N gives the optimum conditions resulting in minimum wear rate and coefficient of friction. The optimum condition for wear rate and coefficient of friction as shown in Figure 5, 6 and 7. Thus, the optimal setting of control factors for better wear resistance of metal matrix composite was arrived at.

Table 1 Process parameters and levels

Level	Load, L (N)	Sliding speed, S (m/s)	Sliding distance, D (m)
1	9.81	1.256	750
2	19.6	1.507	900
3	29.4	1.759	1050

4. Plan of experiment using orthogonal array

Dry sliding wear test was performed with three parameters: applied load, sliding speed, and sliding distance and varying them for three levels. According to the rule that degree of freedom for an orthogonal array should be greater than or equal to sum of those wear parameters, a L9 Orthogonal array which has 9 rows and 3 columns was selected as shown below:

Table 2 Show the Orthogonal array L9 of Taguchi

Experiment No.	Column 1	Column 2	Column 3
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

The selection of Orthogonal array depends on three items in order of priority, viz., the number of factors and their interactions, number of levels for the factors and the desired experimental resolution or cost limitations. A total of 9 experiments were performed based on the run order generated by the Taguchi model. The response for the model is wear rate and coefficient of friction. In Orthogonal array, first column is assigned to applied load, second column is assigned to sliding speed and third column is assigned to sliding distance and the remaining columns are assigned to their interactions. The objective of model is to minimize wear rate and coefficient of friction. The Signal to Noise (S/N) ratio, which condenses the multiple data points within a trial, depends on the type of characteristic being evaluated. The S/N ratio characteristics can be divided into three categories, viz. ‘nominal is the best’, ‘larger the better’ and ‘smaller the better ‘characteristics. In this study, ‘smaller the better’ characteristics was chosen to analyse the dry sliding wear resistance. The S/N ratio for wear rate and coefficient of friction using ‘smaller the better’ characteristic given by Taguchi, is as follows:

$$\text{S/N}\ (\eta) = -10 log \frac{1}{n} \sum_{i=1}^{n} y_i^2$$

Where y1, y2...y_i are the response of friction and sliding wear;
and n is the number of observations.
The response table for signal to noise ratios shows the average of selected characteristics for each level of the factor. This table 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.

5. Result and discussions

The aim of the experimental plan is to find the important factors and combination of factors. Influencing the wear process to achieve the minimum wear rate and coefficient of friction. The experiments were developed based on an orthogonal array, with the aim of relating the influence of sliding speed, applied load and sliding distance. These design parameters are distinct and intrinsic feature of the process that influence and determine the composite performance. Taguchi recommends analyzing the S/N ratio using conceptual approach that involves graphing the effects and visually identifying the significant factors.

5.1 Results of Statistical Analysis of Experiments

The results for various combinations of parameters were obtained by conducting the experiment as per the orthogonal array. The measured results were analyzed using the commercial software MINITAB 15 specifically used for design of experiment applications. Table 3, 4, &5 shows the experimental results average of two repetitions for wear rate and coefficient of friction. To measure the quality characteristics, the experimental values are transformed into signal to noise ratio. The influence of control parameters such as load, sliding speed, and sliding distance on wear rate and coefficient of friction has been analyzed using signal to noise response table. The ranking of process parameters using signal to noise ratios obtained for different parameter levels for wear rate and coefficient of friction are given in Table 3.1-3.2, 4.1-4.2 and Table 5.1-5.2 respectively. The control factors are statistically significant in the signal to noise ratio and it could be observed that the sliding distance is a dominant parameter on the wear rate and coefficient of friction followed by applied load and sliding speed. Figure (3.1-3.2) shows for 7% influence of process parameters on wear rate and coefficient of friction graphically, Figure (4.1-4.2) shows for 14% influence of process parameters on wear rate and coefficient of friction graphically and Figure (5.1-5.2) shows for 21% influence of process parameters on wear rate and coefficient of friction graphically. The analysis of these experimental results using S/N gives the optimum conditions resulting in minimum wear rate and coefficient of friction. The optimum condition for wear rate and coefficient of friction as shown in Figure 3.1-3.2, 4.1-4.2 and 5.1-5.2.Thus,the optimal setting of control factors for better wear resistance of metal matrix composite were arrived at.

5.2 Analysis of variance results for wear test

The experimental results were analyzed with Analysis of Variance (ANOVA) which is used to investigate the influence of the considered wear parameters namely; applied load, sliding speed, and sliding distance that significantly affect the performance measures. By performing analysis of variance, it can be decided which independent factor dominates over the other and the percentage contribution of that particular independent variable. Table 6-7, 8-9 and 10-11 show 7%, 14% &21% of the ANOVA results for wear rate and coefficient of friction for three factors varied at three levels and interactions of those factors. This analysis is carried out for a significance level of $\alpha=0.05$, i.e. for a confidence level of 95%. Sources with a P-value less than 0.05 were considered to have a statistically significant contribution to the performance measures.

Table 3. Results of L9 orthogonal array for Al-6351 / 7%- SiC MMC.

S.No.	Load (N)	Sliding Velocity (m/s)	Sliding Distance (m)	Coefficient of friction	Wear	S/N Ratio of c.o.f	S/N Ratio of wear
1	9.81	1.256	750	0.153	0.007	16.3062	43.0980
2	9.81	1.507	900	0.143	0.006	16.8933	44.4370
3	9.81	1.759	1050	0.091	0.005	20.8192	47.9588
4	19.6	1.256	900	0.214	0.006	13.3917	44.4370
5	19.6	1.507	1050	0.326	0.004	9.7356	47.9588
6	19.6	1.759	750	0.188	0.005	14.5168	46.0206
7	29.4	1.256	1050	0.241	0.004	12.3597	47.9588
8	29.4	1.507	750	0.329	0.005	9.6561	46.0206
9	29.4	1.759	900	0.282	0.003	10.9950	50.4576

Table 3.1 Response Table for S/N ratio for wear (SiC-7%).

