

Experimental Investigation on Mechanical and Tribological Behaviour of Aluminium Metal Matrix Composite & Optimizing the Wear Characteristic for the Application of Clutch Plate

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ABSTRACT: Aluminum-base hybrid composites with reinforced particles have been fabricated on an Al alloy by stir casting method and their wear resistance and Co-efficient of Friction has been investigated by varying the load and percentage of reinforcement of the particles. The dry sliding wear properties of the hybrid composites and that of unreinforced Al alloy at room temperature were investigated by using Pin-on-disk wear testing machine at a constant sliding velocity of 2.09 m/s and sliding distance of 1884m over a various loads of 30N, 40N and 50N for particle weight percentage ranging from 5to25%. The results show that, the addition of reinforcement particulates upto a weight percentage of 25% reduces the wear rate. The results also show that the wear rate of the test specimens decreases with the increasing sliding distance and increases with increase in load. The coefficient of friction decreases with increasing percentage of reinforcements. Hardness of the specimens at the room temperature was also measured by Vickers hardness testing machine. The hardness of the hybrid composite test specimens increases with increasing in percentage of reinforcements. The optical micrographs taken for the micro structure analysis of the hybrid composite specimen" show that the reinforcements are uniformly distributed in the matrix.

KEYWORDS: Al alloy, hybrid composites, Dry sliding wear, coefficient of friction.

1. INTRODUCTION

Hybrid Metal Matrix Composites are engineering materials reinforced by a combination of two or more different type of material in order to achieve the combined advantages of both of them. This gives a high degree of freedom in material design [1].The particulate reinforced aluminium 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[2,3]. The attainable improvements in the properties are dependent on the intrinsic properties of composite constituents and the size, shape, orientation, percentage of reinforcements and distribution of the reinforcing phase in the metal matrix [4,5].Dry Sliding wear behavior of the composites is important wherever there is relative motion between metal components. The sliding wear behavior of the composites were found to be functions of many factors such as percentage of reinforcements and the applied load on the dry sliding metal-metal wear behavior of composites was investigated using a pin-on - disk wear tester. Also the micro hardness of the specimens at room temperature was measured using Vickers hardness testing machine to study the effect of percentage of reinforcements on hardness. The optical microstructure of the test specimens were taken to study the particle distribution and porosity.

II. MANUFACTURING OF THE HYBRID COMPOSITE MATERIAL

Among the variety of manufacturing processes available for particulate reinforced metal matrix composites, the stir

casting technique is the simplest and the most economical process for producing particulate reinforced MMCs[6,7]. In this method, in order to achieve the optimum properties of the metal matrix composite, the distribution of the reinforcement material in the matrix should be uniform and the wettability between the molten matrix and reinforcement particles should be optimized. The porosity level with metal matrix composite should be minimized and the chemical reaction between the reinforcement material and the matrix must be avoided. The vortex method is one of the better known approaches used to create a good distribution of the reinforcement material in the matrix. In this, the reinforcement material is introduced at the side of the vortex after the matrix material is melted, then it is stirred vigorously by a mechanical stirrer to form a vortex at the surface of the melt and Good quality

composites can be produced by this method by proper selection of the process parameters such as pouring temperature, stirring speed, preheating temperature of reinforcement. About 1kg of Al alloy was melted in a graphite crucible in a induction type electric resistance furnace. The temperature of the melt was 725°C. After complete melting and degassing of the alloy by nitrogen, a simple mechanical four-blade alumina coated stainless steel stirrer was introduced into the melt and stirring carried out. The coating of an alumina to the blades of the stirrer is essential to prevent the migration of ferrous ions from the stirrer into the molten metal. The stirrer was rotated a 600 rpm for 20min. During stirring, The reinforcement particles were preheated to 450°C for an hour then it was added inside the vortex and stirring action carried for some time and is poured into required die and was allowed to cool in atmospheric air. Their average diameters were 25 and 45 μm respectively. The billet was then removed from the mould. The Al hybrid composites of various percentages of reinforcement's materials were thus produced by the same technique. A sectional view of the stir casting is shown in Fig.1.



