Optimization of Process Parameters for Wear rate of Magnesium Hybrid Metal Matrix Composites using Taguchi method

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Abstract : Magnesium and its composites were widely used in aerospace and automobile industries due to the lower density. In present work, Magnesium is used as the base metal matrix. Silicon carbide (SiC) and Alumina (Al_2O_3) with varying 5-15 wt% is used as the reinforcing materials. Magnesium hybrid metal matrix composites samples were prepared by powder metallurgy route. A pin on disc apparatus was used to carry out the wear test. Taguchi technique was used to determine the effects of percentage of reinforcements, sliding speed and applied load on wear rate of composites. The results revealed that the weight percentage of reinforcements was the most dominant factor influencing the wear rate followed by load and speed. Also it was found that as applied load and speed of rotating disc increases, wear rate also increases and at 10% reinforced composite has less wear rate.

***Keywords* – Magnesium, Powder metallurgy, Hybrid MMC, Taguchi method, Dry sliding wear.**

I. INTRODUCTION

Particulate reinforced metal matrix composites have combination of low density, high wear resistance, better stiffness & strength and isotropic properties [1]. The magnesium alloys and composites have become promising materials due to their attractive properties. Magnesium metal matrix composites reinforced with hard ceramic particles has emerged as a potential material for wear resistance and weight critical applications.

Many of our modern technologies need materials with extraordinary combinations of properties that cannot be accomplish by the traditional metal alloys, polymeric materials and ceramics. This is especially true for materials that are essential for transportation and aerospace applications. A composite is considered to be any multiphase material that exhibits a significant proportion of the property of both constituent phases such that a better combination of properties is realized [2].

In the course of recent decades, metal matrix composites (MMCs) have been changed from a point of scientific interest to a material of commercial significance. MMCs offer an interesting balance of mechanical and physical properties. Several methods are employed to fabricate Magnesium metal matrix composites including stir casting, squeeze casting, infiltration and mechanical alloying, powder metallurgy. Among these, powder metallurgy technique is most likely used to fabricate Mg metal matrix composites.

The purpose of developing magnesium metal matrix composites is to combine the significant properties of ceramics and metals. However, there are some restrictions in developing better quality of metal matrix composites. One of the major difficulty is to achieve excellent bond between metal matrix and reinforcement particles. The powder metallurgy technique can achieve a more uniform distribution of particulates in the metal matrix and the composites can fabricate from powders without passing through a fully melting state.

II. EXPERIMENTAL DETAILS

2.1 Materials

The magnesium is used as a matrix material for the preparation of composite material. Magnesium has good mechanical properties and is more compatible with the reinforcement. Alumina is used as a reinforcing material, which is more stable with magnesium and withstands high temperature. It is an oxide ceramic having low affinity for the oxygen to form oxides. The Silicon carbide has been selected as the another reinforcement. It has good lubricating effect along with it reduces the noise and vibration during the relative motion.

2.2 Preparation of Composites

The atomized magnesium powder particle of size 63µ, silicon carbide 122µ and aluminium oxide 74µ, were bought from Neeraj industries, Rotak, India. By using ball mill apparatus silicon carbide and aluminum oxide blended thoroughly with magnesium metal powder for different composition to accomplish a uniform distribution of powder. After blending, compaction of powders has been done with the help of die and punch having close tolerances as shown in the fig 2. The mixed powder is poured into the hollow space of die and compacted by punch using Universal Testing Machine to prepare the green compacts. The test green compacts thus prepared were sintered in a vacuum furnace of 530^{0}C for 150 min at the heating rate of 13^{0}C/hour and it was allowed to cool to room temperature in the furnace itself. Figure 1 shows test ready specimens after sintering. In general metals are sintered at 70-90% of the melting point temperature. Sintering of powder sequentially involves the establishment and development of bonds between the particles of powder at their areas of contact. Composite specimens are fabricated with silicon carbide and alumina in different proportions in the magnesium metal matrix.

