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Optimization of Friction and Wear Behaviour in Hybrid Metal Matrix Composites Using Taguchi Technique

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ABSTRACT

Al-7075 alloy-base matrix, reinforced with mixtures of silicon carbide (SiC) and boron carbide (B_4C) particles, know as hybrid composites have been fabricated by stir casting technique (liquid metallurgy route) and optimized at different parameters like sliding speed, applied load, sliding time, and percentage of reinforcement by Taguchi method. The specimens were examined by Rockwell hardness test machine, Pin on Disc, Scanning Electron Microscope (SEM) and Optical Microscope. A plan of experiment generated through Taguchi's technique is used to conduct experiments based on L_{27} orthogonal array. The developed ANOVA and the regression equations were used to find the optimum wear as well as coefficient of friction under the influence of sliding speed, applied load, sliding time and percentage of reinforcement. The dry sliding wear resistance was analyzed on the basis of "smaller the best". Finally, confirmation tests were carried out to verify the experimental results.

Keywords: Hybrid Metal Matrix Composites; Stir-Cast; Dry Sliding Wear, Orthogonal Array; Taguchi Technique; Analysis of Variance

1. Introduction

Two phases namely a matrix phase and a reinforcement phase constitute composite materials. Matrix and reinforcement phase work together to produce combination of material properties that cannot be met by the conventional materials [1]. In this study the composite is produced by using stir casting method, which is one of the economic and commonly used methods in Liquid Metallurgy. Most of studies made in automotive and aerospace field shows that the material used for components should posses good toughness with better tribological properties. Hence to meet the automotive application requirements an attempt has been made to develop the Al-7075 based hybrid composite, having combination of both toughness and tribological properties like wear resistance. The greatest improvement in tribological properties of composite is generally obtained using particle reinforcement of silicon carbide and boron carbide. Yoshiro Iwai *et al.* [2] found that the initial sliding distance require to achieve mild wear decreased with increasing volume fraction and also wear rate decrease linearly with volume fraction. Daoud *et al.* [3] reported that the addition of magnesium alloy to composite during production ensures good bonding between the matrix and the reinforcement. Aluminum alloys possess a number of mechanical and physical properties that make them attractive for automotive applications, but they exhibit extremely poor resistance to seizure and galling [4]. N. Natarajan *et al.* [5] recommended SiC particulate reinforcement of metal matrix is more appropriate aspirant material for automobile purpose, but a new friction material is to be developed. S. Basavarajappa *et al.* [6] inspected in detail sliding speed, load, sliding distance, percentage of reinforcement and mutual effect of these factors, which manipulate the dry sliding wear performance of matrix alloy (Al-2219) reinforced with SiC. N. Radhika *et al.* [7] found taguchi technique as a valuable technique to deal with responses influenced by multi-variables. It is formulated for process optimization and detection of optimal combination of the parameters for a given response. This method significantly reduces the number of trials that are required to model the response function compared with the full factorial design of experiments. The most important benefit of this technique is to find out the possible interaction between the factors. In view of the above article, an assessment is made to investigate the outcome of sliding speed, load, sliding time and volume fraction of reinforcement on the dry sliding wear behavior of the particulate reinforced Al-7075 alloy with a constant weight percentage (3%) of B_4C particulate and

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varying range (5%, 10%, 15%) of SiC particulate composites using taguchi method. The Analysis of variance was used to find the percentage contribution (Pr) of various process parameters and their correlations on dry sliding wear of the hybrid composite materials.

2. Material Selection

In the present investigation, Dry sliding wear tests were performed on SiC and B4C particulates reinforced Al-7075 alloy matrix composite. The Al-Mg-Si base alloys were purchased from Metal Mart Pvt. Ltd., Coimbatore (Tamil Nadu) India. Table 1 shows the nominal composition weight percentage of matrix materials. The hardness measurements were made by applying a load of 100 kg and the average is calculated from 10 different values of the experiments. The density measurements were all set according to the ASTM standard C1270-88. The value of hardness and density for matrix material were 67.17 HRC and 2.81 g/m^3 respectively in tempered condition. The particulate morphology study results such as shape of both reinforcements were angular-irregular and size of SiC (30 µm - 70 µm) and B_4C (5 µm - 20 µm).

2.1. Manufacturing of the Hybrid Composites Material

Stir casting technique is one of the popular Liquid Metallurgy Route (LMR) and also known as a very promising route for manufacturing near net shape hybrid metal matrix composite components at a normal cost [8]. In this present work, stir casting technique was used to fabricate Al-7075 alloy with varying weight percentages of SiC (5%, 10%, and 15%) and a constant weight percentage of B_4C (3%) reinforcements. In order to achieve good binding between the matrix and particulates, one weight percent of magnesium alloy is added. The experimental set up was shown in **Plate 1**. The stir casting furnace is mounted on the floor and the temperature of the furnace is precisely measured and controlled in order to achieve sound quality composite. Two thermocouples and one PID controller were used for this purpose. As mild steel materials are having high temperature stability, they are selected as stirrer rod and impeller.

