Optimization of Tribological properties of Al-6082/SiC Metal Matrix Composite by Grey-Taguchi's Method

Vijayanand Dharanikota

Abstract- Tribological behavior of aluminium alloy Al-6082 reinforced with silicon carbide particles (0%,5% & 10% Volume percentage of SiC) fabricated by powder metallurgy was investigated . In this paper the optimization of dry sliding performances on the aluminum hybrid metal matrix composite was done using grey relational analysis in the Taguchi method. Different loads, sliding speeds, sliding distances and varying percentage of Silicon Carbide are selected as control factors. The multiple responses to evaluate the dry sliding performances are specific wear rate and coefficient of friction. A series of L_{27} orthogonal array of experiments for three different samples of Al-6082 SiC MMCs have been conducted on pin-on-disc wear tester apparatus, the volume loss and frictional force are measured. Based on grey relational analysis, the optimum level parameters for specific wear rate and coefficient of friction have been identified. Analysis of Variance (ANOVA) had given the impact of individual factors on the specific wear rate as well as the coefficient of friction. The results indicated that the four test parameters had a significant role in controlling the friction and wear behavior of composites out of which %vol. was identified as most influential parameter followed by load for specific wear rate and load for coefficient of friction.

Index Terms— Aluminum hybrid metal matrix composite, Gray relation –taguchi's Method, L_{27} orthogonal array , pin-on-disc wear tester Dry sliding wear behavior, Analysis of variance.

◆

1 INTRODUCTION

Today our modern technologies require materials with unusual combinations of properties that cannot be met by conventional ceramics, polymeric materials and metal alloys. This is true, especially for the material needed in transportation, aerospace and under water applications. These combinations of material properties are achieved by development of composites. These materials fulfill the demand of almost all the engineering application due to their tremendous physical and mechanical properties i.e. light weight, high strength, improved density and hardness, high wear and high corrosion resistance.

Al and Al alloys became attractive candidate for the application in aerospace, defense and automotive industries owing to their versatile properties. A major requirement for such applications is the high strength along with reasonable ductility. There has been a constant effort to enhance the mechanical properties of Al alloys by alloying additions, heat treatment, thermo mechanical processing, and severe plastic deformations and so on. The advantage of utilizing the beneficial properties of the constituent materials, to satisfy the specific demands, is the driving force for the development of composites. In this paper, our focus will be on the metal matrix composites (MMCs) and more especially on the aluminium metal matrix composites.

Fabrication of MMCs has several challenges like porosity formation, poor wettability and improper 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 Achieving uniform distribution of reinforcement is the foremost important work.

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 MMC[1].

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 powder metallurgy techniques. The reinforcements were varied by 0%,5% and 10% by volume. The composite was tested for dry sliding wear characteristics. The tribological properties of MMCs are also increased by increasing reinforcements at all applied conditions[2].

Vijayanand Dharanikota, graduated from NIT Warangal, And presently pursuing Masters in Industrial Engineering at Arizona State University, PH: +1-480-358-8930, Email Id: vdharan1@asu.edu

2 DESIGN OF EXPERIMENTS

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 [3]. 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 [4].

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. In the present work, a plan order for performing the experiments was generated by Taguchi method using orthogonal arrays [5]. Analysis of data from these designed experiments yields significance of influence of a factor or the interaction of factors on a particular output response and their % contribution.

3 GREY-RELATIONAL ANALYSIS

Grey relational analysis was proposed by Deng in 1989, is widely used for measuring the degree of relationship between sequences by grey relational grade. Grey relational analysis is applied by several researchers to optimize control parameters having multi-responses through grey relational grade [6]. The use of Taguchi method with grey relational analysis to optimize the specific wear rate and co-efficient of friction with multiple process parameters.

A. Data Pre-Processing

In grey relational analysis, the data pre-processing is the first step performed to normalize the random grey data with different measurement units to transform them to dimensionless parameters. Thus, data pre-processing converts the original sequences to a set of comparable sequences. Different methods are employed to pre-process grey data depending upon the quality characteristics of the original data.

The original reference sequence and pre-processed data (comparability sequence) are represented by $x_0^{(0)}(k)$ and $x_i^{(0)}(k)$ i =1,2,….,m; k =1,2,.....,n respectively, where m is the number of experiments and n is the total number of observations of data. Depending upon the quality characteristics, the three main categories for normalizing the original sequence are identified as follows: If the original sequence data has quality characteristic as 'larger-the-better' then the original data is preprocessed as 'larger-the-best':

$$x_i^*(k) = \frac{x_i^{(0)}(k) - \min x_i^{(0)}(k)}{\max x_i^{(0)}(k) - \min x_i^{(0)}(k)} \quad (1)$$

If the original data has the quality characteristic as 'smaller the better', then original data is pre-processed as 'smaller-the best':

$$x_i^*(k) = \frac{\max x_i^{(0)}(k) - x_i^{(0)}(k)}{\max x_i^{(0)}(k) - \min x_i^{(0)}(k)} \quad (2)$$