Fig1:Stir casting setup

III. EXPERIMENTAL PROCEDURE

The sliding experiments were conducted in air at room temperature in a pin-on-disk wear testing machine. The pins were loaded against the disk by a dead weight loading system. The pin specimens were flat ended pins of 8mm diameter and 32 mm in length. The disk test piece was 100mm in diameter and 10mm in thickness. The pin slid on the disk at a radius of 50mm. The material of the counter disk was high quality hardened steel with hardness HV256. Before the wear test, each specimen was ground by 1 μm alumina powder and the counter disk was ground by 2000 grit paper. Wear tests on composite specimens and unreinforced Al alloy were carried out under dry sliding condition under three different applied loads of 30N, 40N and 50N for a total sliding distance 1884m at a constant



Fig.2 A photograph view of the pin -on-disk type wear testing machine

IV. RESULTS AND DISCUSSION

4.1 Wear Characteristics

The wear test results of the Al hybrid composites and unreinforced specimens under dry sliding condition are presented in Fig.3. sliding speed of 2.09 m/s for all sample. The test duration was 15minutes at a constant disk speed of 400rpm for all the tests. The vertical height of the specimen was continuously measured using linear variable differential transformer (LVDT) of accuracy 1 μ m during the wear test and the height loss was taken as wear of the specimen. A photograph view of the pin-on-disk wear tester used in this investigation is shown in Fig.2. The hardness of the composite test specimens at room temperature was measured.

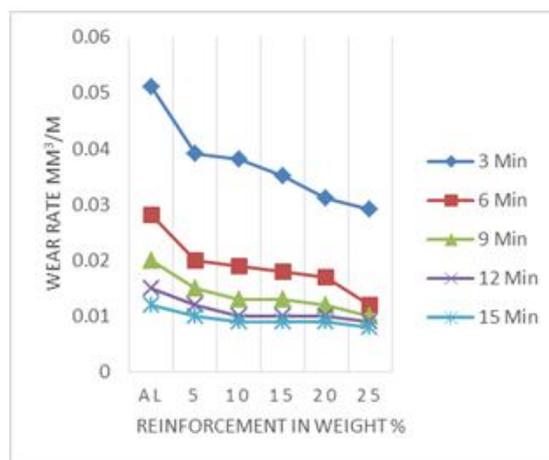


Fig 3:Wear rate Vs reinforcement

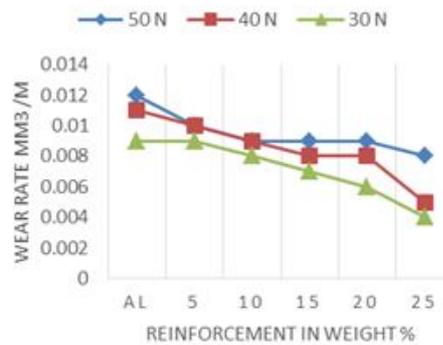


Fig:4 wear rate Vs load

The wear rate of test specimens in mm^3/m obtained from the height loss of the specimens during sliding is plotted against percentage of reinforcements and sliding distance in Fig3 for applied load of 50N .In the figure, wear rates of unreinforced alloy and five different composite specimens with varying percentage of reinforcements particle (5 to 25%) are shown.

As expected, the wear rate of the unreinforced and composite specimens decreases with increasing sliding distance. It is seen from the graphs that the wear rate of the unreinforced alloy specimens increases more rapidly with applied load compared with the composite alloy specimens. The graphs exhibit two regions which may be called „running-in“ and „steady state“ periods. During the running-in period, the wear rate decreases very rapidly with increasing sliding distance. During the steady state period, the wear decreases at a slower rate with increasing sliding distance. The results indicate that the percentage of reinforcements has a marked effect on the wear rate. The wear rate of the composite specimens decrease with increasing percentage of reinforcements particulate. As expected, the wear rate of a composite specimen with a fixed percentage of reinforcements increases with increasing load as shown in Fig.4. At constant applied load, the composite specimens exhibit a lower wear rate compared with the unreinforced alloy.

4.2 Coefficient of Friction

The Coefficient of Friction of test specimens obtained from the frictional force of the specimens during sliding is plotted against percentage of reinforcements and sliding distance in Fig5 for applied load of 50N . In the figure, Coefficient of Friction of unreinforced alloy and five different composite specimens with varying percentage of reinforcements (5 to 25%) are shown.