This stirrer was connected to 1HP DC Motor through flexible link and was used to stir the molten metal in semi solid state. The screw operator lift is used to bring the stirrer in contact with the composite material. The melt was maintained at a temperature between 800˚C to 875˚C for one hour. Vortex was created by using a mechanical stirrer. Weighed quantity of SiC (5, 10 and 15 wt%) along with 3 weight percentage of B_4C particulate, preheated to 600˚C were added to the melt with constant stirring for about 10 min at 500 to 650 rpm. After complete addition of the particles to the melt, the composite alloy was tilt poured into the preheated (300˚C) permanent steel mould and allowed to cool in atmospheric air. The billet was then removed from the mould and machined for required dimensions. The uniform distribution of particulates reinforced in the matrix was examined with the help of Optical-Microscope. The optical micrographs of unreinforced alloy and the composite with 5, 10, 15 wt% of reinforcement are shown in **Plates 2-5** respectively.

Table 1. Chemical composition of the matrix alloy.

Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Ag
>0.130	>0.203	1.62	0.074	2.42	0.183	0.03	>3.6	0.049	0.024
B	Be	Bi	Ca	Cd	Co	Li	Na	P	Pb
0.0025	0.001	0.0013	0.0005	0.0003	0.0003	<0.0010	<0.0002	0.0005	<0.0010
Sn	Sr	V	Zr	Al					
0.004	<0.0001	0.0066	0.0056	90.52					

Plate 1. Stir casting setup.

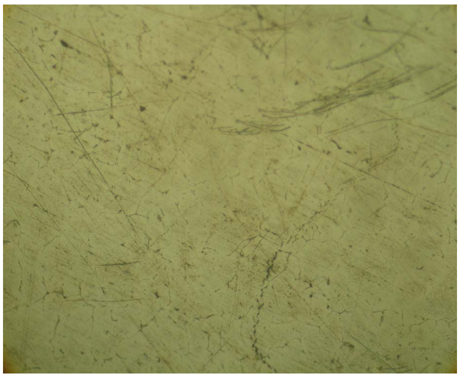

Plate 2. Optical Microscopic image of unreinforced Al (7075) alloy at 100× magnification.

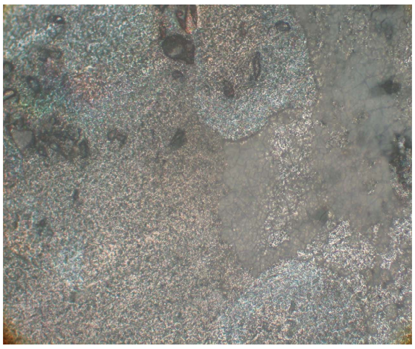

Plate 3. Optical Microscope image of 5% SiC + 3% B_4C particulate reinforced Al (7075) composite at 100× magnification.

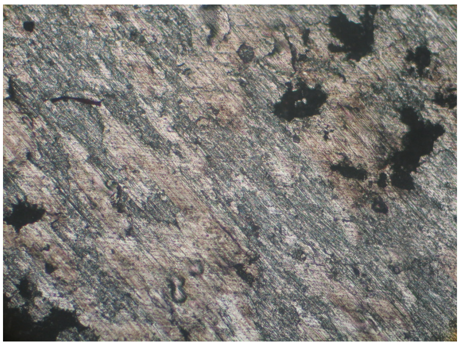

Plate 4. Optical Microscope image of 10% SiC + 3% B_4C particulate reinforced Al (7075) composite at 100× magnification.

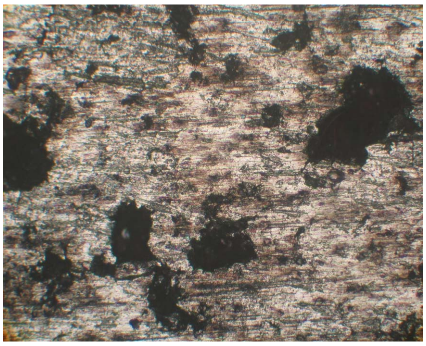

Plate 5. Optical Microscope image of 15% SiC + 3% B_4C particulate reinforced Al (7075) composite at 100× magnification.

2.2. Microstructure and Hardness

The resistance indentation or scratch is termed as hardness. Hardness test was carried out at room temperature using Rockwell hardness tester with at least six indentations of each sample and then the average values were utilized to calculate hardness number. The hardness of MMC increases with the volume fraction of particulate in the alloy matrix. The added amount of SiC and B_4C particles enhances hardness, as these particles are harder than Al alloy rendering their inherent property of hardness to soft matrix as shown in **Figure 1**. Composites with higher hardness could be achieved by this technique which may be due to the fact that silicon carbide and boron carbide particles act as obstacles to the motion of dislocation.