However, if the original data has a target optimum value (OV) then quality characteristic is 'nominal-the-better' and the original data is pre-processed as 'nominal-the-better':

$$x_i^*(k) = 1 - \frac{|x_i^{(0)}(k) - OV|}{\max\{\max x_i^{(0)}(k) - OV, OV - \min x_i^{(0)}(k)\}} \quad (3)$$

Also, the original sequence is normalized by a simple method in which all the values of the sequence are divided by the first value of the sequence.

$$x_i^*(k) = \frac{x_i^{(0)}(k)}{x_i^{(0)}(1)} \quad (4)$$

where max $x_i^{(0)}(k)$ and min $x_i^{(0)}(k)$ are the maximum and minimum values respectively of the original sequence $x_i^{(0)}(k)$. Comparable sequence $x_i^*(k)$ is the normalized sequence of original data.

B. Grey Relation Grade

Next step is the calculation of deviation sequence, $\Delta_{oi}(k)$ from the reference sequence of pre-processes data $x_i^*(k)$ and the comparability sequence $x_i^*(k)$. The grey relational coefficient is calculated from the deviation sequence using the following relation:

$$\gamma(x_0^*(k), x_i^*(k)) = \frac{\Delta\min + \xi\,\Delta max}{\Delta oi(k) + \xi\Delta max} \quad 0 < \gamma(x_0^*(k), x_i^*(k)) \le 1 \quad (5)$$

where $\Delta_{oi}(k)$ is the deviation sequence of the reference sequence $x_0^*(k)$ and comparability sequence $x_i^*(k)$.

$$\Delta oi(k) = |x_0^*(k) - x_i^*(k)|$$

$$\Delta max = \underset{\forall j \in i}{max}\ \underset{\forall k}{max} |x_0^*(k) - x_i^*(k)|\ ;$$

$$\Delta min = \underset{\forall j \in i}{min}\ \underset{\forall k}{min} |x_0^*(k) - x_i^*(k)|$$

ξ is the distinguishing coefficient $\xi \in [0,1]$. The distinguishing coefficient (ξ) value is chosen to be 0.5. A grey relational grade is the weighted average of the grey relational coefficient and is defined as follows:

$$\gamma(x_0^*, x_i^*) = \sum_{k=1}^{n} \beta k \gamma\left(\left(x_0^*(k), x_i^*(k)\right)\right), \sum_{k=1}^{n} \beta k = 1 \quad (6)$$

The grey relational grade $\gamma(x_0^*, x_i^*)$ represents the degree of correlation between the reference and comparability sequences. If two sequences are identical, then grey relational grade value equals unity. The grey relational grade implies that the degree of influence related between the comparability sequence and the reference sequence. In case, if a particular comparability sequence has more influence on the reference sequence than the other ones, the grey relational grade for comparability and reference sequence will exceed that for the other grey relational grades. Hence, grey relational grade is an accurate measurement of the absolute difference in data between sequences and can be applied to appropriate the correlation between sequences.

4 MATERIAL SELECTION

4.1 Aluminium alloy Al6082:

In the present investigation, Al-6082 alloy was chosen as the base matrix as it has the excellent corrosion resistance and high strength in 6000 series alloys. In plate form, Aluminium alloy 6082 is the alloy most commonly used for machining. As a relatively new alloy, the higher strength of Aluminium alloy 6082 has seen it replace 6061 in many applications. The addition of a large amount of manganese controls the grain structure which in turn results in a stronger alloy. After the addition of SiC, due to the property of high hardness and high thermal conductivity, SiC accommodates in soft ductile aluminium base matrix, which enhance the wear resisting behavior of the Al – SiC metal matrix composite.

Element	Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr
%	0.7-1.3	0.0-0.5	0.0-0.1	0.4-1.0	0.6-1.2	0.0-0.2	0.0-0.1	0.0-0.25

Table 1 Chemical Composition of Al-6082 alloy

The above table gives us the chemical composition of Al6082 the rest is aluminium.

4.2 Aluminium Silicon Carbide (Al-6082 Sic):

Aluminium Silicon Carbide (Al SiC) metal matrix composite (MMC) materials have a unique set of material properties that are ideally suited for all electronic packaging applications requiring thermal management. The Al-SiC coefficient of thermal expansion (CTE) value is compatible with direct IC device attachment for the maximum thermal dissipation through the 170 – 200 W/mK thermal conductivity value material. Additionally, the low material density of AlSiC makes it ideal for weight sensitive applications such as portable devices.