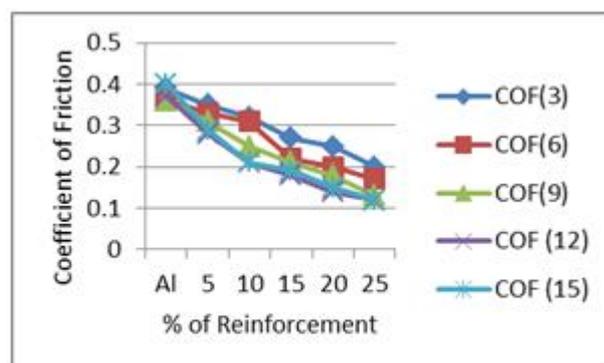


Fig 5 coefficient of friction Vs reinforcement

Fig .5 shows the variation in the coefficient of friction with varying reinforcement for Al6061 alloy and its hybrid composites. Al6061 alloy possesses lower coefficient of friction when compared with the hybrid composites . This

improvement in the anti-frictional behavior of the hybrid composite can be mainly attributed to the excellent lubricating property of reinforcements. The coefficient of friction of both Al alloy and its composites decreases with increased loads.

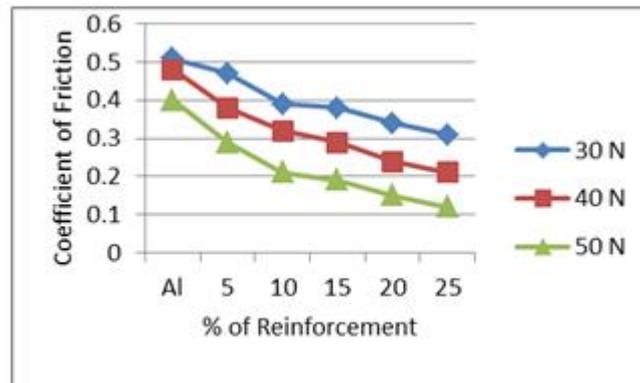


Fig 6 coefficient of friction Vs load

Fig .6 shows the variation in the coefficient of friction with applied loads and reinforcement for Al6061 alloy. It is observed that the coefficient of friction is maximum at a load of 30N for both the matrix alloy and its composites. However the 25% of reinforced hybrid composite possesses the lowest coefficient of friction at this load. It is found that the friction coefficients are in the range of 0.15–0.53. Generally, for Al6061 alloy and all hybrid composites, with the increase in the applied load, the friction coefficient decreases. It can be noted that the load effect on the wear rate is as intense as on the friction coefficient.

4.3 Hardness

The results of hardness measurements of the composite specimens is shown in Fig.7. The plots in Fig.7 clearly show that the hardness (HV) of the composite specimens increase with increasing volume percentage of particulate reinforcement. This may be attributed to the solid solution hardening of the matrix by the addition of reinforcements to the alloy.

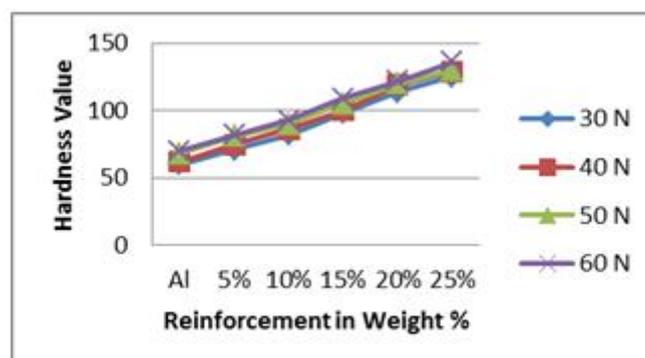


Fig 7 Hardness of unreinforced alloy and composite

4.4 Micron structural Studies

The optical micrographs of 10% and 20% reinforced specimen are shown in Fig.8. The microstructure analysis of these specimens shows that reinforcement particle is uniformly distributed in the matrix. However, the presence of porosity around the reinforcement particles was evident. This observation may be attributed to wetting behavior of Al alloy. It is

also observed from the optical micrographs that the porosity of the specimens increase with increasing volume fractions of the particulate reinforcement.



