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Analysis of Wear Behaviour of Al / Sic Metal Matrix Composite by Taguchi's Techniques

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ABSTRACT: Aluminum metal matrix composites containing two different weight percentages of 5 and 15% of the reinforcement particle i.e., silicon carbide were prepared by using stir casting method. The main steps in stir casting method are melting, adding, mixing, pouring, and solidification. The experiments are performed with the help of pin on disc wear measuring instrument. 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 5% & 15% SiC reinforced Al-6061MMCs. Objective of the model was chosen as "smaller the better" characteristics to analyse the dry sliding wear resistance. 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 co-efficient of friction.

Index Terms- Taguchi"s techniques, Stir casting, Metal Matrix Composites, Orthogonal array, Analysis of variance, wear behaviour.

I. INTRODUCTION

In the last few decades, research has shifted from monolithic materials to composite materials to meet the global demand for wear and corrosion resistant materials, light weight, high performance, environmental friendly. 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 wettability and improper distribution of reinforcement. Achieving uniform distribution of reinforcement is the foremost important work. A new technique of fabricating cast Aluminium matrix composite has been proposed to improve the wettability between alloy and reinforcement. In this, all the materials are placed in graphite crucible and heated in an inert atmosphere until the matrix alloy is melted and followed by two step stirring action to obtain uniform distribution of reinforcement. The fabrication techniques of MMCs play a major role in the improvement of mechanical and tribological properties. The performance characteristics of Al alloy reinforced with 5% volume fraction of SiC fabricated through stir casting and found that the stir casting specimen have higher strength compared to powder metallurgy specimen. The size and type of reinforcement also has a significant role in determining the mechanical and tribological properties of the composites. The effect of type of reinforcements such as SiC whisker, alumina fiber and SiC particle fabricated by Powder Metallurgy on the properties of MMCs has been investigated. It was found that there existed a strong dependence on the kind of reinforcement and its volume fraction. The results revealed that particulate reinforcement is most beneficial for improving the wear resistance of MMCs. 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. The reinforcements were varied by 5% and 15% 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.

II. DESIGN OF EXPERIMENTS (DOE)

Design of Experiment is the powerful tool to study the effect of multiple variables simultaneously 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 behaviour 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 [20].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.

III. MATERIAL SELECTION

The choice of Silicon Carbide as the reinforcement in aluminium composite is primarily meant to use the composite in missile guidance system replacing certain beryllium components because structural performance is better without special handling in fabrication demanded by latter's toxicity Recently aluminium-lithium alloy has been attracting the attention of researches due to its good wettability characteristics.

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
50 to 70 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 aluminium base matrix, enhance the wear resisting behaviour of the Al – SiC metal matrix composite.

Table 1. Chemical composition of matrix alloy Al – 6061.

Chemical composition	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
%	0.4-0.8	0.7	0.15-0.40	0.15	0.8-1.2	0.04-0.35	0.25	0.2	Balance

A. Composite Preparation

Stir-casting techniques shown in are currently the simplest and most commercial method of production of MMCs. This approach involves mechanical mixing of the reinforcement particulate into a molten metal bath and transferred the mixture directly to a shaped mould prior to complete solidification. 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 fibres 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 (10 min). The reinforcements were preheated prior to their addition in the aluminium alloy melt. Degassing agent (hexachloro ethane) was used to reduce gas porosities. The molten metal was then poured into a permanent cast iron mould of diameter 25mm and length 300mm. The die was released after 6 hours and the cast specimens were taken out.

B. Wear Behaviour

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 analysing 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 10 mm diameter and 25 mm length were cut from the cast samples, and then machined. 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 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 and graphs between co-efficient of friction and time was monitored for both of the specimens i.e., 5 % and 15% SiC/ Al-6061 MMCs.

Further, 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.

The results for various combinations of parameters were obtained by conducting the experiment as per the Orthogonal array and show the Table 3. The measured results were analysed using the commercial software MINITAB 15 specifically used for design of experiment applications. Table 4 & Table 5 shows the experimental results average of two repetitions for wear rate and coefficient of friction.