Level	load(A)	Sliding velocity(B)	Sliding distance(C)
1	44.52	45.16	45.05
2	46.14	46.14	46.44
3	48.15	47.50	47.31
Delta(Δ)	3.63	2.33	2.27
Rank	1	2	3

(Table 3.2 Response Table for S/N ratio of coefficient of friction SiC-7%).

Level	load(A)	Sliding velocity(B)	Sliding distance(C)
1	18.01	14.02	13.49
2	12.55	12.10	13.76
3	11.00	15.44	14.30
Delta(Δ)	7.00	3.35	0.81
Rank	1	3	2

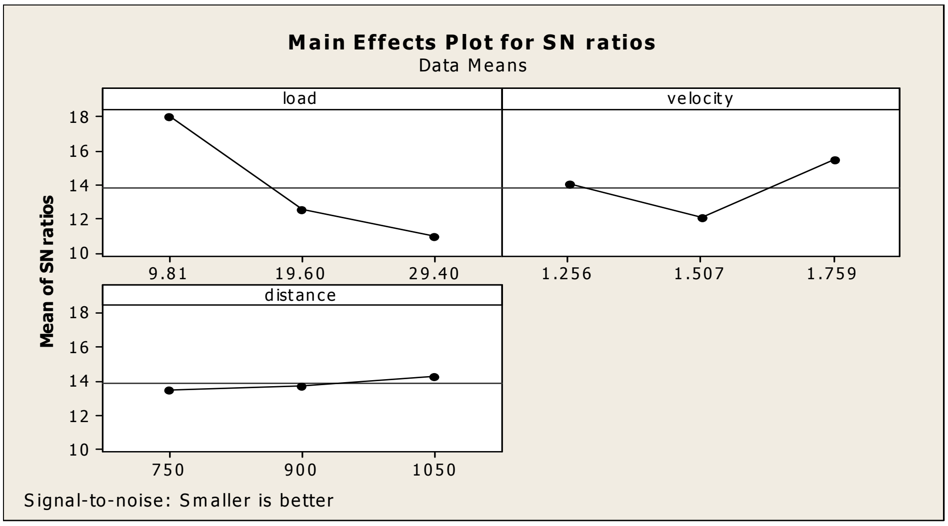

Fig. 3.1 Main effects for plot for S/N Ratios –Coefficient of Friction(SiC-7%)

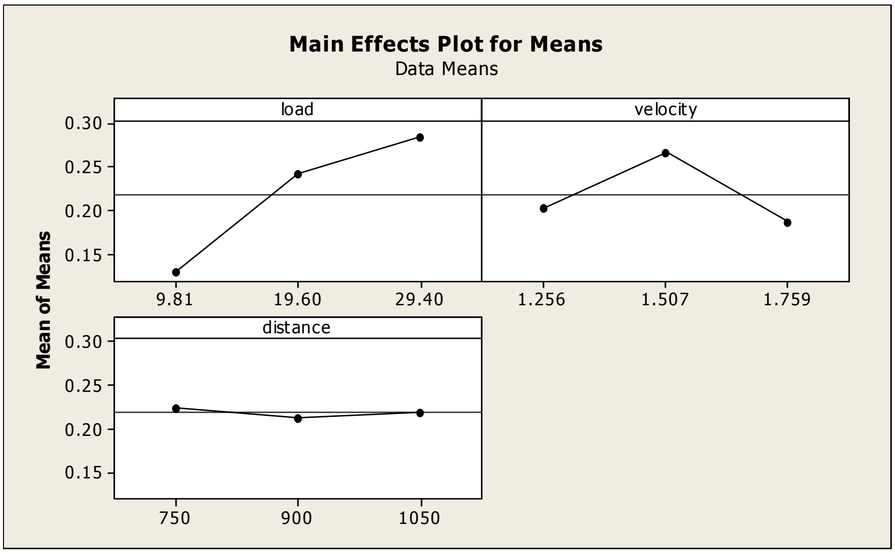

Fig. 3.2 Main effects for plot for Means –Coefficient of Friction (SiC-7%)

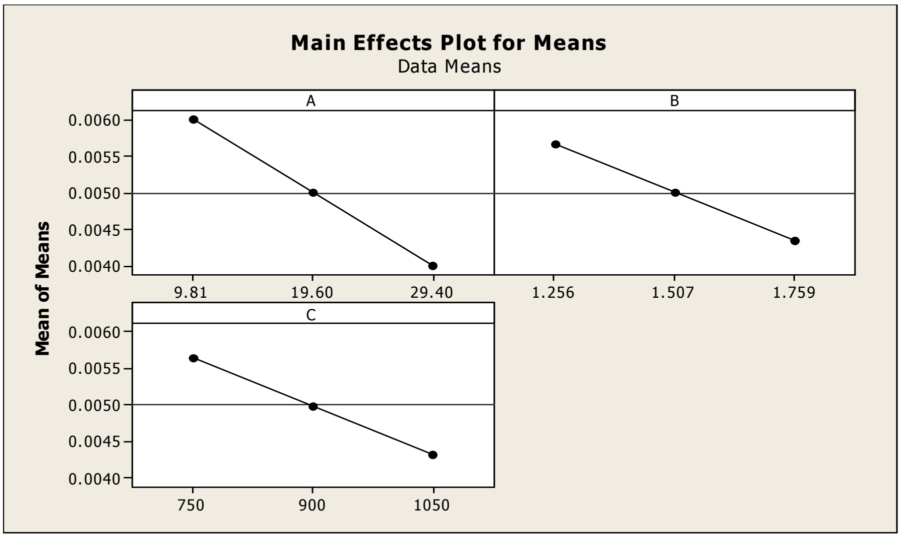

Fig. 3.3Main effects for plot for Means –Wear Rate (SiC-7%)