Fig.8 (a)Al alloy + 10% reinforcement

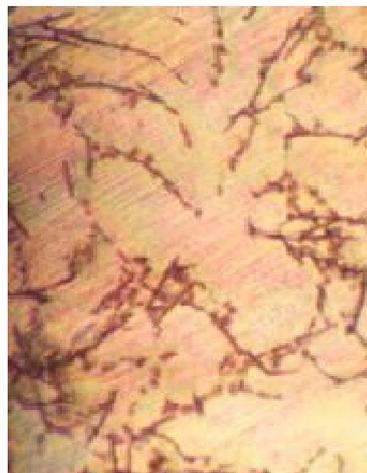


Fig.8b Al alloy + 20% reinforcement

V. OPTIMIZATION

5.1 Taguchi technique

Table 1: Process parameter and level

Level	Load (N)	Time (min)	Percentage of reinforcement (wt%)
1	30	03	05
2	40	09	15
3	50	15	25

Dry sliding wear test were carried out using pin-on-disc type wear tester at different parameters like applying load, sliding time and percentage of reinforcement were varied in range given in table 1

Table 2: Orthogonal array $L_9(3^3)$ of Taguchi method

$L_9(3^3)$	load	Time	Percentage of reinforcement
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

The experiments were conduct as per the standard orthogonal array[8,10,11]. 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 $L_9(3^3)$ orthogonal array was chosen as shown in figure , which has 09 rows corresponding to the number of tests (9 degrees of freedom) and 03 columns at three levels and three factors, as shown in Table 2

The wear parameters chosen for the experiment are (i) applied load (ii) sliding time and (iii) percentage of reinforcement of SiC and Al_2O_3 materials and (iv) sliding speed. As the speed is constant it is not consider for process parameter. The experiment consists of 09 tests (each row in the L_9 orthogonal array) and the columns were assigned with parameters

.First column was assigned to the applied load (L), second column was assigned to the sliding time (T) and third

column was assigned to the percentage of reinforcement (R). 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. 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,

$$(S/N) = -10 * \log 1/n (\sum Y_i^2) \text{ -----Eqn (1)}$$

coefficient of friction. It is suggested that quality characteristics are optimised when the S/N response is as smaller as possible.

Where „n“ is the numbers of observations, „Y_i“
value of wear rate and
is the measured

Table 3: Orthogonal array and result

Load (N)	Time (min)	Percentage of reinforcement (wt%)	Wear rate (mm ³ /m)	S/N ratio of wear rate	Coefficient of friction	S/N ratio of Coefficient of friction
30	03	5	0.025	32.0412	0.55	5.1972
30	09	15	0.010	40.000	0.40	7.9588
30	15	25	0.004	47.9588	0.31	10.1728
40	03	15	0.029	30.7520	0.35	9.1186
40	09	25	0.009	40.9151	0.25	12.0412
40	15	5	0.029	30.7520	0.38	8.4043
50	03	25	0.029	30.7520	0.20	13.9794
50	09	5	0.035	29.1186	0.31	10.1728
50	15	15	0.035	29.1186	0.19	14.4249

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 R 16 as specially utilized for the design of experiment

and statistical analysis of experiment appliances [9]. The influence of controlled process parameters such as 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 3

Table 4: Response for signal to noise ratio-smaller is better (wear rate)

Level	Load	Time	% of reinforcement
1	40.00	31.18	36.64
2	34.14	36.68	33.29
3	29.66	35.94	39.88
Delta	10.34	5.50	9.24
Rank	1	3	2

Table 5: Response for signal to noise ratio-smaller is better (coefficient of friction)

Level	Load	Time	% of reinforcement
1	7.775	9.430	7.923
2	9.855	10.058	10.501
3	12.859	11.001	12.064
Delta	5.084	1.570	4.141
Rank	1	3	2

It is evident from the tables that, among these parameters, load is a dominant factor on the wear rate and coefficient of friction. The influence of controlled process parameters on wear rate and coefficient of friction are graphically represented in figures 9 and 10.