The hardness graph shows that the sample with less than 5 wt% of SiC and 3 wt% B_4C particulate behaves almost the same as unreinforced. But the sample with 15 wt% SiC and 3 wt% B_4C showed slightly high hardness and low toughness as compare to 10 wt% SiC and 3 wt% B_4C. Higher the percentage of particulates in the matrix, lesser is the toughness. Therefore, from this study it is evidently indicated that 10 wt% SiC and 3 wt% boron carbide composite sample have high hardness and good toughness. Hence this may be considered as the optimum weight percentage of the particulate to achieve better hybrid composite properties for heavy vehicle applications.

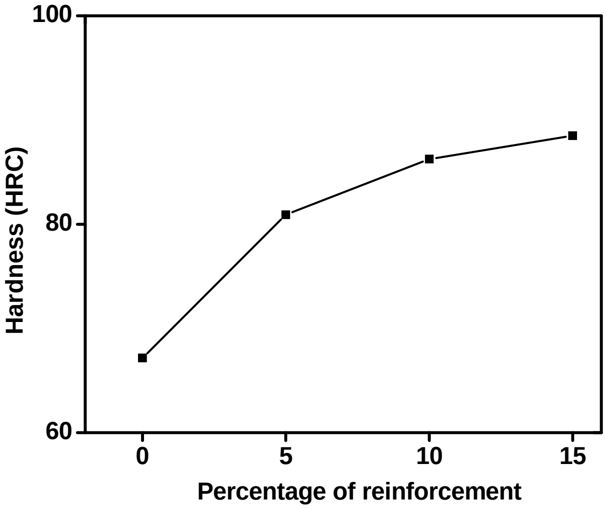

Figure 1. Hardness of unreinforced alloy and composites at different volume fraction.

2.3. Mechanism of Wear Test

The composite specimens were rubbed against hardened steel. Dry sliding wear tests were carried out using pin-on-disc type wear tester at different parameters like sliding speed, applying load, Sliding time and percentage of reinforcement were varied in the range given in **Table 2**.

Plate 6 shows the complete pin-on-disc wear test experimental setup. The slider disc is made up of 0.95% to 1.20% carbon (EN31) hardened steel disc with hardness of 62 HRC having diameter 165 mm. The pin test sample dimensions were 12 mm diameter and 32 mm height. Care should be taken to note that the test sample's end surfaces were flat and polished metallographically prior to testing. Conventional aluminium alloy polishing techniques were used to get ready the contact surfaces of the monolithic composite aluminium specimen for wear test. The procedure involves grinding of composite aluminium surfaces manually by 240, 320, 400 and 600 grit silicon carbide papers and then polishing them with 5, 1 & 0.5 μm alumina using low speed polishing machine. This preparation technique created considerable surface relief between hard and soft aluminium matrix. The polished surfaces were cleaned ultrasonically with acetone and methanol solutions.

The counter face materials were also polished and cleaned ultrasonically in acetone and methanol solutions before each wear test. The steel slider was polished using the above described procedure and all the tests were conducted at room temperature. The wear rates measured in weight units were obtained by weighing the specimen before and after the experiment and then converted to volumetric wear rates. The micro structural investigation and semi quantitative chemical analysis on the worn surfaces were performed by SEM.

Table 2. Process parameters and levels.

Level	Speed (m/s)	Load (N)	Time (min)	Percentage of Reinforcement %
1	1.5	10	5	5
2	3	20	10	10
3	4.5	40	15	15

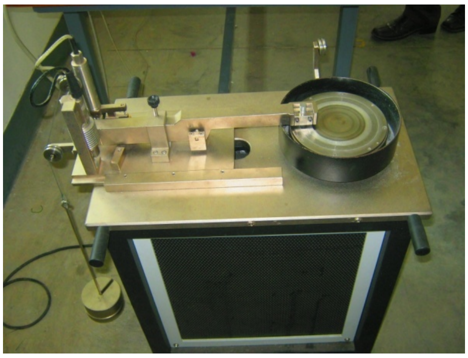

Plate 6. A pin-on-disc wear testing machine.

3. Design of Experiment

An experiment is designed in such a way to evaluate simultaneously two or more factors which possess their ability to affect the resultant average or variability of particular product or process characteristics. To accomplish this in an effective and statistically proper fashion, levels of the factors are varied in a strategic manner. The results of the particular test combinations are observed and the complete set of results are analyzed to determine the preferred level of the various influencing factors whether increases or decreases of those levels will potentially lead to further improvement [9]. The design of experiment process is divided into three main phases or planning phases namely, the conducting phase and the analysis phase, which encompass all experimentation approaches.

Investigation of the experimental outcomes uses signal to noise ratio to support the determination of the finest process design. This method is effectively used to study of dry sliding wear behavior of composites materials [10]. In this work, the "smaller the best" quality characteristics were taken to finding the minimum wear rate and coefficient of friction.

4. Plan of Experiment

The experiments were conduct as per the standard orthogonal array. The selection of the orthogonal array is based on the condition that the degrees of freedom for the orthogonal array should be greater than or at least equals sum of those of wear parameters. In the present investigation an L_{27} (3^{13}) orthogonal array was chosen as shown in **Figure 2**, which has 27 rows corresponding to the number of tests (20 degrees of freedom) and 13 columns at three levels and four factors, as shown in **Table 3**.