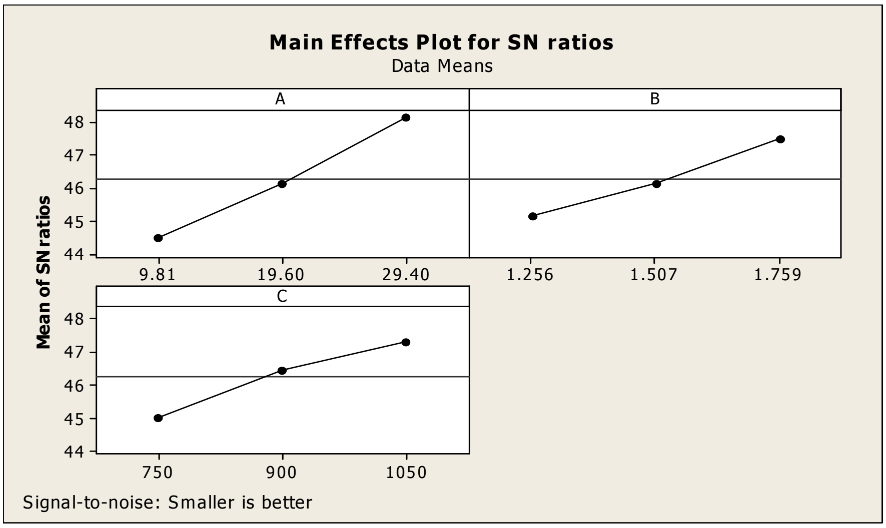

Fig. 3.4 Main effects for plot for S/N Ratio –Wear Rate (SiC-7%)

Table 4 Results of L9 orthogonal array for Al-6351 /SiC-14% MMC.

S.No.	Load (N)	Sliding Velocity (m/s)	Sliding Distance (m)	Coefficient of friction	Wear	S/N Ratio of c.o.f	S/N Ratio of wear
1	9.81	1.256	750	0.193	0.006	14.2889	44.4370
2	9.81	1.507	900	0.224	0.005	12.9950	46.0206
3	9.81	1.759	1050	0.204	0.004	13.8074	47.9588
4	19.6	1.256	900	0.290	0.005	10.7520	46.0206
5	19.6	1.507	1050	0.367	0.004	8.7067	47.9588
6	19.6	1.759	750	0.382	0.003	8.3587	50.4576
7	29.4	1.256	1050	0.346	0.005	9.2185	46.0206
8	29.4	1.507	750	0.302	0.003	10.3999	50.4576
9	29.4	1.759	900	0.418	0.002	7.5765	53.9794

***Table 4.1Response Table for Signal to Noise Ratios (Coefficient of friction)* Smaller is better (SiC-14%).**

Level	load(A)	Sliding velocity(B)	Sliding distance(C)
1	13.697	11.420	11.016
2	9.272	10.701	10.441
3	9.065	9.914	10.578
Delta(Δ)	4.632	1.506	0.575
Rank	1	2	3

Table 4.2 Response Table for Signal to Noise Ratios Smaller is better (Wear Rate) (14% -SiC).

Level	load(A)	Sliding velocity(B)	Sliding distance(C)
1	46.14	45.49	48.45
2	48.15	48.15	48.67
3	50.15	50.80	47.31
Delta(Δ)	4.01	5.31	1.36
Rank	2	1	3

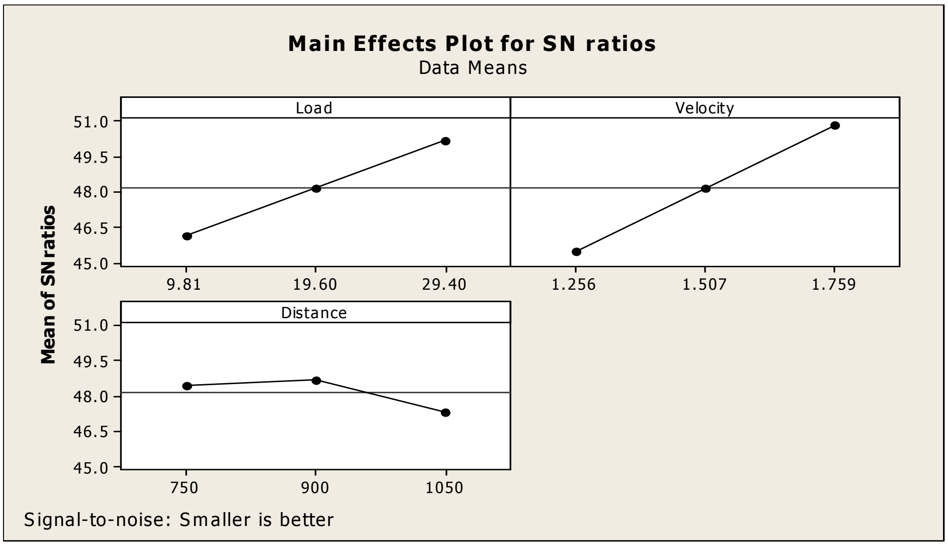

Fig. 4.1 Main effects plot for S/N ratios – Wear Rate (SiC-14%).

