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Scientific Research

Optimization of Tribological Performance of Al-6061T6-15% SiCp-15% Al_2O_3 Hybrid Metal Matrix Composites Using Taguchi Method & Grey Relational Analysis

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Abstract

In this investigation, optimization of tribological performance parameters of Al-6061T6 alloy reinforced with SiC (15% by weight) and Al_2O_3 (15% by weight) particulates having particle size of 37 μm each has been presented. The wear and frictional properties of the hybrid metal matrix composites have been studied by performing dry sliding wear test using pin-on-disc wear tester. A L_{27} orthogonal array is selected for the analysis of the data. From the test results it is observed that sliding distance has the significant contribution in controlling the friction and wear behaviour of hybrid composites. A confirmation test is also carried out to verify the accuracy of the results obtained through the optimization. In addition an optical micrograph test is also performed on the wear tracks to study the wear mechanism.

Keywords

Metal Matrix Composites (MMCs), Friction, Wear, Taguchi Method, Grey Relational Analysis, Analysis of Variance (ANOVA)

1. Introduction

Hybrid metal matrix composites (HMMCs) are engineering materials reinforced by a combination of two or

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more different type of substances in order to achieve the advantage of both of them. This gives rather a high degree of freedom in material design. Hybrid metal matrix composites offer considerable promise to help automotive engineers in the field of fuel economy, increasing styling options, enhancing performance and maintaining safety, quality and profitability which are just a few of the challenges addressed daily by the automotive industry.

The particulate reinforced aluminum MMCs are a preferred choice for weight critical application in the aerospace and automotive industries due to their high specific strength, high specific stiffness, superior wear resistance and low density. The attainable improvements in the properties are dependent on the intrinsic properties of composite constituents and the size, shape, orientation, volume/weight fraction and distribution of the reinforcing phase in the metal matrix. The selection of proper reinforcement is therefore crucial for obtaining the most optimum combination of properties at substantially low cost.

Venkatraman *et al.* [1] concluded that the presence of a stable, thin and hard mechanically mixed layer will provide the best wear resistance even though the coefficient of friction will be high. Miyajima *et al.* [2] concluded dry sliding pin-on-disk wear test for 2024 Al/29% SiC_w/26% Al_2O_{3f}. From the test they reported that wear resistance of MMC is strongly dependent on the kind of reinforcement as well as its volume fractions. Kaur *et al.* [3] preferred dry sliding wear for the effect of SiC reinforcement along with immiscible element in spray formed Al-Si base alloy. From the test all the samples (Al-Si, Al-Si/SiC, Al-Si-5Sn/SiC & Al-Si-10SiC) show that the nature of wear changes from lower loads to higher loads. The severe deformation wear occurs in spray formed alloy at higher loads.

The tribological behaviour of Al-7.5% SiCp MMC was studied for varying applied load, sliding speed and time using Taguchi orthogonal array design and grey relational grade. It is observed that time is the most significant parameter influencing the tribological behaviour of MMCs [4]. Siriyala *et al.* [5] studied the wear behaviour for Al alloy-5% SiCp MMC and optimized the testing parameter using Taguchi and grey relational method. Sahin [6] performed the abrasive wear test of Al-15% SiC at different loads, sliding distances and reinforcement particles size. Radhika *et al.* [7] performed a wear test of Al/Al_2O_3/Graphite hybrid metal matrix composite at different operating parameters using Taguchi Method. In this study sliding distance has the highest influence on wear rate followed by applied load and sliding speed as well as incorporation of graphite as primary reinforcement increases the wear resistance of composites. Mishra *et al.* [8] observed that wear rate decreases with increasing weight percentage of reinforcement for different mesh size of SiC. Similar work has performed and presented that sliding distance has the highest influence on wear rate for Al-6061/10% SiC metal matrix composites [9]. Basvarajappa *et al.* [10] studied Taguchi's technique to dry sliding behavior of Al/SiC/Graphite MMCs and reported that graphite particles increases the wear resistance of the composites and sliding distance is the wear factor that has the highest influence on the wear of composites. Wang *et al.* [11] conducted wear test on pin-on-disk wear test for MMCs and reported that different orientation of reinforcement gives the better result. The friction performance of Al-10% SiCp MMCs against steel was studied for varying tribological test parameters. Applied load is the most important factor which is influencing the friction performance.