Figure 1: Specimen after sintering

Figure 2: Compaction of powder by using UTM

The Magnesium metal matrix composites were prepared for various compositions are as shown in Table 1

Table 1 Specimen Composition

Specimen code	Magnesium (%)	Silicon carbide (%)	Aluminium oxide (%)
A	90	5	5
B	80	10	10
C	70	15	15

2.3 Experimental Setup and Procedure

Dry sliding wear test was carried out for the different composition of specimens, using pin-on-disc type wear testing machine by considering more number of parameters such as load, speed and percentage of reinforcements, which affect the wear mechanism and wear rate. The pin samples which are obtained after machined and polished were cleaned with acetone and samples are weighed using a digital weigh scale. The pin sample was then held and pressed against the rotating steel disc during the test. At the end of each test, the pin sample was again weighed and the difference between the initial and final mass of the sample provides mass loss due to wear. The wear rate of the samples was then calculated.

2.4 Plan of Experiments

Wear behavior of the composite were studied as per L9 orthogonal array which has 9 rows and 3 columns by conducting dry sliding wear test. The wear process parameters were applied load, sliding speed and percentage of reinforcement. The process parameters and levels are shown in the table 2.

Table 2 Process parameters with their levels

Process parameter	Code	Units	Level 1	Level 2	Level 3
Load	L	N	19.62	39.24	58.86
Speed	S	Rpm	200	400	600
Reinforcement	R	Wt%	5	10	15

III. RESULTS AND DISCUSSION

3.1 Dry Sliding Wear Behaviour

Based on L9 orthogonal array, dry sliding wear rate of magnesium metal matrix composites was calculated and their results are tabulated in table 3.

Table 3 Wear Experimental details

Sl.No	Load (N)	Speed(Rpm)	%wt reinforcement	Wear rate (mm^3/m)
1	19.62	200	5	0.0026455
2	19.62	400	10	0.0008139
3	19.62	600	15	0.0096273
4	39.24	200	10	0.0018843
5	39.24	400	15	0.0095962
6	39.24	600	5	0.0091533
7	58.86	200	15	0.0094400
8	58.86	400	5	0.0102920
9	58.86	600	10	0.0056279

3.2 Signal to Noise Ration Analysis

Signal to noise ratio analysis was used to determine the influence of process parameters such as applied load (L), sliding speed of rotating disc (S) and percentage of reinforcements (R) on wear rate. Process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance. These analysis was been done by using MINITAB-17 software. The S/N ratio was determined based on "smaller the better" characteristic given by taguchi and as follows.

$$S/N\ Ratio = -10\log_{10}(1/n \sum y^2) \quad (1)$$

Where, 'n' = number of tests in a trial
'y' = Response value

The S/N ratio was calculated by using above equation (1) and tabulated in the below table 4.

Table 4 S/N Ratio for sliding wear rate

L9 Array	SN Ratio (db)
1	51.5498
2	61.7886
3	40.3299
4	54.4970
5	40.3580
6	40.7684
7	40.5006
8	39.7500
9	44.9931

Table 5 shows Response table for S/N ratio, where delta values were used to determine the most affecting process parameter on the wear rate. Larger the delta value, higher is the influence of that parameter on the wear rate. From the table 5, it is found that influence of percentage of reinforcement is higher on the wear rate of magnesium metal matrix composites.

Table 5 Response table for S/N ratio

Level	Load	Speed	%wt reinforcement
1	51.22	48.85	44.02
2	45.21	47.30	53.76
3	41.75	42.03	40.40
Delta	9.47	6.82	13.36
Rank	2	3	1

3.3 Influence of Process Parameters on Wear rate

The influence of load, speed and percentage of reinforcement on wear rate was analyzed with the help of main effects plot of Mean and S/N ratio as shown in fig 3 and 4.