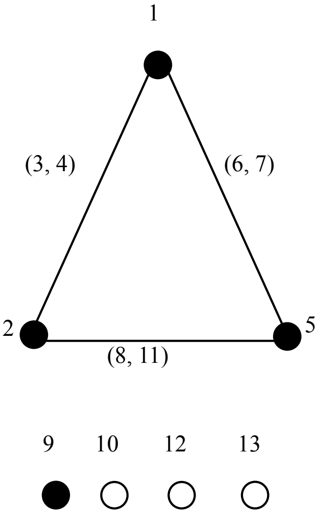

Figure 2. Linear graphs for L_{27} array.

The wear parameters chosen for the experiment are 1) sliding speed; 2) applied load; 3) sliding time; and 4) percentage of reinforcement of SiC and B_4C materials. The experiment consists of 27 tests (each row in the L_{27} orthogonal array) and the columns were assigned with parameters. The first column was assigned to sliding speed (S), second column was assigned to applied load (L), fifth column was assigned to sliding time (T) and ninth column was assigned to percentage of reinforcement (R) and the remaining columns were assigned to their interactions. The experiments were conducted as per the orthogonal array with level of parameters given in each array row. The output to be studied is wear rate and coefficients of friction of the test samples are repeated three times corresponding to 81 tests. The experimental observations are further transformed into Signal to noise ratio. The response to be studied was the wear rate and coefficient of friction with the objective as smaller the best, which is calculated as logarithmic transformation of loss function as shown below,

$$\left(\frac{S}{N}\right) = -10 \times \log \frac{1}{n}\left(\sum Y_i^2\right) \quad (1)$$

where "n" is the numbers of observations, "Y_i" is the measured value of wear rate and coefficient of friction. It is suggested that quality characteistics are optimised when the S/N response is as smaller as possible.

5. Results and Dissussion

Experimental values of wear rate and coefficient of friction and the calculated values of signal to noise ratio for a given response using Equation (1), and are listed in **Table 4**. The Taguchi's technique suggested that the analyzing of signal to noise ratio using conceptual approach that involves graphing the special effects and visually making out the significant aspects.

Table 3. Orthogonal array L_{27} (3^{13}) of taguchi method.

L_{27} (3^{13})	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2	2	2	2	2	2
3	1	1	1	1	3	3	3	3	3	3	3	3	3
4	1	2	2	2	1	1	1	2	2	2	3	3	3
5	1	2	2	2	2	2	2	3	3	3	1	1	1
6	1	2	2	2	3	3	3	1	1	1	2	2	2
7	1	3	3	3	1	1	1	3	3	3	2	2	2
8	1	3	3	3	2	2	2	1	1	1	3	3	3
9	1	3	3	3	3	3	3	2	2	2	1	1	1
10	2	1	2	3	1	2	3	1	2	3	1	2	3
11	2	1	2	3	2	3	1	2	3	1	2	3	1
12	2	1	2	3	3	1	2	3	1	2	3	1	2
13	2	2	3	1	1	2	3	2	3	1	3	1	2
14	2	2	3	1	2	3	1	3	1	2	1	2	3
15	2	2	3	1	3	1	2	1	2	3	2	3	1
16	2	3	1	2	1	2	3	3	1	2	2	3	1
17	2	3	1	2	2	3	1	1	2	3	3	1	2
18	2	3	1	2	3	1	2	2	3	1	1	2	3
19	3	1	3	2	1	3	2	1	3	2	1	3	2
20	3	1	3	2	2	1	3	2	1	3	2	1	3
21	3	1	3	2	3	2	1	3	2	1	3	2	1
22	3	2	1	3	1	3	2	2	1	3	3	2	1
23	3	2	1	3	2	1	3	3	2	1	1	3	2
24	3	2	1	3	3	2	1	1	3	2	2	1	3
25	3	3	2	1	1	3	2	3	2	1	2	1	3
26	3	3	2	1	2	1	3	1	3	2	3	2	1
27	3	3	2	1	3	2	1	2	1	3	1	3	2

Table 4. Orthogonal array and results of HMMC's.