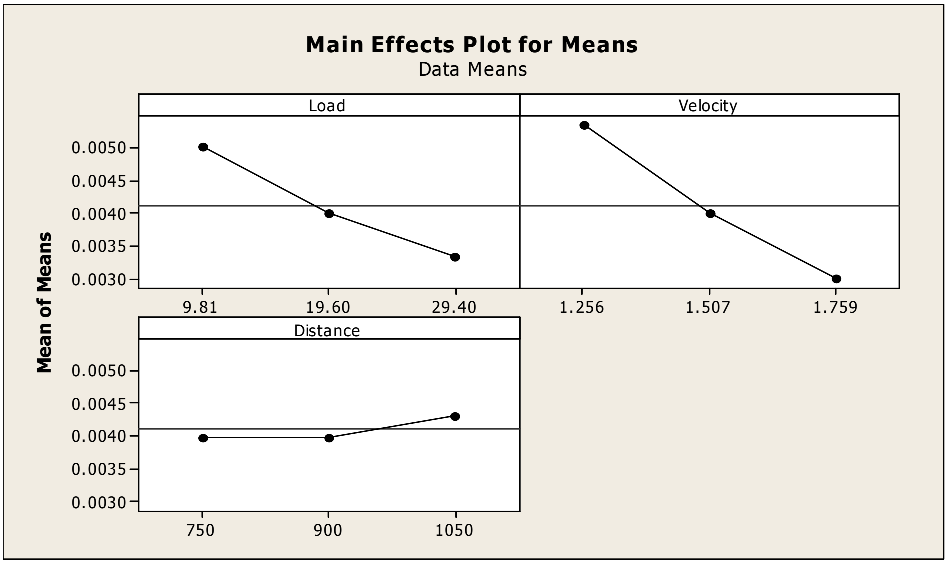

Fig. 4.2 Main effects plot for Means – Wear Rate (SiC-14%).

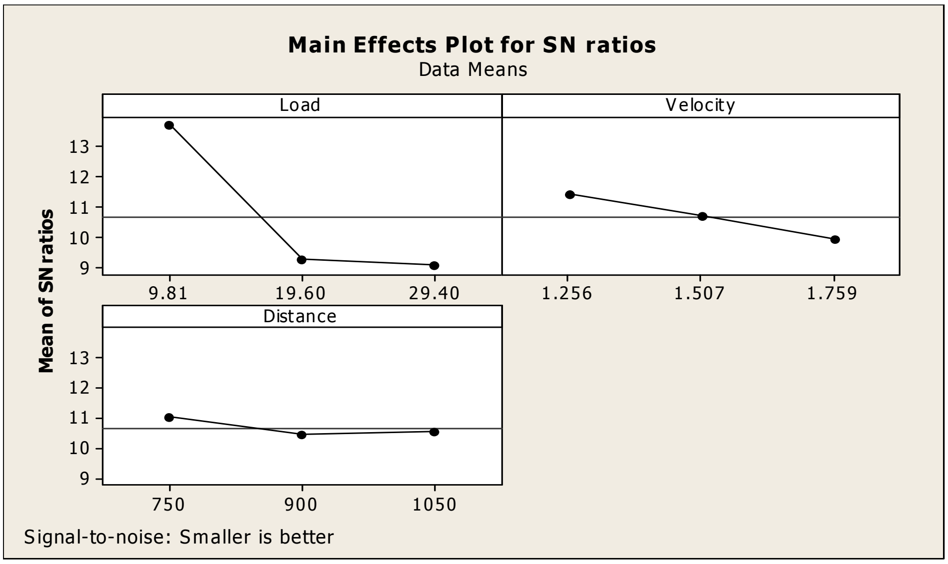

Fig. 4.3 Main effects plot for S/N ratio – Coefficient of Friction (SiC-14%)

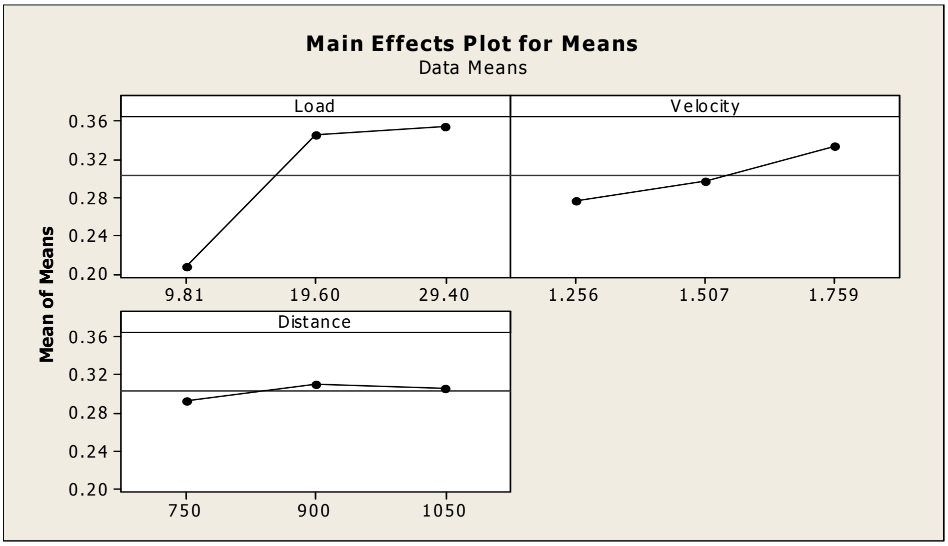

Fig. 4.4 Main effects plot for Means – Coefficient of Friction (SiC-14%).