For the present tribological study Al-6061T6 is used as base metal and Silicon Carbide (SiC), Alumina (Al_2O_3) is used as reinforcements. The MMC is synthesized by stir casting process in liquid metallurgy route where silicon carbide, alumina (15% by weight) is introduced into the Al-6061T6 alloy. The tribological tests are conducted on the material to study the friction and wear properties of materials. The result data are generalized to grey relational grade and analyzed by Taguchi Method. A statistical analysis of variance (ANOVA) is performed. Finally confirmation test is carried out to verify the optimal process parameters combination. The microstructure study is carried out with the help of optical microscopy to judge the wear mode of the material.

2. Taguchi Method

The Taguchi Method [12] [13] is a powerful method for designing high quality systems based on orthogonal array (OA) experiments that provide much reduced performance for the experiments with an optimum setting for process control parameters. This method achieves the integration of design of experiments (DOE) [14] with the parametric optimization of the process yielding the desired results. 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 conditions. The DOE process in 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 setup results uses a signal to noise (S/N) ratio to aid in the determination of the best process designs. Which are logarithmic functions of desired output to serve as objective functions for optimization? The S/N ratio takes both the mean and the variability into account and is defined as the ratio of mean (Signal) to the standard deviation (noise). The ratio depends on the quality characteristics of the product/process to be optimized. The three categories of S/N ratios are used: lower the better (LB), higher the better (HB), and nominal the best (NB). For the case of minimization of wear, LB characteristic needs to be used. This technique has been successfully used by researchers in the study of dry sliding wear behavior of composites [15]. These methods focus on improving the design of manufacturing processes.

Furthermore, a statistical analysis of variance (ANOVA) [14] is performed to find which process parameters are statistically significant. With the S/N ratio & ANOVA analyses, the optimal combination of the process parameters can be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design.

3. Grey Relational Analysis

The grey system theory was proposed by Deng [16]. Grey refers to the primitive data with poor, incomplete and uncertain information in the grey systematic theory. The incomplete relationship of information among these data is called the grey relation. In grey relational analysis the first step is to perform the grey relational generation in which the results of the experiment are normalized in the range between 0 and 1. Then the second step is to calculate the grey relational coefficient from the normalized data to represent the correlation between the desired and actual experimental data. The overall grey relational grade is then computed by averaging the grey relational coefficient corresponding to each performance characteristics is based on the calculated grey relational grade.

As a result, optimization of the complicated multiple performance characteristic is converted into optimization of a single grey relational grade. The optimal level of the process parameters is the level with the highest grey relational grade. The aim of the present paper is to optimize the tribological test parameters to minimize friction & wear of Al-6061T6/15% SiC/15% Al_2O_3.

Furthermore, analysis of variance (ANOVA) is performed to predict the importance and significance of each process parameter and their interaction on the tribological properties of Al-6061T6/15% SiC/15% Al_2O_3 MMCs. Finally confirmation test is performed to verify the optimal combination of process parameters obtained from the analysis.

4. Experimental Detail

4.1. Fabrication Process

In the present investigation Al-6061T6 alloy was choosen as the base matrix and which is reinforced with Silicon Carbide and alumina having particle size 37 µm. The chemical composition of the matrix metal Al-6061T6 is given in **Table 1**. Silicon Carbide and Alumina being hard and brittle in nature gets accommodated in soft ductile aluminium base matrix, enhancing the overall stiffness and strength of the hybrid metal matrix composites (HMMC). In order to achieve high level of mechanical properties in the composite, a good interfacial bonding between the dispersed phase and the liquid matrix has to be obtained. To increase the wettability of the molten metal cerium is added (2% by weight). The silicon carbide and alumina are pre heated at 500˚C for 1 hour before mixing in the molten metal. Care was taken to maintain an optimum range of casting parameters such as stirring speed (350 rpm), stirring time (4 - 5 min) and pouring temperature (700˚C). The molten metal was then poured into green silica sand mould of diameter 14 mm and length 120 mm. And after cooling, the samples required for tribological tests are prepared by different machining processes.