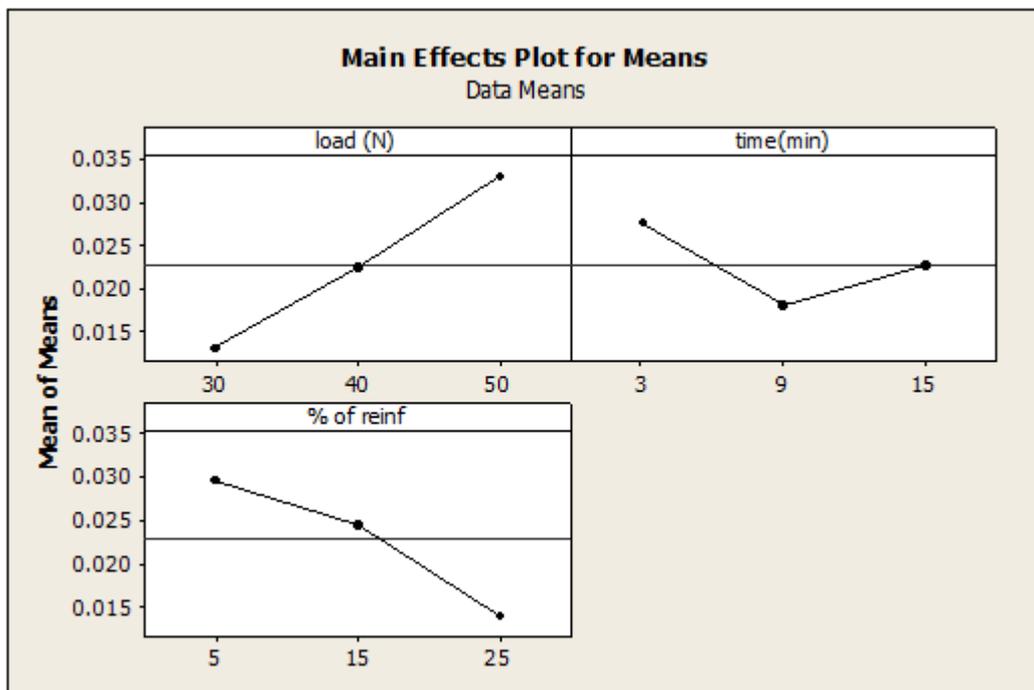


Figure 9a: Main Effects Plot for Means – Wear Rate

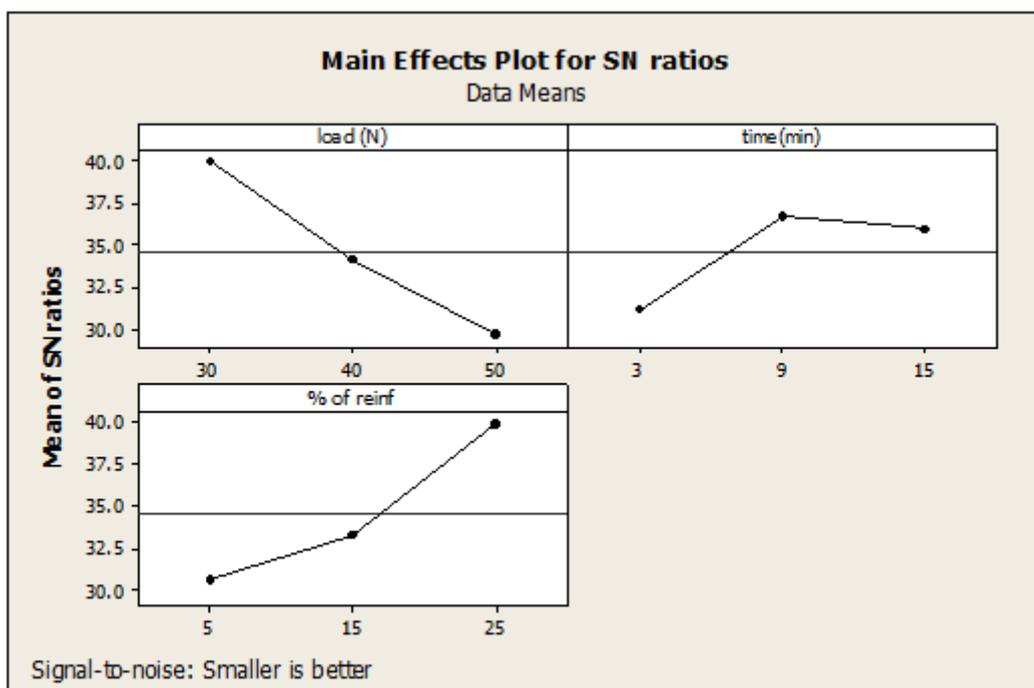


Figure 9b: Main Effects Plot for S/N Ratios – Wear Rate

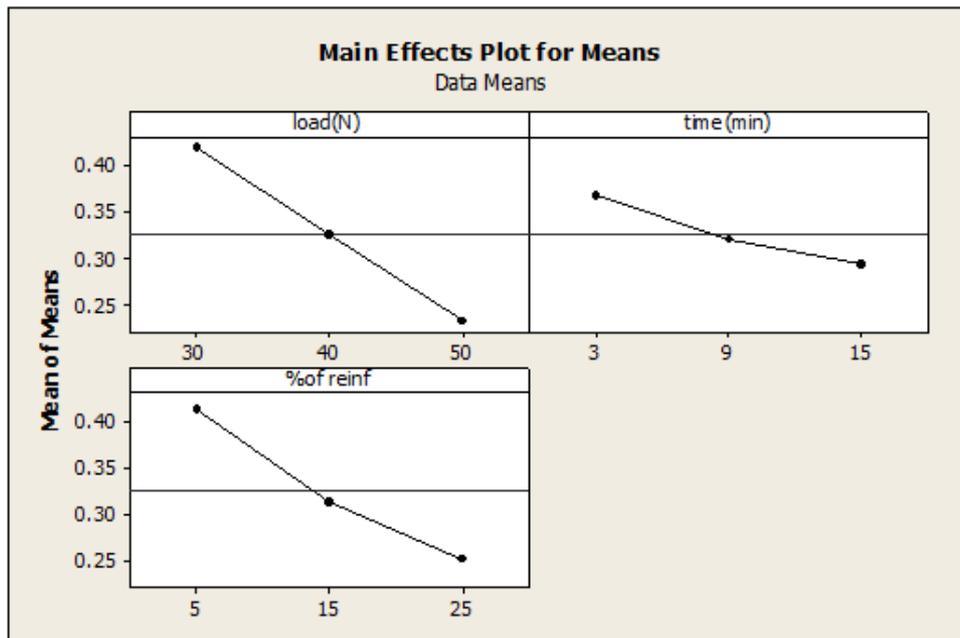


Figure 10a: Main Effects Plot for Means – Coefficient of Friction

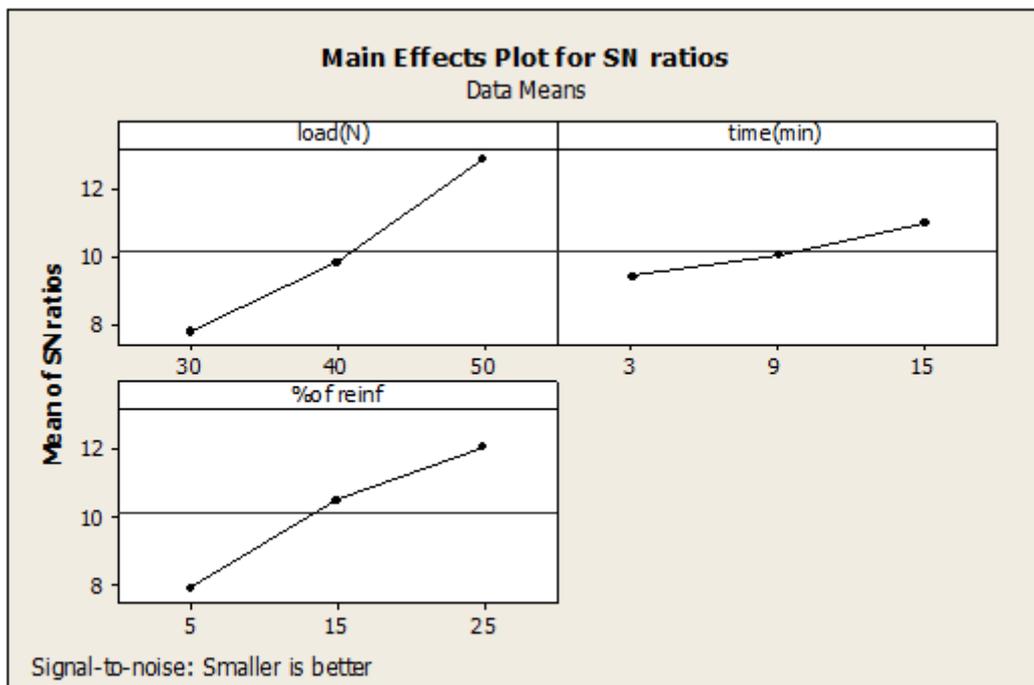


Figure 10b: Main Effects Plot for S/N Ratios – Coefficient of Friction

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 figure 9 and 10. The figures clearly indicate that the third level of load, first level of time and third level of percentages of reinforcement are the optimum points. Hence the optimum conditions tested separately and the results are given in table 6