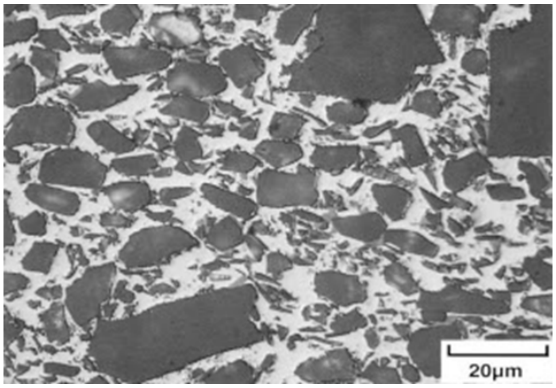


Figure 1 Al-6082 SiC Microstructure

The ideal AlSiC material properties and the AlSiC net-shape fabrication process provide low-cost high performance functional thermal management packaging solutions.

Material	Density	Thermal Conductivity	Bend Strength	Young's Modulus
AlSiC 68v%SiC	3 g/cm^3	170-200 W/mK	450 MPa	175 GPa

Table 2 Properties of Al-6082 SiC

Figure 2 Al-6082 Sic Samples of Different Compositions used for Wear test

5 EXPERIMENTAL DETAILS

The aim of the experiment 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 and Volume% . And the wear test is carried out using Pin-on-Disc wear device according to ASTM G99 standards. It consist of a rotary horizontal steel disc driven by variable speed motor A stationary test specimen with a defined normal force is pressed against the surface of another test specimen placed on the rotary disk.

During the test, the pin was held pressed against a rotating disc by applying load that acts as counterweight and balances the pin. The load, sliding speed and sliding distance were varied in the range given in Table 3. 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 \ the specimens i.e.,0 %, 5% and 10% vol. SiC/ Al-6082 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

Figure 3 Pin-On-Disc Friction and Wear tester

5 PLAN OF EXPERIMENTS

In full factorial design, the number of experimental runs exponentially increases with the increase in the number of factors as well as their levels. This results in huge experimentation cost and considerable time period. So, in order to compromise these two adverse factors and to search for the optimal process condition through a limited number of experimental runs Taguchi's L_{27} orthogonal array consisting of 27 runs was selected to optimize the tribological properties of Al-6082 Sic alloy. Experiments were conducted with the Factor levels as given in Table 3.

Symbol	Experimental Variables	Level 1	Level 2	Level 3
A	Sliding Distance (m)	1000	2000	3000
B	Load (N)	9.81	29.42	49.03
C	Sliding Speed (m/s)	1	2	3
D	Volume %	0	5	10

Table 3 Experimental Factors And Their Levels

Selected design matrix shown in Table 4 based on the Taguchi L_{27} orthogonal array consisting of 27 sets of coded conditions and the experimental results for the responses of specific wear rate (w_s) and coefficient of friction (μ_a). All these data are used for the analysis and evaluation of the optimal parameters combination.

The specific wear rate and co-efficient of friction is calculated using following formulas:

Sliding Speed (m/s) = $(2\pi N)/60$
Sliding Distance (m) = πD * number of revolutions
Time (sec) = Sliding Speed / Sliding Distance
Wear Rate (g/s) = Weight loss / Time
Weight Loss = Initial Weight – Final Weight
Density (kg/mm^3) = Mass / Volume
Specific Wear Rate (mm^3/N-m) = V/ L*D
Coefficient of friction = F_t / F_n
Where, N = Speed of disc in rpm
D = Wear track diameter in m

S. No	Load (A)	Sliding Speed (B)	Vol% (C)	Sliding Distance (D)	Specific wear rate x 10^{-5} (mm3/ Nm)	Coefficient of friction
1	9.81	1	0	1000	39.837	0.3999
2	9.81	1	5	2000	7.198	0.4998
3	9.81	1	10	3000	22.478	0.6998
4	9.81	2	0	3000	22.522	0.7991
5	9.81	2	5	1000	9.338	0.6998
6	9.81	2	10	2000	7.841	0.7997
7	9.81	3	0	2000	12.107	0.4998
8	9.81	3	5	3000	10.375	0.2999
9	9.81	3	10	1000	6.273	0.5998
10	29.42	1	0	3000	14.846	0.2667
11	29.42	1	5	1000	1.946	0.1999
12	29.42	1	10	2000	6.406	0.3333
13	29.42	2	0	2000	23.051	0.3667
14	29.42	2	5	3000	4.8	0.2333

15	29.42	2	10	1000	3.138	0.3333
16	29.42	3	0	1000	4.819	0.2999
17	29.42	3	5	2000	4.022	0.2333
18	29.42	3	10	3000	3.966	0.2666
19	49.03	1	0	2000	13.793	0.2
20	49.03	1	5	3000	3.866	0.14
21	49.03	1	10	1000	5.648	0.18
22	49.03	2	0	1000	10.003	0.22
23	49.03	2	5	2000	3.114	0.18
24	49.03	2	10	3000	1.857	0.14
25	49.03	3	0	3000	4.116	0.18
26	49.03	3	5	1000	39.837	0.2
27	49.03	3	10	2000	7.198	0.2

Table 4 Orthogonal Array L_{27} Of The Experimental Runs & Results

The results for various combinations of parameters were obtained by conducting the experiment as per the Orthogonal array show in the Table 4. The measured results were analyzed using the commercial software JMP specifically used for design of experiment applications.