Table 5 Results of L9 orthogonal array for Al-6351 /SiC-21% MMC.

S.No.	Load (N)	Sliding Velocity (m/s)	Sliding Distance (m)	Coefficient of friction	Wear	S/N Ratio of c.o.f	S/N Ratio of wear
1	9.81	1.256	750	0.285	0.003	10.9031	50.4576
2	9.81	1.507	900	0.275	0.004	11.2133	47.9588
3	9.81	1.759	1050	0.234	0.002	12.6157	53.9794
4	19.6	1.256	900	0.295	0.003	10.6036	50.4576
5	19.6	1.507	1050	0.377	0.002	8.4732	53.9794
6	19.6	1.759	750	0.413	0.003	7.6810	50.4576
7	29.4	1.256	1050	0.353	0.001	9.0445	60.0000
8	29.4	1.507	750	0.326	0.002	9.7356	53.9794
9	29.4	1.759	900	0.380	0.001	8.4043	60.0000

Table 5.1 Response Table for Signal to Noise Ratios (Coefficient of friction) Smaller is better. (SiC-21%).

Level	load(A)	Sliding velocity(B)	Sliding distance(C)
1	11.577	10.184	9.440
2	8.919	9.807	10.074
3	9.061	9.567	10.044
Delta(Δ)	2.658	0.617	0.634
Rank	1	3	2

Table 5.2 Average effect response Table for S/N ratio for wear (SiC-21%).

Level	load(A)	Sliding velocity(B)	Sliding distance(C)
1	50.80	53.64	51.63
2	51.63	51.97	52.81
3	57.99	54.81	55.99
Delta(Δ)	7.19	2.84	4.35
Rank	1	3	2

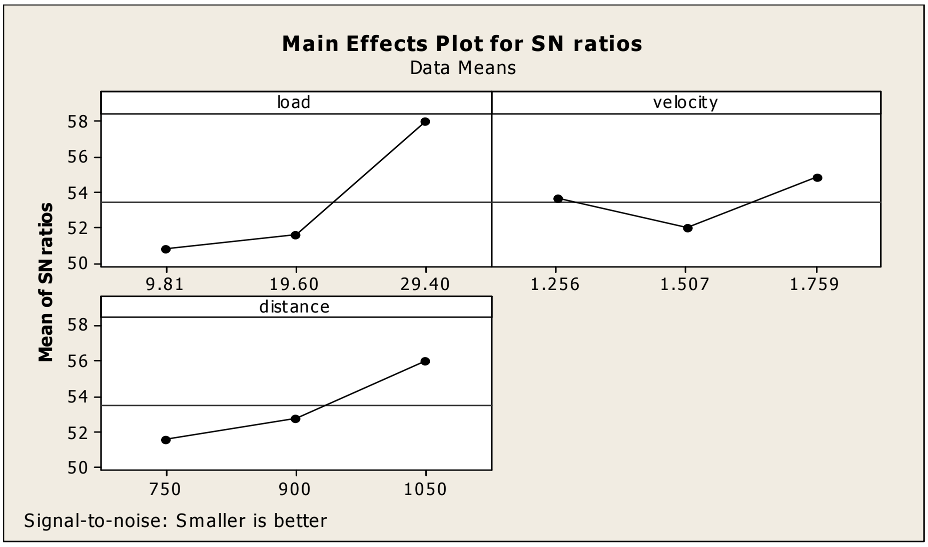

Fig. 5.1 Main effects plot for S/N ratios – Wear Rate (SiC-21%).

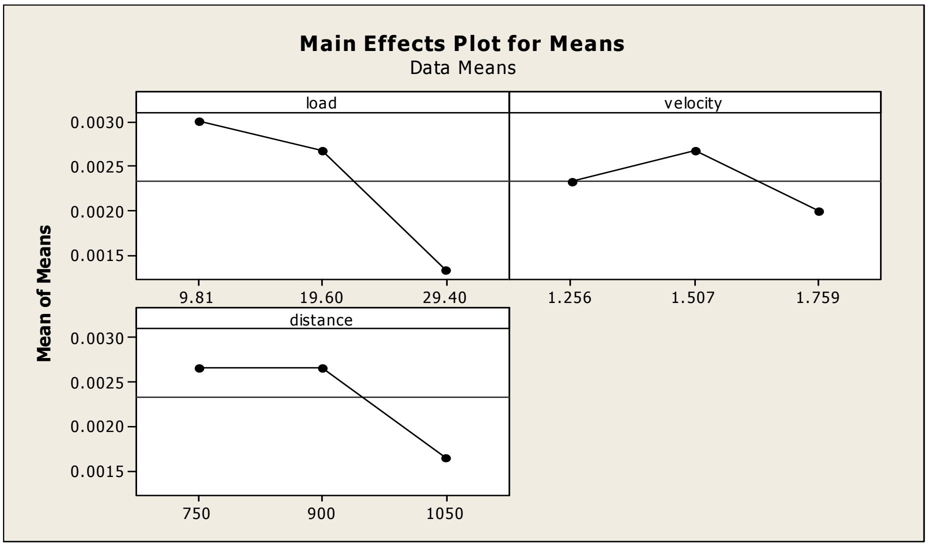

Fig. 5.2 Main effects plot for Means – Wear Rate (SiC-21%).