Table 2. Process parameters and levels.

Level	Load	Sliding speed,S(m/s)	Sliding distance,D(m)
1	15	1	700
2	20	2	900
3	25	3	1100

IV. EXPERIMENTS PLAN

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 3. 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:

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

Where $y_1, y_2 ... y_n$ are the response of friction and sliding wear and n is the number of observations. The response table for signal to noise ratios show 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. Analysis of varience of the S/N ratio is performed to identify the statistically significant parameters.

V. RESULTS 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 analysing the S/N ratio using conceptual approach that involves graphing the effects and visually identifying the significant factors.

A. 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 analysed using the commercial software MINITAB 15 specifically used for design of experiment applications . Table 4 & Table 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 analysed 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 (4.1-4.2) and Table (5.1-5.2) respectively for 5% &15% reinforced SiC MMCs.

Table 4 Results of L9 Orthogonal array for Al /5% SiC.

S. No.	Load(N)	S (m/s)	S(m)	C.o.f.	Wear (mm3/m)	S/N ratio c.o.f.	S/N ratio wear rate
1	15	1	700	0.256	0.00451	11.8352	46.9165
2	15	2	900	0.21	0.0034	13.5556	49.3704
3	15	3	1100	0.121	0.00158	18.3443	56.0269
4	20	1	900	0.31	0.00412	10.1728	47.7021
5	20	2	1100	0.34	0.00212	9.3704	53.4733
6	20	3	700	0.352	0.0034	9.0691	49.3704
7	25	1	1100	0.34	0.00276	9.3704	51.1818
8	25	2	700	0.41	0.0035	7.7443	49.1186
9	25	3	900	0.36	0.00234	8.8739	52.6157

Table 4.1 Responses table for S/N ratio for wear (5% SiC).

Level	Load (A)	Sliding velocity(B)	Sliding distance(C)
1	50.77	48.6	48.47
2	50.18	50.65	49.9
3	50.97	52.67	53.56
Delta(Δ)	0.79	4.07	5.09
Rank	3	2	1

Table 4.2: Responses table for S/N ratio of coefficient of friction (5% SiC)

Level	Load (A)	Sliding velocity(B)	Sliding distance(C)
1	14.578	10.459	9.55
2	9.537	10.223	10.867
3	8.663	12.096	12.362
Delta(Δ)	5.915	1.872	2.812
Rank	1	3	2

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 (4.1 - 4.4) shows for 5% influence of process parameters on wear rate and coefficient of friction graphically and Figure (5.1 - 5.4) shows for 15% influence of process parameters on wear rate and coefficient of friction graphically. The analysis of these experimental results using S/Nratios 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 Table 10.

B. Analysis of Variance Results for Wear Test

The experimental results were analysed 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) and Table (8&9) shows 5% &15% SiC MMCs 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 α=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.

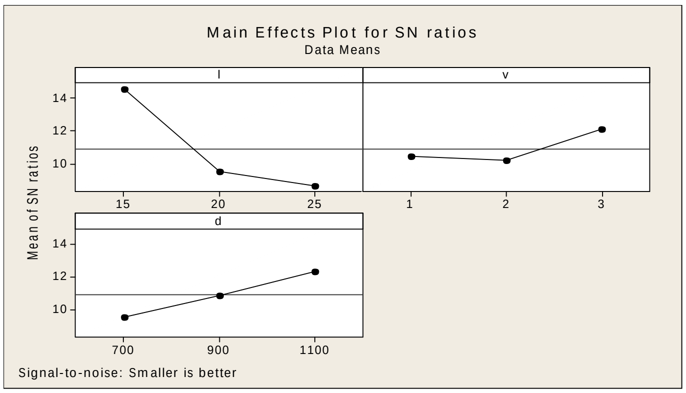

Fig.4.1 Main effects for plot for S/N Ratios –Coefficient of Friction.