6 ANALYSIS OF RESULTS

6.1 Grey relation analysis

The experimental results for specific wear rate (w_s) , coefficient of friction (μ_a) are listed in the Table 4.Typically, smaller values of w_s, μ_a are desirable. Thus the data sequences have the smaller-the-better characteristic, the "smaller-the-better" methodology, i.e. Equation (2).The normalized S/N ratio values were obtained based on the quality of characteristics.

S.No	S/N ratios		Normalized S/N ratios		Deviation Sequences	
	s_w	μ_a	s_w	μ_a	s_w	μ_a
1	-32.006	7.961	0	0.398	1	0.602
2	-17.144	6.023	0.559	0.270	0.441	0.730
3	-27.035	3.101	0.187	0.077	0.813	0.923
4	-27.052	1.948	0.186	0.00046	0.814	0.999
5	-19.405	3.101	0.473	0.077	0.527	0.923
6	-17.888	1.941	0.530	0	0.470	1
7	-21.661	6.024	0.388	0.270	0.612	0.730
8	-20.320	10.460	0.439	0.563	0.561	0.437
9	-15.949	4.439	0.603	0.165	0.397	0.835
10	-23.432	11.479	0.322	0.630	0.678	0.370
11	-5.783	13.984	0.985	0.796	0.015	0.204
12	-16.132	9.543	0.596	0.502	0.404	0.498
13	-27.254	8.714	0.178	0.447	0.822	0.553
14	-13.625	12.642	0.690	0.707	0.310	0.293
15	-9.932	9.543	0.829	0.502	0.171	0.498
16	-13.658	10.460	0.689	0.563	0.311	0.437
17	-12.088	12.642	0.748	0.707	0.252	0.293
18	-11.966	11.483	0.752	0.630	0.248	0.370
19	-22.793	13.979	0.346	0.795	0.654	0.205
20	-11.746	17.077	0.761	1	0.239	0
21	-15.038	14.894	0.637	0.856	0.363	0.144
22	-20.002	13.151	0.451	0.741	0.549	0.259
23	-9.866	14.894	0.831	0.856	0.169	0.144
24	-5.374	17.077	1	1	0	0
25	-12.289	14.894	0.740	0.856	0.260	0.144
26	-8.454	13.979	0.884	0.795	0.116	0.205
27	-10.252	13.979	0.817	0.795	0.183	0.205

Table 5 S/N ratio values, normalized S/N ratio values, and deviation sequences for Al-6082 SiC

The grey relational coefficients and grade values for each experiment are given in Table 6. Average grey relational coefficient and grades for each level of a testing parameter calculated as per Taguchi method.

For both Specific wear rate and co-efficient of friction			For Specific wear rate			For co-efficient of friction		
Exp. N.o	Grey Relation Grade	Rank	Exp. N.o	Grey Relation Coefficient	Rank	Exp. N.o	Grey Relation Coefficient	Rank
24	1	1	24	1	1	20	1	1
11	0.841	2	11	0.971	2	24	1	2
20	0.839	3	26	0.812	3	21	0.776	3
23	0.762	4	23	0.747	4	23	0.776	4
26	0.761	5	15	0.745	5	25	0.776	5
27	0.721	6	27	0.732	6	11	0.71	6
25	0.717	7	20	0.677	7	19	0.709	7
21	0.678	8	18	0.668	8	26	0.709	8
17	0.648	9	17	0.665	9	27	0.709	9
14	0.624	10	25	0.658	10	22	0.659	10
15	0.623	11	14	0.617	11	14	0.631	11
18	0.622	12	16	0.617	12	17	0.631	12
16	0.576	13	21	0.579	13	10	0.575	13
19	0.571	14	9	0.557	14	18	0.575	14
22	0.568	15	12	0.553	15	8	0.534	15
12	0.527	16	2	0.531	16	16	0.534	16
8	0.503	17	6	0.515	17	12	0.501	17
10	0.500	18	5	0.487	18	15	0.501	18
2	0.469	19	22	0.477	19	13	0.475	19
9	0.466	20	8	0.471	20	1	0.454	20
7	0.429	21	7	0.45	21	2	0.407	21
13	0.427	22	19	0.433	22	7	0.407	22
6	0.424	23	10	0.424	23	9	0.375	23
5	0.419	24	3	0.381	24	3	0.351	24
1	0.394	25	4	0.381	25	5	0.351	25
3	0.366	26	13	0.378	26	4	0.333	26
4	0.357	27	1	0.333	27	6	0.333	27

Table 6 The calculated grey relational coefficient and grey relational grade Al-6082 SiC

The following are the response tables for specific wear rate, coefficient of friction, and for both specific wear rate and coefficient of friction.