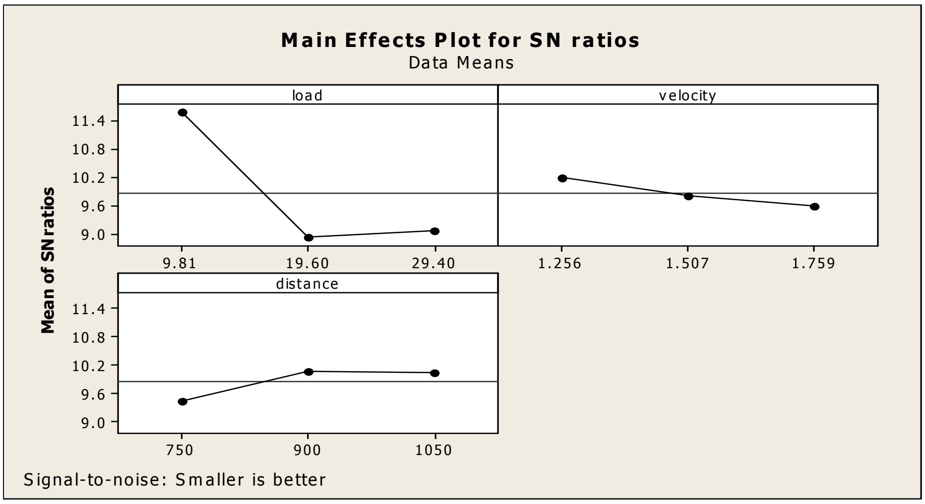

Fig. 5.3 Main effects plot for S/N ratio – Coefficient of Friction (SiC-21%).

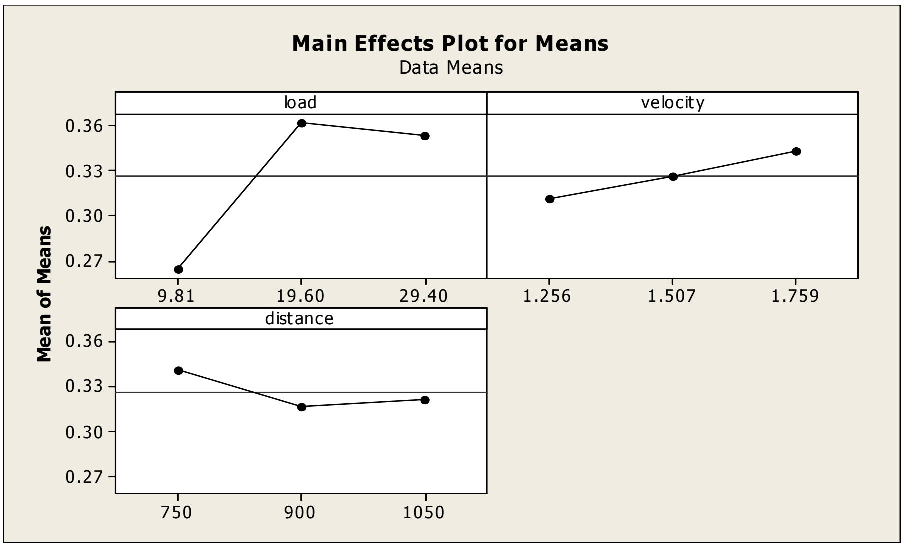

Fig. 5.4 Response Graph for wear for mean ratio of c.o.f. (**SiC**-21%).

5.3 Analyze the result and optimum factor-level combination

To study the effect of output responses on the wear behavior of material, the data was required to be analyzed to determine the better condition of the work. It is necessary to determine which parameter gives the lower wear rate. The smaller wear rate represents better or improved wear resisting condition and parameter. The average effect response table for the raw data and S/N ratio for SiC- 7%, 14% and 21% are shown below

Table 6 Analysis of Variance for wear rate (mm3/m) with 7%

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**pr%**
l	2	0.000006	0.000006	0.000003	9.00	0.100	50
s	2	0.000003	0.000003	0.000001	4.00	0.200	25
d	2	0.000003	0.000003	0.000001	4.00	0.200	25
Error	2	0.000000	0.000000	0.000000			.8
Total	8	0.000012					100

Table 7 Analysis of Variance for coefficient of friction with 7%

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**pr%**
l	2	0.038654	0.038654	0.019327	6.25	0.138	69.6
s	2	0.010498	0.010498	0.005249	1.70	0.371	18.9
d	2	0.000163	0.000163	0.000081	0.03	0.974	0.3
Error	2	0.006188	0.006188	0.003094			11.2
Total	8	0.055502					100

The regression equation is
wear = 0.0150 - 0.000102 LOAD - 0.00265 SPEED - 0.000004 DISTACE

The regression equation is
c.o.f = 0.123 + 0.00791 LOAD - 0.031 SPEED - 0.000013 DISTACE

Table 8 Analysis of Variance for wear rate (mm3/m) with 14%

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**pr%**
l	2	0.000004	0.000004	0.000002	9.65	0.050	30.7
s	2	0.000008	0.000008	0.000004	16.86	0.026	61.4
d	2	0.000001	0.000001	0.000000	1.28	0.500	7.6
Error	2	0.000000	0.000000	0.000000			0.3
Total	8	0.000013					100