4.2. Plan of Experiments

Dry sliding wear test was performed with three parameters applied load (L), sliding speed (S) and sliding distance (D) and varying them for three levels as shown in **Table 2**. According to the method degree of freedom for an orthogonal array should be greater than or equal to sum of wear parameters given in **Table 2**. A L_{27} Orthogonal array (OA) which has 27 rows and 13 columns was selected to optimize the wear parameters as shown in **Table 3**. To check the degree of freedom (DOF) in the experiment design for the three level test, the three main factors take six DOFs. The DOFs for three second order interactions (LxS, LxT, SxT) is twelve and the total DOFs required is eighteen. As per the Taguchi Method, the total DOFs of selected OA must be greater than or equal to the total DOFs required for the experiment and hence L_{27} OA has selected. The coefficient of friction and wear rate are taken as system response. In orthogonal array, first column is assigned to the applied load, second column is assigned to sliding speed and fifth column is assigned to sliding distance and remaining columns are assigned to their interactions. The objective of the model is to minimize wear rate and coefficient of friction. The responses were tabulated and results were subjected to Analysis of Variance (ANOVA). The S/N ratio for

Table 1. Chemical composition of matrix Al-6061.

Chemical composition	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
wt%	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

Table 2. Process parameters and levels used in experiment.

Level	Load in N	Sliding speed in m/s	Sliding distance in m
1	25	2.0	1000
2	30	2.25	1500
3	35	2.50	2000

Table 3. L_{27} Orthogonal array with processes parameters and Interactions assigned.

Trial No.	1 (L)	2 (S)	3 (L × S)	4 (L × S)	5 (D)	6 (L × D)	7 (L × D)	8 (S × D)	9	10	11 (S × D)	12	13	COF	Wear rate (mm^3/m)
1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.5382	0.0046
2	1	1	1	1	2	2	2	2	2	2	2	2	2	0.4417	0.0044
3	1	1	1	1	3	3	3	3	3	3	3	3	3	0.3355	0.0048
4	1	2	2	2	1	1	1	2	2	2	3	3	3	0.5802	0.0041
5	1	2	2	2	2	2	2	3	3	3	1	1	1	0.4989	0.0046
6	1	2	2	2	3	3	3	1	1	1	2	2	2	0.4761	0.0038
7	1	3	3	3	1	1	1	3	3	3	2	2	2	0.5963	0.0052
8	1	3	3	3	2	2	2	1	1	1	3	3	3	0.5632	0.0044
9	1	3	3	3	3	3	3	2	2	2	1	1	1	0.5128	0.0037
10	2	1	2	3	1	2	3	1	2	3	1	2	3	0.6512	0.0044
11	2	1	2	3	2	3	1	2	3	1	2	3	1	0.4965	0.0038
12	2	1	2	3	3	1	2	3	1	2	3	1	2	0.4032	0.0046
13	2	2	3	1	1	2	3	2	3	1	3	1	2	0.4617	0.0048
14	2	2	3	1	2	3	1	3	1	2	1	2	3	0.3842	0.0042
15	2	2	3	1	3	1	2	1	2	3	2	3	1	0.3078	0.0037
16	2	3	1	2	1	2	3	3	1	2	2	3	1	0.5823	0.0039
17	2	3	1	2	2	3	1	1	2	3	3	1	2	0.5069	0.0027
18	2	3	1	2	3	1	2	2	3	1	1	2	3	0.4803	0.0034
19	3	1	3	2	1	3	2	1	3	2	1	3	2	0.4913	0.0037
20	3	1	3	2	2	1	3	2	1	3	2	1	3	0.4284	0.0032
21	3	1	3	2	3	2	1	3	2	1	3	2	1	0.3685	0.0025
22	3	2	1	3	1	3	2	2	1	3	3	2	1	0.4922	0.0040
23	3	2	1	3	2	1	3	3	2	1	1	3	2	0.4465	0.0043
24	3	2	1	3	3	2	1	1	3	2	2	1	3	0.3825	0.0038
25	3	3	2	1	1	3	2	3	2	1	2	1	3	0.5006	0.0044
26	3	3	2	1	2	1	3	1	3	2	3	2	1	0.4787	0.0040
27	3	3	2	1	3	2	1	2	1	3	1	3	2	0.4635	0.0042

wear rate and coefficient of friction using "smaller the better" characteristic given by Taguchi, is as follows:

$$\frac{S}{N} = -10\log\left(\frac{\sum y^2}{n}\right)$$

where "y" represents the response of friction and sliding wear and "n" is the number of observations.