	A	B	C	D
Levels				
1	0.4562	0.5424	0.4612	**0.6198**
2	0.6264	0.5941	**0.6642**	0.556
3	**0.6794**	**0.6256**	0.6367	0.5863
Delta	0.2232	0.0832	0.203	0.0638
Rank	1	3	2	4
Avg. grey relation grade = 0.5874				

Table 7 Response Table for specific wear rate of Al-6082 SiC

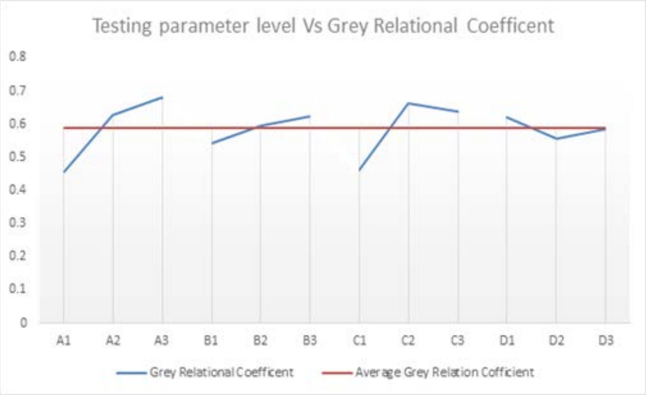
	A	B	C	D
Levels				
1	0.3939	**0.6092**	0.5469	0.5632
2	0.5703	0.5621	**0.6388**	0.5498
3	**0.7904**	0.5833	0.569	**0.6417**
Delta	0.3965	0.0471	0.0919	0.0919
Rank	1	4	3	2
Avg. grey relation grade = 0.5849				

Table 8 Response Table for Coefficient of Friction Al-6082 SiC

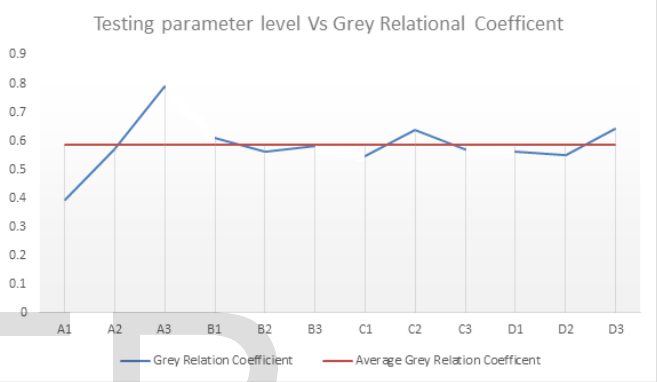
	A	B	C	D
Levels				
1	0.4252	0.5761	0.5043	0.5918
2	0.5987	0.5782	**0.6518**	0.5914
3	**0.7561**	**0.6048**	0.603	**0.6142**
Delta	0.3309	0.0287	0.1475	0.0228
Rank	1	4	2	3
Avg. grey relation grade = 0.5913				

Table 9 Response Table for both specific wear rate and coefficient of friction of Al-6082 SiC

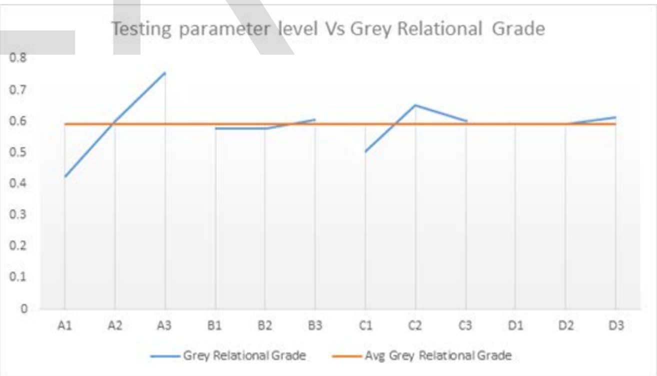
The bold characters are shown to denote the optimum value of grey relational coefficient and grade in Tables 7, 8, 9. The effects of the testing parameter level versus the grey relational grade and grey relational coefficient values are given below for Al SiC MMCs.



Graph 1 Effects of dry sliding parameter levels on specific wear rate of Al-6082 SiC



Graph 2 Effects of dry sliding parameter levels on coefficient of friction of Al-6082 SiC



Graph 3 Effects of dry sliding parameter levels for both specific wear rate and coefficient of friction of Al-6082 SiC

By using the grey relational coefficient values and grey relational grade values, the graphs are plotted for different parameter levels and grey relations. The optimum values are also drawn from the graphs.