Ex. No	Speed (m/s) S	Load (N) L	Time (min) T	Reinforcement (%) R	Wear Rate mm^3/m Wr	S/N Ratio for Wear (db)	Coefficient of Friction Cf	S/N Ratio for Coefficient of Friction (db)
1	1.5	10	5	5	0.002354	52.563870	0.38348	8.325145
2	1.5	10	10	10	0.001756	55.109509	0.32987	9.633143
3	1.5	10	15	15	0.0012368	58.154010	0.306	10.28557
4	1.5	20	5	10	0.0019123	54.368879	0.331	9.603440
5	1.5	20	10	15	0.001348	57.406202	0.32	9.897000
6	1.5	20	15	5	0.0025103	52.005487	0.39	8.178707
7	1.5	40	5	15	0.001981	54.062310	0.3422	9.314399
8	1.5	40	10	5	0.002782	51.112857	0.432	7.290325
9	1.5	40	15	10	0.00231	52.727760	0.3623	8.818633
10	3	10	5	10	0.001012	59.896389	0.30554	10.29863
11	3	10	10	15	0.000739	62.627111	0.2867	10.85144
12	3	10	15	5	0.00112	59.015639	0.35608	8.969048
13	3	20	5	15	0.001039	59.667689	0.30335	10.36112
14	3	20	10	5	0.00239	52.432041	0.3784	8.440977
15	3	20	15	10	0.00168	55.493814	0.3213	9.861785
16	3	40	5	5	0.002392	52.424776	0.4052	7.846611
17	3	40	10	10	0.002076	53.655453	0.3418	9.324558
18	3	40	15	15	0.00176	55.089746	0.322775	9.822002
19	4.5	10	5	15	0.000613	64.250790	0.16677	15.55764
20	4.5	10	10	5	0.001013	59.887811	0.28376	10.94097
21	4.5	10	15	10	0.0007326	62.702661	0.2837	10.94281
22	4.5	20	5	5	0.00173	55.239077	0.29918	10.48134
23	4.5	20	10	10	0.001582	56.015870	0.27819	11.11316
24	4.5	20	15	15	0.000998	60.017389	0.246	12.18129
25	4.5	40	5	10	0.001672	55.535274	0.3222	9.837489
26	4.5	40	10	15	0.001032	59.726406	0.31751	9.964851
27	4.5	40	15	5	0.00186	54.609741	0.354	9.019934

5.1. Results of Statistical Analysis of Experiments

The investigational results and calculated values were obtained based on the plan of experiment and then the results were analyzed with the help of commercial software MINITAB 14 as specially utilized for the design of experiment and statistical analysis of experiment appliances. The influence of controlled process parameters such as sliding speed, applied load, sliding time and percentage of reinforcement has been analyzed and the rank of involved factors like wear rate and coefficient of friction which supports signal to noise response is given in **Tables 5** and **6**.

It is evident from the tables that, among these parameters, load is a dominant factor on the wear rate and percentage of reinforcement for coefficient of friction. The influence of controlled process parameters on wear rate and coefficient of friction are graphically represented in **Figures 3-6**.

Table 5. Response for signal to noise ratio—smaller is better (wear rate).

Level	Speed (m/s)	Load (N)	Time (min)	Percentage of Reinforcement %
1	54.17	59.36	56.45	54.37
2	56.70	55.85	56.44	56.17
3	58.67	54.33	56.65	59.00
Delta	4.50	5.03	0.20	4.63
Rank	3	1	4	2

Table 6. Response for signal to noise ratio—smaller is better (coefficient of friction).

Level	Speed (m/s)	Load (N)	Time (min)	Percentage of Reinforcement %
1	9.038	10.645	10.181	8.833
2	9.531	10.013	9.717	9.937
3	11.116	9.027	9.787	10.915
Delta	2.077	1.618	0.463	2.082
Rank	2	3	4	1

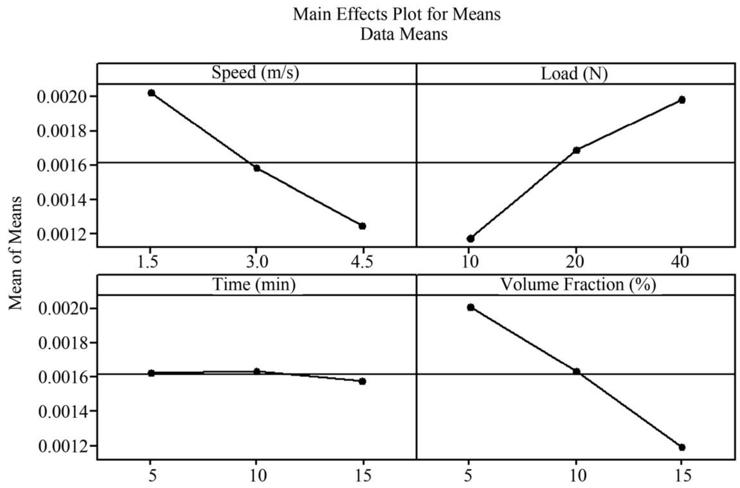

Figure 3. Main effects plot for means—wear rate.

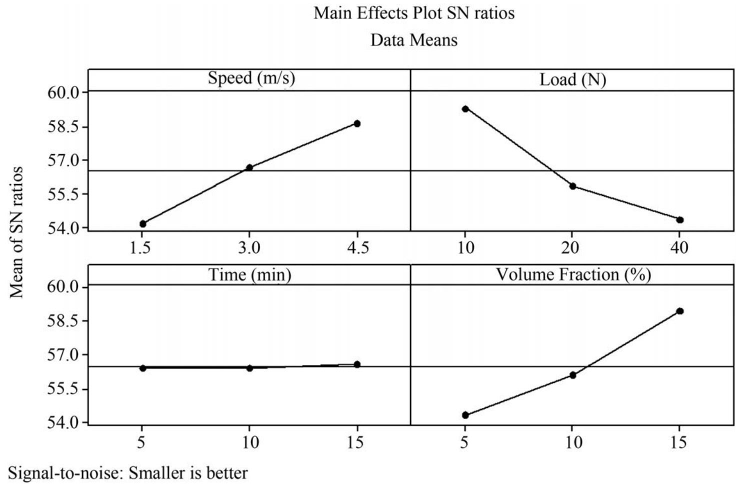

Figure 4. Main effects plot for S/N ratios—wear rate.