4.3. Wear Test

A pin-on-disc test apparatus was used to determine the sliding wear characteristics of the hybrid composite. The tribological tests are carried out on pin-on-disc testing machine TR20CH (Ducom, India) (**Figure 1** and **Figure 2**) under dry non lubricated condition and at ambient temperature (30˚C). The configuration of testing machine has EN-32 steel disc. The composite samples having dimension 12 mm diameter and 30 mm length are pressed against a rotating steel disc of hardness 65HRC. The track diameter was varied for each trial of experiments in the range of 50 mm to 160 mm and 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 to 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 arm generates a signal which is used to determine the maximum wear and coefficient of friction is monitored continuously as wear occurs. Weight loss of each specimen was obtained by weighing the specimen before and after the experiment by a single pan electronic weighing machine with an accuracy of 0.0001 g after thorough cleaning with aceton solution.

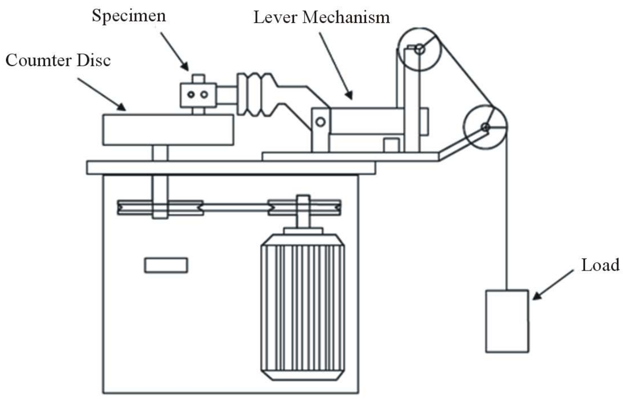


Figure 1. Layout of pin-on-disc tribotester.

Figure 2. Close up view of specimen loading in pin-on-disc tribotester.

After wear tests Optical Microscopy is carried out to evaluate the microstructure images. It is determined that whether the wear tracks are adhesive or abrasive in nature.

5. Result and Discussion

The aim of present study is to minimize friction and wear for Al-6061T6/15% SiC/15% Al_2O_3 metal matrix composite using Taguchi Method. The experimental plan is to find the important control parameters viz applied load, sliding speed and sliding distance which influence the wear process to achieve minimum friction and wear. Coefficient of friction (COF) and wear depth are taken as system responses. The experimental results for friction and wear tests are shown in **Table 3**. Grey relational analysis is carried out following the step mentioned earlier. **Table 4** shows the calculated values for each steps of grey relational analysis.

5.1. Analysis of S/N Ratio for Grey Relational Grade

The desired factor levels are calculated by the S/N ratio analysis. In this study the friction coefficient and wear depth are taken as the performance index. In response table (**Table 5**) the mean S/N ratio for each level of the controlling factors is shown. All calculations are performed using Minitab Software. The response table includes ranks based on delta value (highest minus lowest); rank 1 is assigned to the parameter with highest delta value, rank 2 to second highest delta value and so on. In this case sliding distance has the highest delta value thus rank

Table 4. Computation of grey relational grade.