The grey relation grades in Table 7-9 can be further arranged in matrix form shown as follows:

$$\gamma = \left| \begin{array}{llll} \gamma(W,A) & \gamma(W,B) & \gamma(W,C) & \gamma(W,D) \\ \gamma(C_f,A) & \gamma(C_f,B) & \gamma(C_f\ C) & \gamma(C_f,D) \\ \gamma(WC_f,A) & \gamma(WC_f,B) & \gamma(WC_f,C) & \gamma(WC_f,D) \end{array} \right|$$

$$= \begin{vmatrix} 0.6794 & 0.6256 & 0.6642 & 0.6198 \\ 0.7904 & 0.6092 & 0.6388 & 0.6417 \\ 0.7561 & 0.6048 & 0.6518 & 0.6142 \end{vmatrix}$$

In grey relation analysis, the maximum analysis, the maximum value in each row represents the most influential factors that affect the output variables. By comparing Row 1, Row 2, Row 3, Row 4, some conclusion from this matrix. In the first row, $\gamma(W,A) > \gamma(W,C) > \gamma(W,B) > \gamma(W,D)$, it means that the order of importance for the controllable factor Specific wear rate (W), in sequence is the factor A,C,B,D. In the second row $\gamma(C_f,A) > \gamma(C_f,D) > \gamma(C_f,C) > \gamma(C_f,B)$, the order of importance for the controllable factors to Coefficient of friction (C*f*) in the sequence is the factor A,D,C,B. Similarly , based on the third row, $\gamma(WC_f,A) > \gamma(WC_f,C) > \gamma(WC_f,D) > \gamma(WC_f,B)$, The order of importance for the controllable factors to both specific Wear rate and Coefficient of friction (WC*f*), in the sequence is the factor A,C,D,B

6.2 Analysis Of Variance (ANOVA)

The experimental results were analyzed with Analysis of Variance (ANOVA) which is used to investigate the influence of the considered wear parameters namely, sliding distance , applied load, sliding speed, and Sic volume% 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) SiC MMCs of the ANOVA results for wear rate and coefficient of friction for four 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. After performing initial analysis on residuals it is found out that data need to be transformed to Stabilize the variance and interpret the results currently .

Specific Wear rate: $S_w^* = \text{1og}(S_w)$

Co-efficient of friction: $\mu_a^* = 1/(\mu_a)$

S. No	Load (A)	Sliding Speed (B)	Vol% (C)	Sliding Distance (D)	1ogS_w	$1/\mu_a$
1	9.81	1	0	1000	1.600	2.501
2	9.81	1	5	2000	0.857	2.001
3	9.81	1	10	3000	1.352	1.429
4	9.81	2	0	3000	1.353	1.251
5	9.81	2	5	1000	0.970	1.429
6	9.81	2	10	2000	0.894	1.250
7	9.81	3	0	2000	1.083	2.001
8	9.81	3	5	3000	1.016	3.334
9	9.81	3	10	1000	0.797	1.667
10	29.42	1	0	3000	1.172	3.750
11	29.42	1	5	1000	0.289	5.003
12	29.42	1	10	2000	0.807	3.000
13	29.42	2	0	2000	1.363	2.727
14	29.42	2	5	3000	0.681	4.286
15	29.42	2	10	1000	0.497	3.000
16	29.42	3	0	1000	0.683	3.334
17	29.42	3	5	2000	0.604	4.286
18	29.42	3	10	3000	0.598	3.751
19	49.03	1	0	2000	1.140	5.000
20	49.03	1	5	3000	0.587	7.143
21	49.03	1	10	1000	0.752	5.556
22	49.03	2	0	1000	1.000	4.545
23	49.03	2	5	2000	0.493	5.556
24	49.03	2	10	3000	0.269	7.143
25	49.03	3	0	3000	0.614	5.556
26	49.03	3	5	1000	0.423	5.000
27	49.03	3	10	2000	0.513	5.000

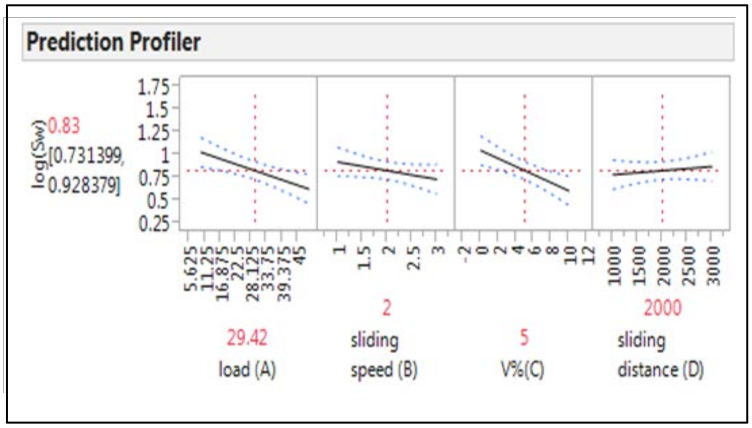
Table 10 Experimental Data after Transformation

Table 11 gives the results of analysis of variance (ANOVA) for specific wear rate of Al-6082 Sic using JMP Software. According to table 11, the factor C i.e. Vol% of Sic with 25.73% of contribution is the most significant controlled parameters for dry sliding performance, followed by load with 21.25% contribution, and the last significant factor is interaction term between Load(A) and sliding distance(D) with 9.21% contribution for the minimization of specific wear rate.