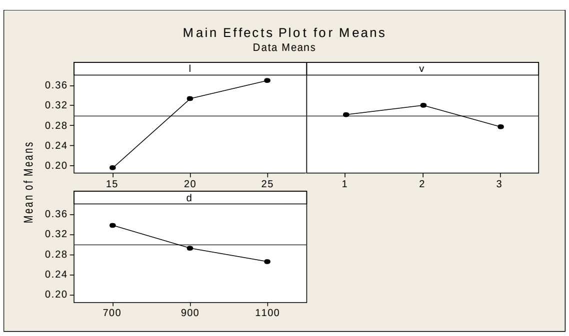

Fig.4.2 Main effects for plot for Means –Coefficient of Friction.

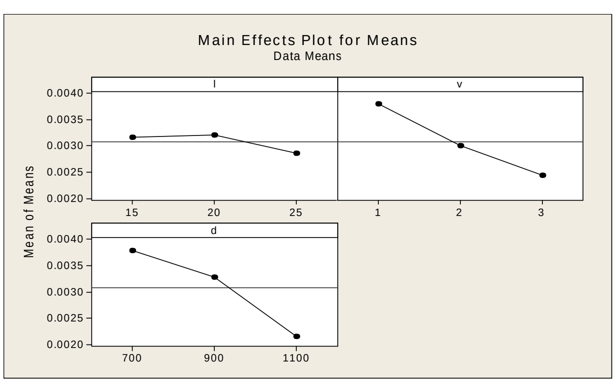

Fig.4.3. Main effects for plot for Means –Wear Rate.

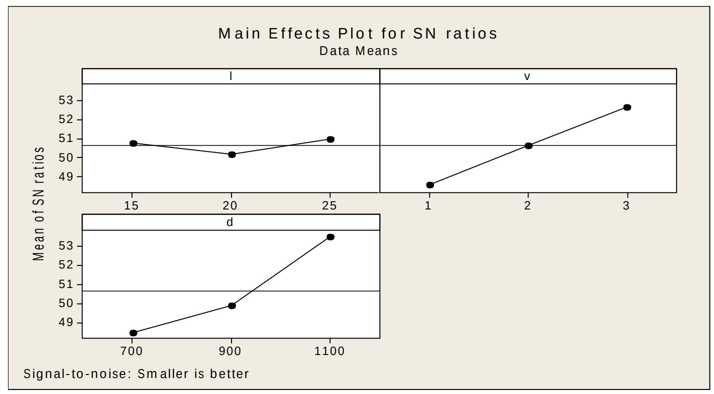

Fig.4.4 Main effects for plot for S/N Ratio –Wear Rate.

Table 5: Results of L9 Orthogonal array for Al – 6061 / 15% SiC MMC

S. No.	Load (N)	S (m/s)	S (m)	Wear (mm3/m)	C.o.f	S/N ratio wear	S/N ratio C.o.f
1	15	1	700	0.0034	0.341	49.3704	9.3449
2	15	2	900	0.00314	0.31	50.0614	10.1728
3	15	3	1100	0.00573	0.24	44.8369	12.3958
4	20	1	900	0.00402	0.416	47.9155	7.6181
5	20	2	1100	0.00212	0.4	53.4733	7.9588
6	20	3	700	0.00229	0.46	52.8033	6.7448
7	25	1	1100	0.00201	0.51	53.9361	5.8486
8	25	2	700	0.02115	0.65	33.4938	3.7417
9	25	3	900	0.00149	0.621	56.5363	4.1382

Table 5.1: Response Table for Signal to Noise Ratios (Coefficient of friction) Smaller is better.

Level	Load	Sliding speed	Sliding distance
1	10.638	7.604	6.61
2	7.441	7.291	7.31
3	4.576	7.76	8.734
Delta(Δ)	6.062	0.468	2.124
Rank	1	3	2

Table 5.2: Response Table for Signal to Noise Ratios (Wear) Smaller is better.