Table 6a: Optimum level process parameter for wear rate

s.no	Speed rpm	Load N	Time min	%of reinforcement	Wear rate mm ³ /m	S/N ratio for wear rate(db)
1	400	30	9	25	0.008	41.9382

Table 6b: Optimum level process parameter coefficient of friction

s.no	Speed rpm	Load N	Time min	%of reinforcement	Co. eff friction	S/N ratio for wear rate(db)
1	400	50	15	25	0.12	18.416

VI. ANALYSIS OF VARIANCE

Table 7 shows the results of the analysis of variance on the wear rate for SiC and Al₂O₃ particulates reinforced Al-6061 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.

Table 7: ANOVA for wear:

Factor	Dof	S _{.sq}	Mean S _{.sq}	F _{.Test}	P test	Pr
load	2	0.000600889	0.000300444	2704	0.00037	53.366239
time	2	0.000140222	7.01111E-05	631	0.000578	12.438302
%of reinforcement	2	0.000384222	0.000192111	1729	0.000578	34.116486
err	2	2.22222E-07	1.11111E-07			0.0789
total	8					99.921027

From table 7, one can easily observe that the load factor has greater influence on wear rate (Pr-L=53.366239%). Hence applying load is an important control process parameter to be taken into account while wear process. Applied load is further followed by percentage of reinforcement (Pr-R=34.116486%) and sliding time (Pr-T=12.438302%).

Table 8: ANOVA for coefficient of friction:

Factor	Dof	S.sq	Mean S.sq	F.Test	P test	Pr
load	2	0.05226	0.02613	653.25	0.001528	52.2845
time	2	0.00826	0.00413	103.25	0.009592	8.196
vol.fr	2	0.0392	0.0196	490	0.002037	39.198
err	2	0.00008	0.00004			0.3222
total	8					99.678

From table 8, one can clearly infer that the load factor has greater control on coefficient of friction (Pr-L = 52.2845%)

VII. MULTIPLE LINEAR REGRESSION MODELS

Statistical software MINITAB R16 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 than the other factors. This parameter is then followed by load (Pr-R=39.198%), time (Pr-T=8.196%)

The regression equation developed for wear rate is,

$$\text{Wear} = -0.00172 + 0.0100 \text{ load} - 0.000417 \text{ time} - 0.000783 \text{ vol.fr. } R\text{-Sq}(\text{adj}) = 85.1\%$$

The regression equation developed for coefficient of friction is,

$$\text{Co. eff friction} = 0.875 - 0.0933 \text{ load} - 0.00611 \text{ time} - 0.00800 \text{ vol.fr. } R\text{-Sq}(\text{adj}) = 98.3\%$$

VIII. CONCLUSION

The present investigation on the effect of reinforcement content on the wear behavior of Al alloy hybrid composites led to the following conclusions:

- (1) The heat loss can be controlled, the oxidation reaction can be avoided and time consumption can be reduced if the stir casting setup is carried in a closed atmosphere in presence of argon & krypton gas.
- (2) The solidification becomes rapid at time of pouring in the die, in order to avoid that the die is to be preheated to more or less control the rapid solidification. Temperature maintenance, Solidification rate & proper distribution of reinforcement is hard even at 25% of reinforcement because of hybrid composite.
- (3) The reinforcement of Al alloy with reinforcement particulates upto a volume fraction of 25% has a marked effect on the wear rate. The wear rate and coefficient of friction decreases with increasing percentage of reinforcements.
- (4) The coefficient of friction and wear rates of the hybrid composites are less when compared with the matrix alloy and the individual composites.
- (5) The hardness of the composite specimens measured after the wear test increases with the increasing percentage of the reinforcements.

- (6) The optical micrographs of hybrid composites produced by stir casting method show that the distribution of reinforcement particulates in the metal matrix is uniform. The porosity of the test specimens increases with increasing percentage of particulate reinforcement.
- (7) Optimum wear rate and coefficient of friction were obtained from the experiment. The wear rate and coefficient of friction are dominated by different parameters in the order of applied load, percentage of reinforcement and sliding time. ANOVA test concluded that for that optimal result load contribution is maximum followed by volume fraction and time
- (8) If this specimens under goes heat treatment, hardness will get improve compare to current condition

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