Exp. No	Experimental data		Normalized data		Value of Δ		Grey relational coefficients		Grey relational grade
	COF	Wear rate (mm^3/m)	Norm. COF	Norm. WR	ΔValue COF	ΔValue WR	ξ value COF	ξ value WR	
1	0.5382	0.00469	0.3292	0.2166	0.6708	0.7834	0.427	0.3893	0.40821
2	0.4417	0.0044	0.6103	0.3221	0.3897	0.6779	0.5691	0.4245	0.4932
3	0.3355	0.00481	0.9194	0.1729	0.0858	0.8271	0.8612	0.3768	0.619
4	0.5802	0.00414	0.2067	0.4153	0.7932	0.5846	0.3866	0.46106	0.4238
5	0.4989	0.00466	0.4436	0.2256	0.5563	0.7743	0.4733	0.3924	0.4328
6	0.4761	0.00381	0.51	0.5347	0.4899	0.4653	0.5051	0.518	0.51157
7	0.5963	0.00528	0.1599	0	0.8401	1	0.3731	0.3333	0.3532
8	0.5633	0.00446	0.2561	0.3004	0.7438	0.6996	0.40199	0.4168	0.4094
9	0.5128	0.00379	0.4032	0.5433	0.5968	0.4566	0.456	0.5227	0.4893
10	0.6512	0.00442	0	0.3133	1	0.6867	0.3333	0.4219	0.3776
11	0.4965	0.00385	0.4506	0.5206	0.5493	0.4793	0.4764	0.5112	0.4938
12	0.4032	0.0046	0.7224	0.24644	0.2775	0.7535	0.643	0.3989	0.5209
13	0.4617	0.00483	0.552	0.1662	0.4479	0.8337	0.5274	0.374	0.4507
14	0.3842	0.00421	0.7775	0.3896	0.2224	0.6104	0.6921	0.4503	0.5712
15	0.3078	0.00369	1	0.5764	0	0.4236	1	0.5414	0.7707
16	0.5823	0.00395	0.2005	0.4842	0.7994	0.5157	0.3847	0.4923	0.4385
17	0.5069	0.00268	0.4203	0.9451	0.57967	0.0548	0.4631	0.40135	0.6822
18	0.4803	0.00339	0.4978	0.6856	0.50218	0.3143	0.4989	0.614	0.5564
19	0.4913	0.00378	0.4657	0.5467	0.5342	0.4532	0.4834	0.5245	0.5039
20	0.4284	0.00324	0.6489	0.7396	0.3511	0.26039	0.5832	0.6576	0.6225
21	0.3685	0.00253	0.8234	0.9999	0.1766	0.000069	0.7389	1	0.8694
22	0.4922	0.00402	0.463	0.4599	0.5368	0.5401	0.4822	0.4808	0.4815
23	0.4465	0.00426	0.5962	0.3726	0.4038	0.6274	0.5532	0.4435	0.4984
24	0.3825	0.00378	0.7827	0.544	0.2179	0.4559	0.697	0.5231	0.6101
25	0.50061	0.0044	0.4386	0.3204	0.5613	0.6793	0.4711	0.4239	0.4475
26	0.4787	0.00404	0.50246	0.4498	0.4975	0.5502	0.5012	0.4761	0.4887
27	0.4635	0.00421	0.5468	0.3883	0.4532	0.6117	0.5245	0.4449	0.48716

Table 5. Response table for grey relational grade.

Level	Load (N)	Speed (m/s)	Distance (m)
1	0.4601	0.5454	0.4317
2	0.5402	0.5279	0.5214
3	0.5566	0.4836	0.6038
Delta	0.0965	0.0618	0.1722
Rank	2	3	1
Total mean grey relational grade = 0.5189			

1 is assigned to sliding distance. The corresponding main effect is shown in **Figure 3**. The interaction plots for parameters: applied load, sliding speed and sliding distance are given in **Figure 4**, **Figure 5** and **Figure 6**. In main effect plot the significance of each parameter can be judged by the inclination of plot. From the main effect plot, it is seen that the parameter sliding distance (D) is the most signifcant parameter while other parameters load and speed are also important paremeters in controlling the tribological behaviour of the HMMC. From the interaction plots in **Figure 4**, **Figure 5** and **Figure 6**, it can be seen that the lines are intersecting each other. From present analysis, it is observed that sliding distance (D) is the most influencing parameter for tribological characteristics of Al-6061T6/15% SiC/15% Al_2O_3 hybrid composites followed by applied load and sliding speed respectively. The optimal process parameter combination is the one that yields maximunm mean value and thus it is found to be L3S1D3, *i.e.* the highest level of applied load along with the lowest level of sliding speed and highest level of sliding distance within the experimental domain considered in the present study.

5.2. Analysis of Variance for Grey Relational Grade

The results for various combinations of parameters are obtained by conducting the experiment as per the Orthogonal Array. The measured results are analyzed using the Minitab 15 Software. Using Minitab, ANOVA is performed to determine which parameter and interaction significantly affect the performance characteristics.