Level	Load	Sliding speed	Sliding distance
1	48.09	50.41	45.22
2	51.4	45.68	51.5
3	47.99	51.39	50.75
Delta(Δ)	3.41	5.72	6.28
Rank	3	2	1

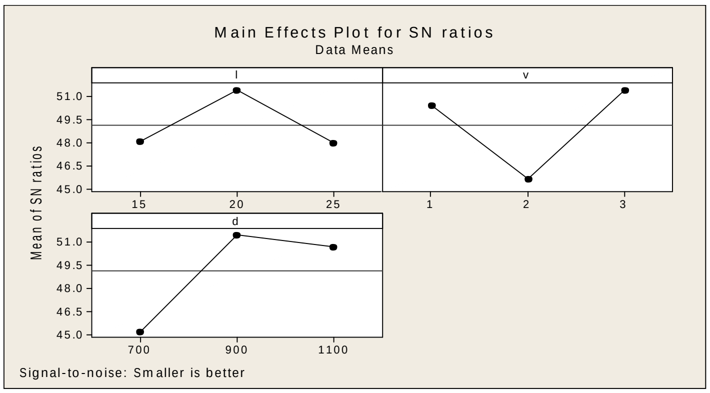

Fig 5.1: Main effects plot for S/N ratios – Wear Rate.

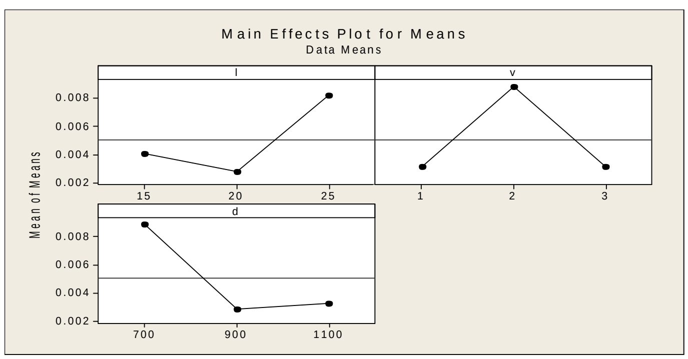

Fig 5.2: Main effects plot for Means – Wear Rate.

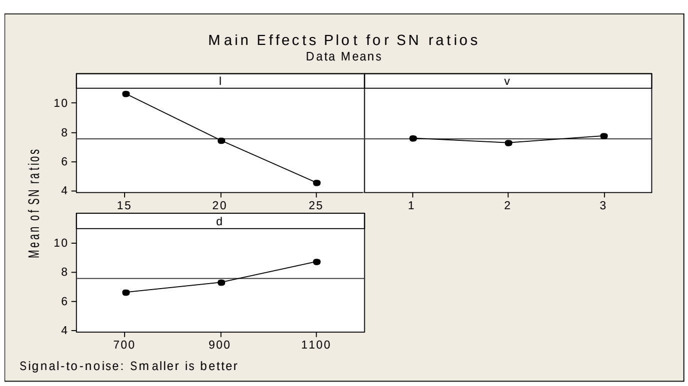

Fig 5.3: Main effects plot for S/N ratio – Coefficient of Friction.

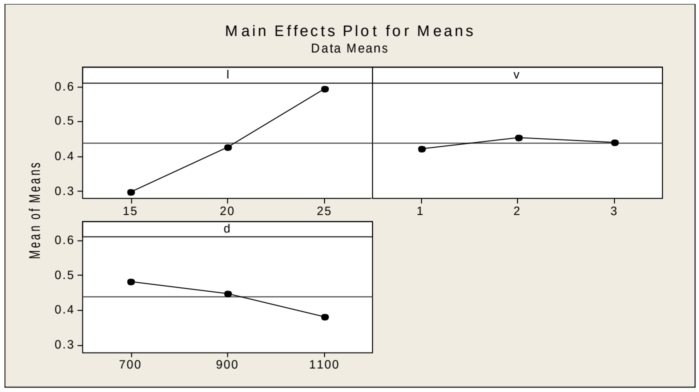

Fig 5.4: Main effects plot for Means – Coefficient of Friction.