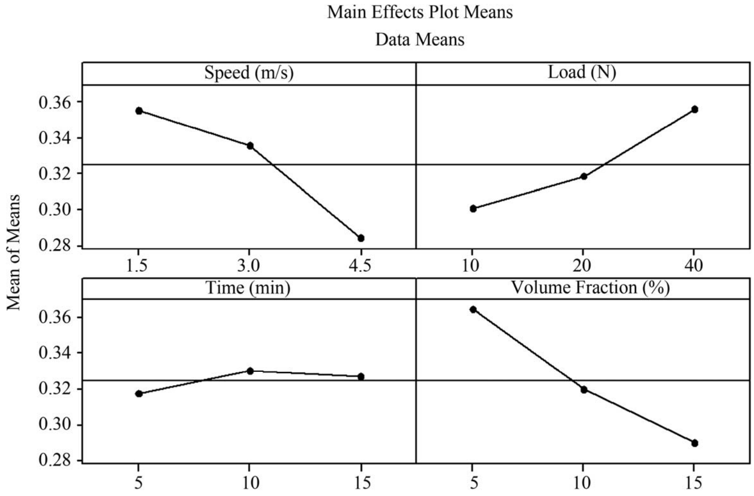

Figure 5. Main effects plot for means—coefficient of friction.

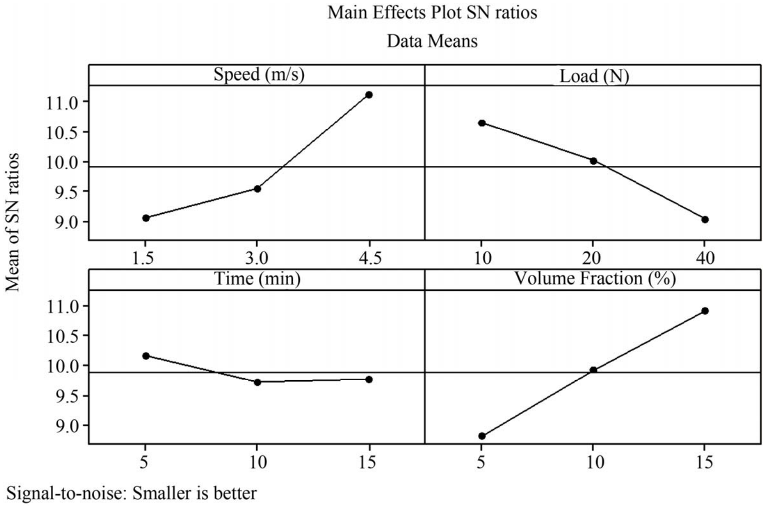

Figure 6. Main effects plot for S/N ratios—coefficient of friction.

Based on the analysis of these experimental results with the help of signal to noise ratio, the optimum conditions resulting in wear rate and coefficient of friction are shown in **Figures 4** and **6**. The figures clearly indicate that the third level of sliding speed, first level of load and third level of both sliding time and percentages of reinforcement are the optimum points, but these optimum conditions are not available in L_{27} orthogonal array. Hence the optimum conditions tested separately and the results are given in **Table 7**.

5.2. Analysis of Variance for Wear Rate

Table 8 shows the results of the analysis of variance on the wear rate for SiC and B_4C particulates reinforced Al-7075 alloy matrix composite. This analysis is carried out at a level of 5% significance that is up to a confidence level of 95%. The last column of the table indicates the percentage of contribution (Pr) of each factor on the total variation indicating the degree of their influence on the results.

From **Table 8**, one can easily observe that the percentage of reinforcement factor has grater influence on wear rate (Pr-R = 30.99%). Hence the percentage of reinforcement is an important control process parameter to be taken into account while wear process. Percentage of reinforcement is further followed by applied load (Pr-L = 29.96%), sliding speed (Pr-S = 26.89%). Based on the interaction terms, the interaction between sliding speed and load alone have significance influence (Pr-S∗L = 2.45%) on wear rate of the hybrid metal matrix composites.

5.3. Analysis of Variance for Coefficient of Friction

From **Table 9**, one can clearly infer that the percentage of reinforcement factor has greater control on coefficient of friction (Pr-R = 34.16%) than the other factors. Hence added percentage of reinforcement is an important parameter to be taken into account while considering coefficient of friction. This parameter is then followed by sliding speed (Pr-S = 33.31%), load (Pr-L = 18.89%), and sliding time (Pr-T = 0.18%). Based on the interaction terms, the interaction between load and sliding speed alone have significance influence (Pr-L∗S = 1.59%) on coefficient of friction of the hybrid metal matrix composites.