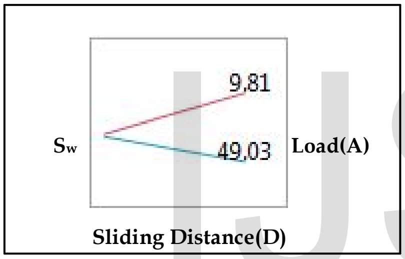
Source	DF	SS	MS	F Ratio	Prob>F	%P
Load(A)	1	0.669	0.669	12.128	**0.005***	**21.25**
Sliding Speed (B)	1	0.149	0.149	2.7	0.126	4.73
Vol. % [C]	1	0.81	0.81	14.674	**0.002***	**25.73**
Sliding Distance (D)	1	0.033	0.033	0.602	0.453	1.05
A*B	1	0.104	0.104	1.879	0.196	3.3
A*C	1	0.058	0.058	1.06	0.324	1.84
A*D	1	0.29	0.29	5.262	**0.041***	**9.21**
B*C	1	0.246	0.246	4.463	0.056	7.81
B*D	1	0.068	0.068	1.226	0.29	2.16
C*D	1	0.098	0.098	1.769	0.208	3.11

A*B*C	1	0.018	0.018	0.33	0.577	0.57
A*B*D	1	0.126	0.126	2.277	0.157	4
A*C*D	1	0.146	0.146	2.647	0.13	4.64
B*C*D	1	0.137	0.137	2.49	0.141	4.35
Error	12	0.662	0.552			21.03
Total	26	3.148				100

Table 11 ANOVA for specific wear rate



Graph 4 Main Factors v/s Specific Wear rate

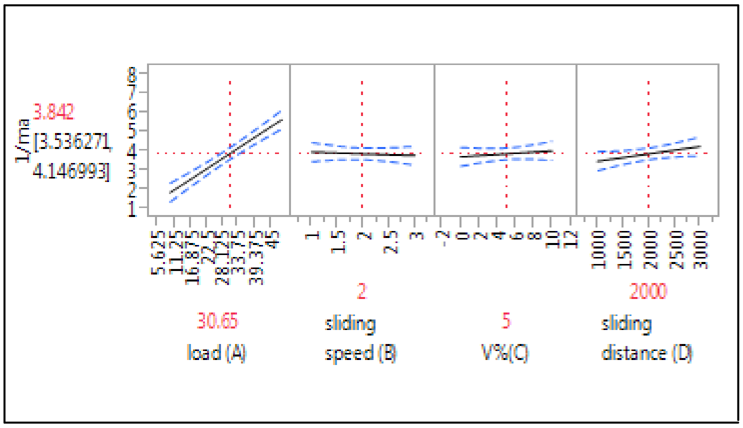


Graph 5 Interaction between load & Sliding distance v/s Specific Wear rate

From Table 11 A*D interaction is significant and from graphs 4 & 5 to obtain minimum specific Wear rate Load ,sliding speed, Vol% and sliding distance should maintained at high level (i.e. 49.03N, 3m/s ,10%, 3000m respectively).

Source	DF	SS	MS	F Ratio	Prob>F	%P
Load(A)	1	59.423	59.423	112.774	**<.0001***	**76.1**
Sliding Speed (B)	1	0.069	0.069	0.131	0.724	0.1
Vol. % [C]	1	0.317	0.317	0.602	0.453	0.4
Sliding Distance (D)	1	2.227	2.227	4.227	0.062	2.9
A*B	1	1.343	1.343	2.549	0.136	1.7
A*C	1	0.496	0.496	0.942	0.351	0.6
A*D	1	0.485	0.485	0.92	0.356	0.6
B*C	1	0.06	0.06	0.113	0.742	0.1
B*D	1	0.101	0.101	0.192	0.669	0.1
C*D	1	0.446	0.446	0.846	0.376	0.6
A*B*C	1	0.596	0.596	1.132	0.308	0.8
A*B*D	1	1.064	1.064	2.019	0.181	1.4
A*C*D	1	0.046	0.046	0.088	0.772	0.1
B*C*D	1	0.233	0.233	0.442	0.519	0.3
Error	12	6.323	0.527			14.2
Total	26	78.06				100

Table 12 ANOVA for Co-efficient of friction



Graph 6 Main Factors v/s Co-efficient of friction

Table 12 gives the results of analysis of variance (ANOVA) for Co-efficient of Al-6082 Sic using JMP software. According to table 12, the factor A i.e. Load with 76.1% of contribution is the most significant controlled parameters for dry sliding performance, for the minimization of Co-efficient of friction and no interaction terms are significant. And to obtain to obtain minimum Co-efficient of friction Load , Vol% and sliding distance should maintained at low level (i.e. 9.81N, , 0%, 1000m respectively) and sliding speed at high level (i.e. 3m/s) .