Table 6:Analysis of Variance for Means (Wear Rate) (5% SiC).

Source	DF	Seq SS	Adj SS	AdjMS	F	P	Pr(%)
Load	2	0	0	0	3.57	0.219	0
Speed	2	0.000003	0.000003	0.000001	47.25	0.021	42.857
Distance	2	0.000004	0.000004	0.000002	72.49	0.014	57.143
Residual Error	2	0	0	0			0
Total	8	0.000007					100

Table 7: Analysis of Variance for Means (Coefficient of Friction) (5% SiC).

Source	DF	Seq SS	Adj SS	AdjMS	F	P	Pr(%)
Load	2	0.050824	0.050824	0.025412	23.03	0.042	79.685
Speed	2	0.002708	0.002708	0.001354	1.23	0.449	4.246
Distance	2	0.008042	0.008042	0.004021	3.64	0.215	12.609
Residual Error	2	0.002207	0.002207	0.001103			3.5
[Total	8	0.063781					100

Table 8: Analysis of Variance for Means (Coefficient of Friction) (15% SiC).

Source	DF	Seq SS	Adj SS	AdjMS	F	P	Pr(%)
Load	2	0.132817	0.132817	0.066408	113.5	0.009	87.95
Speed	2	0.001454	0.001454	0.000727	1.24	0.446	0.963
Distance	2	0.015581	0.015581	0.00779	13.31	0.07	10.32
Residual Error	2	0.001171	0.001171	0.000585			0.8
Total	8	0.151022					100

Table 9: Analysis of Variance for Means (Wear Rate) (15% SiC).

Source	DF	Seq SS	Adj SS	AdjMS	F	P	Pr(%)
Load	2	0.000048	0.000048	0.000024	0.38	0.72	15.74
Speed	2	0.000064	0.000064	0.000032	0.51	0.66	20.98
Distance	2	0.000069	0.000069	0.000034	0.55	0.64	22.62
Residual Error	2	0.000125	0.000125	0.000062			40.7
Total	8	0.000305					100

It can be observed that for aluminium (5% & 15%) SiC Metal Matrix Composites, from the Table 6 & 9, that the sliding distance has the highest influence (Pr = 57.14% & Pr = 22.62%) on wear rate. Hence sliding distance is an important control factor to be taken into consideration during wear process followed by applied loads (P=0 & P=15.74%) & sliding speed (Pr=42.857%
& Pr=20.98%) respectively. In the same way from the Table 7 & Table 8 for coefficient of friction, it can observe that the load has the highest contribution of about 79.685% & 87.95%, followed by sliding distance (12.609% & 10.32%) & sliding speed (4.246% & 0.963%) for Al-6061 with (5% & 15%) SiC metal matrix composites.

The interaction terms has little or no effect on coefficient of friction & the pooled errors accounts only 3.5% & 0.9%. From the analysis of variance & S/N ratio, it is inferred that the sliding distance has the highest contribution on wear rate & coefficient of friction followed by load & sliding speed.

VI. CONCLUSIONS

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

- Sliding distance (57.143%) has the highest influence on wear rate followed by sliding speed(42.857%) and applied load (0 %) and for coefficient of friction, the contribution of applied load is 79.685%, sliding distance is 12.609% for **Al / 5% SiC** metal matrix composites.
- Applied load (15.74%) has the highest influence on wear rate followed by sliding distance (22.62%) and sliding speed (20.98%) and for coefficient of friction, the contribution of applied load is 87.95%, sliding distance is 10.32% for **Al / 15% SiC** metal matrix composites.
- Increasing incorporation of SiC (5% & 15%) increases the wear resistance of composites by forming a protective layer between pin & counterface.

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