Table 7. Optimum level process parameters for wear rate and coefficient of friction.

Ex. No	Speed (m/s)	Load (N)	Time (min)	Percentage of Reinforcement %	Wear Rate mm^3/m	S/N Ratio for Wear (db)	Coefficient of Friction	S/N Ratio for Coefficient of Friction (db)
1	4.5	10	5	15	0.000613	64.25079	0.1667	15.55764

Table 8. Analysis of variance for wear rate (mm^3/m).

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Pr%
S (m/sec)	2	0.0000027	0.0000027	0.0000014	34.67702069	0.000504817	26.88556
L (N)	2	0.000003	0.000003	0.0000015	37.15395074	0.000417041	29.96494
T (Min)	2	0	0	0	0	1	–0.82882
R (%)	2	0.0000031	0.0000031	0.0000015	37.15395075	0.000417041	30.99139
S (m/sec)∗L (N)	4	0.0000004	0.0000004	0.0000001	2.476930049	0.153914958	2.44820
L (N)∗R (%)	4	0.0000002	0.0000002	0	0	1	0.39529
R (%)∗S (m/sec)	4	0.0000001	0.0000001	0	0	1	–0.63117
Error	6	0.0000036					10.77459
Total	26	0.0000131					100

Table 9. Analysis of variance for coefficient of friction.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Pr%
S (m/sec)	2	0.0247533	0.0247533	0.0123766	41.6568802	0.000303179	33.3057555
L (N)	2	0.0142994	0.0142994	0.0071497	24.06420125	0.001362003	18.89398901
T (Min)	2	0.0007243	0.0007243	0.0003622	1.21891135	0.359552708	0.179330236
R (%)	2	0.0253694	0.0253694	0.0126847	42.69370373	0.000283005	34.15511214
S (m/sec)∗L (N)	4	0.0023454	0.0023454	0.0005863	1.973515588	0.21774874	1.594990663
L (N)∗R (%)	4	0.0013486	0.0013486	0.0003371	1.134767256	0.422936085	0.220800281
R (%)∗S(m/sec)	4	0.0019142	0.0019142	0.0005785	1.610686253	0.28629882	1.00053752
Error	6	0.0017827					10.64948465
Total	26	0.0725373					100

5.4. Multiple Linear Regression Models

Statistical software MINITAB R14 is used for developing a multiple linear regression equation. This developed model gives the relationship between independent/predictor variable and a response variable by fitting a linear equation to the measured data.

The regression equation developed for wear rate is,

$$\begin{aligned} \mathrm{Wr} = {} & 0.00268 - 0.000258\ \mathrm{S}\ (\mathrm{m/s}) + 0.000025\ \mathrm{L}\ (\mathrm{N}) \\ & - 0.000006\ \mathrm{T}\ (\mathrm{min}) - 0.000082\ \mathrm{R}\ (\%) \end{aligned} \quad (2)$$

R-Sq = 86.5%

The regression equation developed for coefficient of friction is,

$$\begin{aligned} \mathrm{Cf} = {} & 0.419 - 0.0239\ \mathrm{S}\ (\mathrm{m/s}) + 0.00185\ \mathrm{L}\ (\mathrm{N}) \\ & + 0.000925\ \mathrm{T}\ (\mathrm{min}) - 0.00745\ \mathrm{R}\ (\%) \end{aligned} \quad (3)$$

R-Sq = 86.6%

5.5. Scanning Electron Microscope Examination

Wear rate depends on the presence of carbide phase in matrix. **Plates 7-9** show the SEM worn surface micrographs of reinforced samples. The pure Al-7075 has a smooth surface nature and more tribolayers are formed hence the wear rate is more in the unreinforced sample. The examination of hybrid composite sample worn surfaces as shown in **Plates 7-9** showed that rough surface nature and less tribolayers due to silicon carbides and boron carbide embedded in matrix as compared to the unreinforced alloy.

6. Confirmation Experiment

Confirmation test is the last step in the plan process. **Table 10** indicates the values used for conducting the dry sliding wear test and **Table 11** shows the results of confirmation experiment and their comparison with regression model which helps to identify the optical parameter values from the experimental analysis. The mathematical model was developed with the help of regression Equations (2) and (3) and also the comparison result values obtained experimentally were analyzed. From the analysis, the actual wear rate and coefficient of friction are found to be varying from the calculated one using regression equation and the error percentage ranges between 6.90% to 11.76% for wear rate and 4.66% to 9.23% for coefficient of friction. As these values are closely resembling the actual data with minimum error, design of experiments by Taguchi method was successful for calculating wear rate and coefficient of friction from the regression equation. **Figure 7** shows a comparison between wear rate and coefficient of the obtained contribution percentage (Pr%) of each factor with the source of variance.