Table 6 shows the ANOVA results for tribological behaviour of Al-6061T6/SiC/Al_2O_3 hybrid Metal Matrix Composites. ANOVA calculates the F-ratio, which is the ratio between regression mean square and mean square error. The F-ratio is also called variance ratio, *i.e.* the ratio of variance due to the effect of a factor and variance due to the error term. In general when the F-value increases, the significance of the parameter also increases. The ANOVA table shows the percentage contribution of each parameter. From ANOVA results it is seen that sliding distance (D) is the most significant parameter influencing the tribological behaviour while parameters applied load and sliding speed are also important. The interaction of parameters have less influence on friction and wear property of hybrid composite.

5.3. Confirmation Test

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 and to validate the experimental results. The estimated S/N ratio $\hat{\eta}$ using the optimal level of the testing parameters can be calculated as

$$\hat{\eta} = \eta_m + \sum_{i=1}^{0}\left(\overline{\eta_i} - \eta_m\right)$$

where, η_m is the total mean S/N ratio, $\overline{\eta_i}$ is the mean S/N ratio at optimal testing parameter level and 0 is the number of main design process parameters that significantly affect the friction and wear performance of Al-6061T6/15% SiC/15% Al_2O_3 HMMC.

Table 7 shows the comparison of the estimated grey relational grade with the actual grey relational grade from initial to optimal condition is 0.0968. Thus there is an improvement of 16.56% in grey relational grade.

5.4. Microstructure Analysis

Optical micrographs of the worn out surfaces of the Al-6061T6/15% SiC/15% Al_2O_3 hybrid MMC specimens after wear tests at an applied load 30 N, sliding speed 2.25 ms^{-1} and a sliding distance 1000 m are given in **Figure 7**. Another tribological tested specimen with parameters has been shown in **Figure 8**.

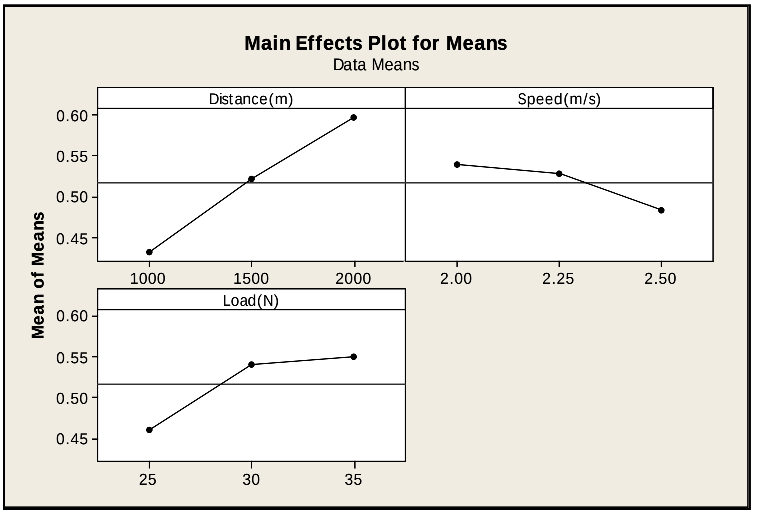


Figure 3. Main effects plot for grey relational grade.

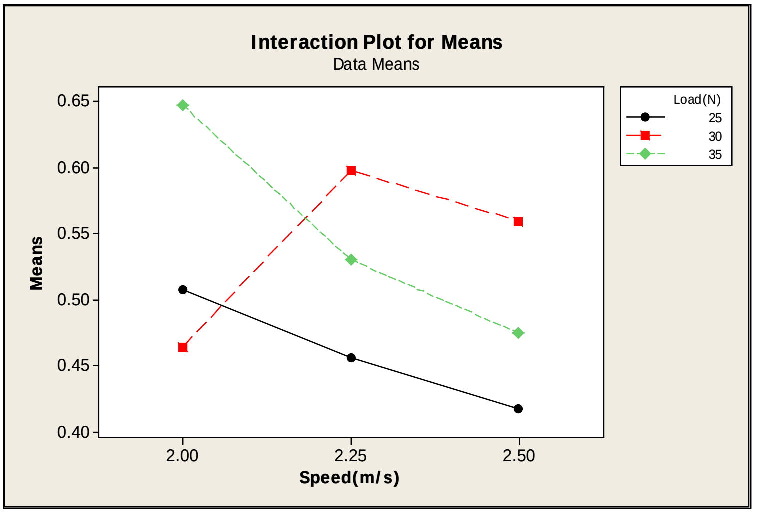


Figure 4. Interaction plot between load and speed.