Table 9 Analysis of Variance for coefficient of friction with 14%

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**pr%**
l	2	0.041498	0.041498	0.020749	6.42	0.135	77.3
s	2	0.005227	0.005227	0.020749	0.81	0.553	9.7
d	2	0.000539	0.000539	0.000269	0.08	0.923	1
Error	2	0.006460	0.006460	0.003230			12
Total	8	0.053723					100

The regression equation is
WEAR = 0.0118 - 0.000085 LOAD - 0.00464 SPEED + 0.000001 DISTACE

The regression equation is
COF = - 0.060 + 0.00757 LOAD + 0.116 SPEED + 0.000044 DISTACE

Table 10 Analysis of Variance for wear rate (mm3/m) with 21%

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**pr%**
l	2	0.000004	0.000004	0.000002	7.00	0.125	50
s	2	0.000001	0.000001	0.000000	1.00	0.500	12.5
d	2	0.000002	0.000002	0.000001	3.00	0.250	25
Error	2	0.000001	0.000001	0.000000			12.5
Total	8	0.000008					

Table 11 Analysis of Variance for coefficient of friction with 21%

Source	DF	Seq SS	Adj SS	Adj MS	F	P	pr%
l	2	0.017287	0.017287	0.008643	2.24	0.309	62.8
s	2	0.001474	0.001474	0.000737	0.19	0.840	5.4
d	2	0.001030	0.001030	0.000515	0.13	0.882	3.8
Error	2	0.007730	0.007730	0.003865			28
Total	8	0.027520					

The regression equation is
WEAR = 0.00800 - 0.000085 LOAD - 0.00066 SPEED - 0.000003 DISTACE

The regression equation is
COF = 0.204 + 0.00451 LOAD + 0.0623 SPEED - 0.000067 DISTACE

It can be observed that for aluminum (7%,14% & 21%) SiC Metal Matrix Composites, from the Table 6,8 & 10, that the applied load has the highest influence (Pr =50%,Pr=30.7% & Pr=50%) on wear rate. Hence load is an important control factor to be taken into consideration during wear process followed by sliding speed (Pr=25%, Pr=61.4 & P=12.5%) & sliding distance (Pr=25%,Pr=7.6 & Pr=25%) respectively. In the same way from the Table 7, 9 & 11 for coefficient of friction, it can observe that the load has the highest contribution of about 69.6%,77.3% & 62.8%, followed by sliding speed 18.9%,9.7% & 5.4%) & sliding distance (0.3%,1% & 3.8%) for Al-6351 with (7%, 14% & 21%) SiC metal matrix composites.

6. Multiple Linear Regression Model

A multiple linear regression model is developed using statistical software “MINITAB 15”. This model gives the relationship between an independent / predicted variable & a response variable by fitting a linear equation to observe data. Regression equation thus generated establishes correlation between the significant terms obtained from ANOVA analysis namely applied load, sliding speed & sliding distance.

The regression equation developed for Al / (7%) SiC MMCs wear rate and coefficient of friction are as follows

wear = 0.0150 - 0.000102 LOAD - 0.00265 SPEED - 0.000004 DISTACE Eq(1)
c.o.f = 0.123 + 0.00791 LOAD - 0.031 SPEED - 0.000013 DISTACE Eq(2)

Similarly, regression equation for Al / (14%) SiC MMCs wear rate and coefficient of friction are as follows

wear = 0.0118 - 0.000085 LOAD - 0.00464 SPEED + 0.000001 DISTACE Eq (3)

c.o.f = - 0.060 + 0.00757 LOAD + 0.116 SPEED + 0.000044 DISTACE Eq (4)

Similarly, regression equation for Al / (21%) SiC MMCs wear rate and coefficient of friction are as follows

wear = 0.00800 - 0.000085 LOAD - 0.00066 SPEED - 0.000003 DISTACE Eq (5)

c.o.f = 0.204 + 0.00451 LOAD + 0.0623 SPEED - 0.000067 DISTACE Eq (6)

From Eq (1), it is observed that the load, sliding speed & sliding distance increases or decreases at any parametric value, it will be decrease the wear rate of the value of 0.0150mm^3/m But in case of coefficient of friction Eq (2), applied load plays a major role as well as followed by sliding speed and sliding distance. Overall for the 7% reinforced SiC in Al-6351 MMCs regression equation gives the clear indication about coefficient of friction is highly influenced by applied load.

From Eq (3) & Eq (4), it is observed that the sliding speed plays a major role on wear rate as well as coefficient of friction. Eq (4) is highly influenced by load & sliding speed means that if load & sliding speed increases it also increase the coefficient of friction, sliding distance minutely affect the wear rate & coefficient of friction for 14% reinforcement of SiC in Al-6351 MMCs.

From Eq (5) & Eq (6), it is observed that the applied load plays a major role on wear rate as well as coefficient of friction. Eq (6) is highly influenced by applied load & sliding speed means that if applied load & sliding speed increases it also increase the coefficient of friction, sliding distance minutely affect the wear rate & coefficient of friction for 21% reinforcement of SiC in Al-6351 MMCs.

From Eq (1) & Eq (2),observed that the negative value of coefficient of speed reveals that increase in sliding speed decreases the wear rate & coefficient of friction of 7% reinforced SiC MMCs. this can be attributed to the oxidation of aluminum alloy Al – 6351 which forms an oxide layer at higher interfacial temperature thus preventing the sliding, thereby decreases the wear rate & coefficient of friction and a similar behavior has been observed .