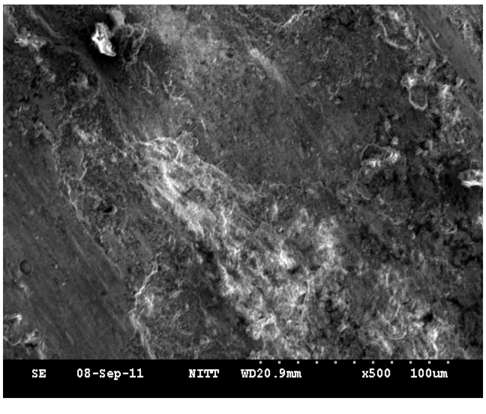

Plate 7. SEM texture of 5% SiC + 3% B_4C particulate reinforced Al (7075) composite after wear.

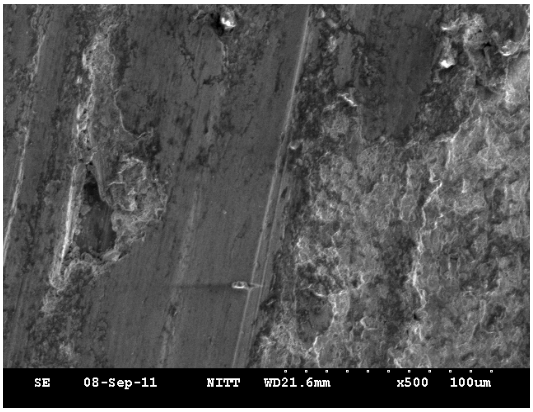

Plate 8. SEM texture of 10% SiC + 3% B_4C particulate reinforced Al (7075) composite after wear.

Plate 9. SEM texture of 15% SiC + 3% B_4C particulate reinforced Al (7075) composite after wear.

Table 10. Confirmation experiment for wear rate and coefficient of friction.

Level	Speed (m/s)	Load (N)	Time (min)	Percentage of Reinforcement %
1	1.8	15	6	5
2	3.3	25	9	10
3	4.2	35	12	15

Table 11. Result of confirmation experiment and their comparison with regression model.

Exp. No	Exp. wear rate (mm^3/m)	Reg. model Equation (1), Wear Rate (mm^3/m)	% Error	Exp. coefficient of friction	Reg. model Equation (2), coefficient of friction	% Error
1	0.002345549	0.0021446	9.37	0.4064	0.37203	9.23
2	0.001688592	0.0015796	6.90	0.3473	0.32021	8.47
3	0.001306921	0.0011694	11.76	0.2959	0.28272	4.66

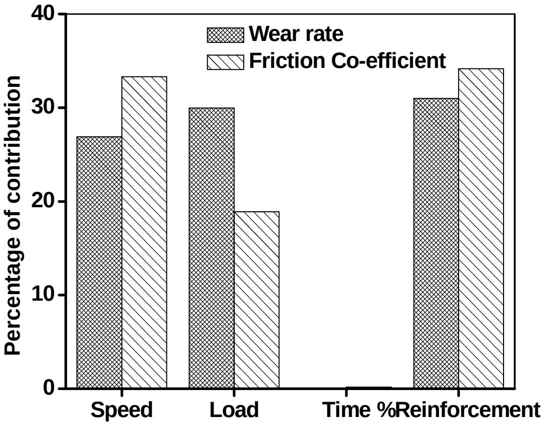

Figure 7. Wear and friction coefficient of contribution percentage (Pr%).

7. Conclusions

Taguchi's method is used to find the optimum conditions for dry sliding wear of the hybrid metal matrix composite materials. The following are the conclusions drawn from the present study.

1) Optimum wear rate and coefficient of friction were obtained from the experiment.

2) The wear rate is dominated by different parameters in the order of percentage of reinforcement, applied load, sliding speed, and sliding time. ANOVA test concluded that as percentage of reinforcement increases the wear rate also decreases significantly.

3) Coefficient of friction is dominated by different parameters in the order of percentage of reinforcement, sliding speed, applied load, and sliding time.

4) 4.5 m/s sliding speed, 10 N applied load, 5 min sliding time and 15% of reinforcement are the optimum conditions for both wear rate and the coefficient of friction.

5) Percentage of reinforcement (30.99%) is the wear factor that has the highest physical properties as well as statistical influence on the dry sliding wear rate of the composites among the other factors such as applied load (29.96%), sliding speed (29.89%).

6) The interactions between the sliding speed and the applied load will contribute more (2.45%) than other interactions.

7) The pooled error obtained with the help of Anova with respect to the parameters for wear rate and coefficient of friction are 10.78% and 10.65% respectively. The multiple regression values obtained for wear rate and coefficient of friction are 0.865 and 0.866 respectively.

8) From confirmation tests, the errors associated with wear rate ranges between 6.90% to 11.76 % and 4.66 % to 9.23 % for coefficient of friction resulting in the conclusion that the design of experiments by Taguchi method was successful for calculating wear rate and coefficient of friction from the regression equation.

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