6.2.1 Multiple Linear Regression Model

A multiple linear regression model is developed using statistical software “JMP”. 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, Vol% & sliding distance.

The reduced regression equation developed for Al-6082 SiC MMCs wear rate and coefficient of friction are as follows:

$$S_w = 1.37-0.012A-0.039C-0.000004(A-29.42)*(D-2000) \text{ -- Eq(7)}$$

$$\mu_a = 0.919+0.0953A \text{ ----- Eq(8)}$$

From Eq (7), it is observed that the load, Vol%, Sliding distance increases, it will be decrease the wear rate But in case of coefficient of friction Eq (8), load plays a major role. Overall regression equation gives the clear indication about coefficient of friction is highly influenced by load.

7 CONCLUSION

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

1) For the lowest specific wear rate, 49.03 N applied load, 2 m/s sliding speed, 3000m sliding distance and 10 Vol.% Silicon Carbide percentage are used as optimal combination.
2) For the lowest coefficient of friction, 49.03 N applied load, 1 m/s sliding speed, 3000m sliding distance and 5 Vol.% Silicon Carbide percentage are used as optimal combination.
3) For both specific wear rate and coefficient of friction, the lowest values given are 49.03 N applied load, 2 m/s sliding speed, 3000m sliding distance and 10 Vol.% Silicon Carbide percentage.
4) Based on the ANOVA, Silicon Carbide volume percentage (25.73%) followed load (21.25%) , interaction t between load and sliding distance (9.21%) exert a significant influence on specific wear rate of Aluminium composites.
5) Based on the ANOVA, load(76.1%) exert a significant influence on coefficient of friction of Aluminium composites.
6) The order of importance for controllable factors to the minimum specific wear rate, in sequence, is Vol% of Sic, load, sliding Speed and sliding distance; order to the coefficient of friction, in sequence is load, sliding distance, Vol.% of SiC sliding speed.
7) However, it is observed through ANOVA that the applied load is the most influential control factor among the four dry sliding performance input parameters of Al SiC.

ACKNOWLEDGMENT

The wish to thank Prof. Dr. N. Selvaraj, Head, Department of Mechanical Engineering, National Institute of Technology, Warangal, Mr. Jeevan, PhD Scholar, NITW, and Prof. Rong Pan, Associate Professor, Arizona State University .

REFERENCES

[1] Ashok Kr. Mishra, Rakesh Sheokand, Dr. R K Srivastava , Tribological Behaviour of Al-6061 / SiC Metal Matrix Composite by Taguchi's Techniques, ijsrp Vol.2, Issue 10, ISSN 2250-3153

[2] Manoj Singla, D. Deepak Dwivedi, Development of Aluminium Based Silicon Carbide Particulate Metal Matrix Composite Journal of Minerals & Materials Characterization & Engineering, Vol. 8, No.6, pp 455-467.

[3] G. Taguchi, introduction to quality engineering, Asian productivity organization, 1990

[4] R. A. Fisher, Design of Experiments, Oliver & Boyd, Edinburgh, UK, 1951

[5] P. J. Ross, Taguchi Technique for Quality Engineering, McGraw Hill, New York, NY, USA, 2nd edition1996

[6] Sadasiva Rao T., Rajesh V., Venu Gopal A, Taguchi based Grey Relational Analysis to Optimize Face Milling Process with Multiple Performance Characteristics, ICTIME'2012, March 24-25, 2012 Dubai

[7] JMP User Manual 8 Design of Experiments Guide, Second Edition Cary, NC: SAS Institute Inc.

[8] S. Dharmalingam, R. Subramanian, Optimization of Tribological Properties in Aluminum Hybrid Metal Matrix Composites Using Gray-Taguchi Method, JMEPEG (2011) 20:1457–1466.

[9] Hui-Hui Fu, Wear properties of Saffil/Al, Saffil/Al2O3/Al and Saffil/SiC/Al Hybrid metal matrix composites, Wear 256 (2004) 705–713.

[10] Design and Analysis of experiments , Douglas C.Montgomery, Wiley student 8th edition.

[11] N.Radhika,R.Subramanian, Tribological Behaviour of aluminium / Alumina / Graphite Hybrid Metal Matrix Composite Using Taguchi‟s Techniques, Journal of Minerals & materials Characterization & Engineering, Vol. 10, No.5, pp.427-443, 2011.

[12] T. Sritharan, L.S. Chan , A feature of the reaction between Al and SiC particles in an MMC, Materials Characterization 47 (2001) 75– 77.

[13] P.K.Rohatgi, B.F.Schultz, Tribological performance of A206 aluminum alloy containing silica sand particles , Tribology International 43 (2010) 455–466.

[14] S. Basavarajappa, G. Chandramohan , Application of Taguchi techniques to study dry sliding wear behaviour of metal matrix composites, Materials and Design 28 (2007) 1393–1398