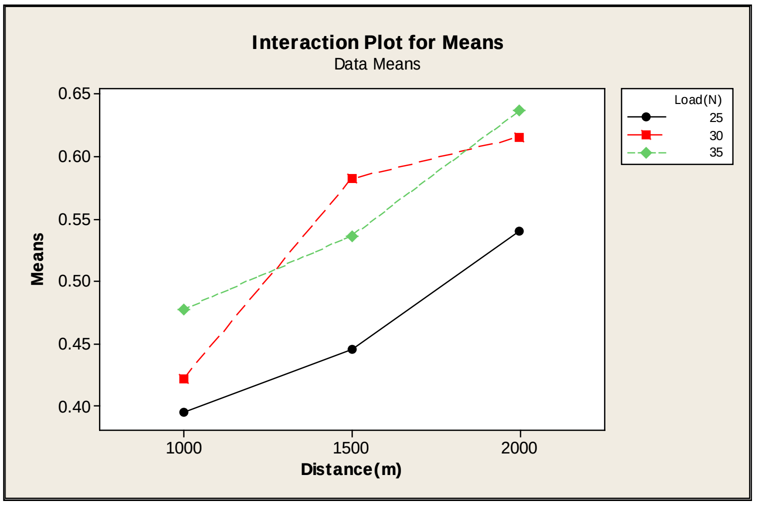


Figure 5. Interaction plot between load and distance.

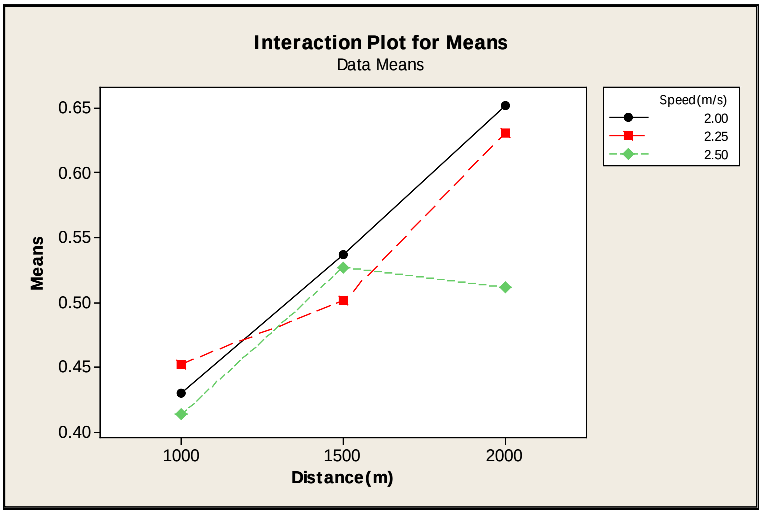


Figure 6. Interaction plot between speed and distance.

Table 6. Results of ANOVA for grey relational grade.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%
Load (N)	2	0.04804	0.04804	0.0224019	5.17	0.036	13.46
Speed (m/s)	2	0.01826	0.01826	0.00913	1.96	0.202	5.12
Distance (m)	2	0.1335	0.1335	0.06675	14.36	0.002	37.42
Load (N) × speed (m/s)	4	0.07994	0.07994	0.019985	4.30	0.038	22.40
Load (N) × distance (m)	4	0.0126	0.0126	0.003151	0.68	0.626	3.53
Speed (m/s) × distance (m)	4	0.02718	0.02718	0.006796	1.46	0.30	7.62
Residual error	8	0.03719	0.03719	0.004649			
Total	26	0.35672					

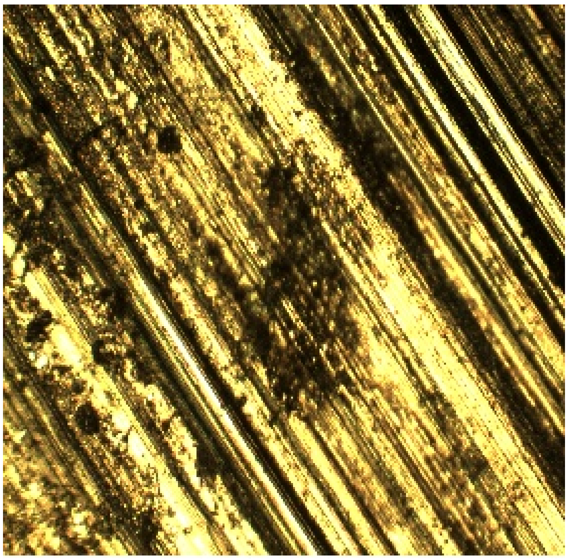
Table 7. Results of confirmation test of multiple performance.