From Eq (4) & Eq (6), it is observed that the positive value of coefficient of speed reveals that increase in sliding speed increases the wear rate & coefficient of friction of 14% & 21% reinforced SiC metal matrix composites. This can be related to the reinforcement of weight percentage of silicon carbide in Al–6061 MMCs from 7% to 21% , resulted the brittlement property of the material. Wear rate are largely governed by the interaction of two sliding surfaces.

7. Confirmation Test

A confirmation experiment is the final step in the Design process. A dry sliding wear test was conducted using a specific combination of the parameters & levels to validate the statistical analysis.

After the optimal level of testing parameters have been found, it is necessary that verification tests are carried out in order to evaluate the accuracy of the analysis & to validate the experimental results.

Table 12: Confirmation Experiment for Wear Rate and Coefficient of Friction

MMCs	Exp.No.	Load(N)	Sliding Speed (m/s)	Sliding Distance(m)
Al-6351+ 7%sic	**1**	**9.81**	**1.256**	**750**
	2	**19.6**	**1.507**	**900**
	3	**29.4**	**1.759**	**1050**
Al-6351+ 14%sic	**1**	**9.81**	**1.256**	**750**
	2	**19.6**	**1.507**	**900**
	3	**29.4**	**1.759**	**1050**
Al-6351+ 21%sic	**1**	**9.81**	**1.256**	**750**
	2	**19.6**	**1.507**	**900**
	3	**29.4**	**1.759**	**1050**

Table 13: Result of Confirmation Experiment and their comparison with Regression

MMCs	Exp.Wear Rate(mm3/m)	Reg ModelEq(1) Wear rate (mm3/m)	% Error	Exp.Cofficient of Friction (mm3/m)	Reg ModelEq(2) Wear rate (mm3/m)	% Error
Al-6351+ 7%SiC	0.007	0.00673	7.43	0.153	0.167	4.56
	0.006	0.00587	4.9	0.143	0.164	7.31
	0.005	0.00457	11.46	0.091	0.119	9.61
MMCs	Exp.Wear Rate(mm3/m)	Reg ModelEq(3) Wear rate (mm3/m)	% Error	Exp.Cofficient of Friction (mm3/m)	Reg ModelEq(4) Wear rate (mm3/m)	% Error
Al-6351 + 7%SiC	0.006	0.00578	9.43	0.193	0.216	7.67
	0.005	0.00483	4.59	0.224	0.245	7.05
	0.004	0.00376	7.86	0.204	0.217	4.51
MMCs	Exp.Wear Rate(mm3/m)	Reg ModelEq(5) Wear rate (mm3/m)	% Error	Exp.Cofficient of Friction (mm3/m)	Reg ModelEq(6) Wear rate (mm3/m)	% Error
Al-6351+ 7%SiC	0.003	0.00278	9.72	0.285	0.293	4.21
	0.004	0.00387	5.11	0.275	0.289	6.87
	0.002	0.00172	8.36	0.234	0.253	8.64

The experimental value of wear rate is found to be varying from wear rate calculated in regression equation by error percentage between 4. 9% to 11. 46%, while for coefficient of friction it is between 4.56% to 9.61% for 7% weight percentage of SiC reinforced with Al-63511 MMCs. But in case of 14% weight percentage of SiC reinforced with Al-6351MMCs gives the experimental value of wear rate is found to be varying from wear ratecalculated in regression equation by error percentage between 4.59% to 9.43%,while for coefficient of friction it is between 4.51% to 7.67%. But in case of 21% weight percentage of SiC reinforced with Al-6351MMCs gives the experimental value of wear rate is found to be varying from wear rate calculated in regression equation by error percentage between 5.11% to 9.72%,while for coefficient of friction it is between 4.21% to 8.64%.

8. CONCLUSIONS

Following are the conclusions drawn from the study on dry sliding wear test using Taguchi‟s technique.

1) Applied load (50%) has the highest influence on wear rate followed by sliding speed(25%) and sliding distance is 25% and for coefficient of friction, the contribution of applied load is 69.6%, sliding distance is 0.3% for for **Al –6351/ 7% SiC** metal matrix composites.
2) Sliding speed (61.4%) has the highest influence on wear rate followed by applied load (30.7%) and sliding distance (7.6%) and for coefficient of friction, the contribution of applied load is 77.3%, sliding distance is 1% for **Al–6061/ 14%- SiC** metal matrix
    a. composites
3) Applied load (50%) has the highest influence on wear rate followed by sliding distance (25%) and sliding speed (12.5%) and for coefficient of friction, the contribution of applied load is 62.8%, sliding distance is 3.8% for **Al – 6351/ 21% SiC** metal matrix composites.
4) Increasing incorporation of SiC (10% & 15%) increases the wear resistance of composites by forming a protective layer between pin & counter face.

From the above conclusion we predict that sliding speed & applied load have the highest influence on wear rate in all the three composites.

Similarly applied load is only parameter which is largely influence the coefficient of friction in all the three composites.

Regression equation generated for the (7%,14% & 21% SiC MMCs) present model was used to predict the

wear rate & coefficient of friction of Al – 6351/(7%, 14% & 21%) SiC MMCs for inter mediate conditions with reasonable accuracy.
Confirmation experiment was carried out & made a comparison between experimental values showing an error associated with dry sliding wear & coefficient of friction in all the three composites varying from 4.59% to 11.46% and 4.21% to 9.61% respectively. Thus design of experiments by Taguchi method was successfully used to predict the tribological behavior of composites.

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