	Initial parameter	Optimal parameter	Experimental
Level	L2S2D2	L3S1D3	L3S1D3
Wear	0.0042		0.0025
COF	0.3842		0.3685
Grade	0.5712	0.668	0.8694
Improvement of grey relational grade = 0.0968			

It is observed that the Al_2O_3 and SiC particles are uniformly distributed throughout the matrix in all specimens. Agglomerates of SiC and Al_2O_3 particles, and voids in the matrix are rarely observed in the microstructure. From the optical micrographs, it can be observed that the worn out surfaces mainly consist of longitudinal grooves and partially irregular pits. The presence of grooves indicates abrasive wear which is resulted from micro-cutting and micro-ploughing. The presence of pits and prows can be observed in the micrographs. Thus occurance of adhesive wear is also visible. From microstructure study it can be concluded that mostly abrasive wear has taken place with some traces of adhesive wear. The present observation on wear mechanism match with other studies [4] [7] [17].

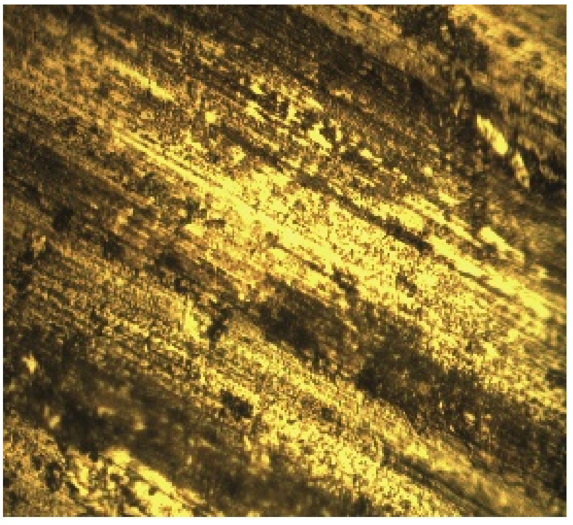
6. Conclusions

Following are the conclusions drawn from the study on dry sliding friction and wear test for Al-6061T6/15% SiC/5% Al_2O_3 HMMC using Taguchi and Grey relational grade.



L = 30 N, S = 2.25 m/s, D = 1000 m, Mag = 800 X, 5/12/2013

Figure 7. Optical micrograph of Al-6061T6/15% SiC/15% Al_2O_3 worn surface at 800× magnification.



L = 35 N, S = 2 m/s, D = 2000 m, Mag = 800 X, 5/12/2013

Figure 8. Optical micrograph of Al-6061T6/15% SiC/15% Al_2O_3 worn surface at 800× magnification.

- Sliding distance (37.42%) has the highest influence on tribological behaviour followed by applied load and sliding speed. The interaction set of parameters have the less influence on friction and wear property of hybrid composite.
- From the Taguchi's technique the optimal combination of process parameter for minimum wear and friction is found to be L3S1D3, *i.e.*, the highest level of sliding distance and applied load along with lowest level of sliding speed.
- Wear depth is reduced by 40.47% from initial to optimal process parameter condition and friction is slightly decreased by 4.08%.
- Incorporation of SiC and Al_2O_3 particulate increases the wear resistance of hybrid composites by performing a protective layer between pin and counterface. It has a significant effect on the friction and wear depth.
- Confirmation test was carried out and made a comparison between initial and optimal experimental parame-

ter values which shows wear depth is reduced by 40.47% and friction is slightly decreased by 4.08%.

- From the microstructure study of worn surfaces, it is observed that mostly abrasive wear mechanism has occurred on wear tracks with some traces of adhesive wear mechanism.

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