Figure 3: Main Effects Plot for Means

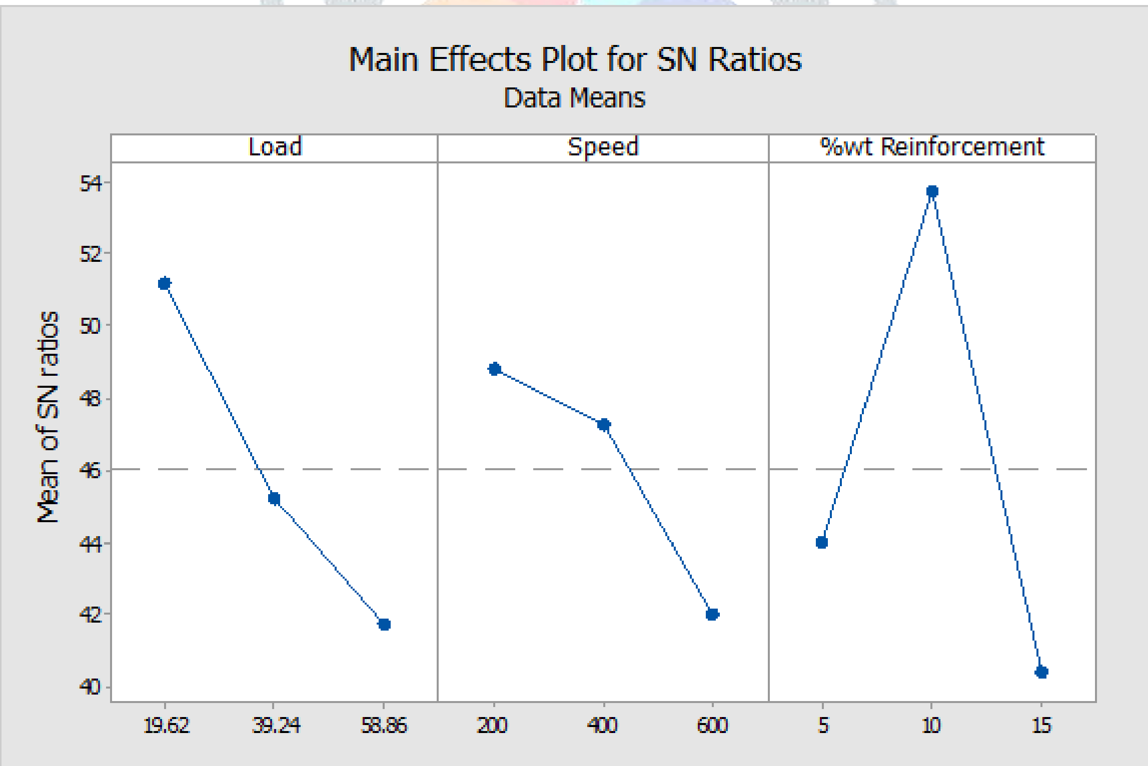

Figure 4: Main Effects Plot for S/N ratio

From fig 3, as the applied load increases, the contact between the disc and composite surface increases, thus the wear rate of the composite also increased. As the speed of rotating disc increases, the wear rate of the composites increased due to the non uniform contact between the rotating disc and surface of composite. As the percentage of reinforcement increased from 5wt% to 10wt%, wear rate of composites decreased due to the large amount of harder reinforcement particles. As the percentage of reinforcement increased from 10wt% to 15wt%, wear rate of composites increased due to the improper distribution of reinforcement particles into the matrix. From the main effect plot for S/N ratio (fig 4), it was found that a factor combination of $A_1B_1C_2$ gives minimum wear rate. This implies the selection of Load 19.62N, speed of 100rpm and 10% reinforcement for minimum wear rate.

3.4 Analysis of Variance

Analysis of variance (ANOVA) was used to analyze the influence of process parameter like applied load, speed, and percentage of reinforcement on the wear rate (Table 6).

Table 6 ANOVA test results for sliding wear rate

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Percentage Contribution (%)
Load	2	0.000026	0.000013	9.75	0.093	21.84
Speed	2	0.000019	0.000009	7.12	0.123	15.96
%wt reinforcement	2	0.000072	0.000036	27.40	0.035	60.50
Error	2	0.000003	0.000001			2.52
Total	8	0.000119				

The ANOVA analysis was undertaken for a confidence level of 95% with significance of 5%. The percentage of contribution for each process parameter was shown in last column of ANOVA table. From the table 6, it was found that %wt Reinforcement (60.50%) is the most influencing parameter on wear rate followed by applied load (21.84%) and sliding speed (15.96%). Total error associated in this analysis is around 2.52 %.

3.5 Regression Analysis

By using MINITAB statistical software, a linear regression equation was developed. This analysis attempts to determine the correlation between response variable and the predicted variable. The regression equation for sliding wear rate of composite is as follows.

$$\text{Wear rate} = -0.00320 + 0.000104\,L + 0.000009\,S + 0.000219\,R$$

Where, L is applied load in N, S is sliding speed in rpm, R is the percentage of reinforcement in %.

The confirmation tests were conducted in order to validate the regression equation for the optimum parameter as shown in table 7 and dry sliding wear test was performed for the chosen parameters.

Table 7 Results for Confirmation Experiment

Test No.	Load	Speed	%wt reinforcement	Experimental Wear rate (mm^3/m)	Regression Wear rate (mm^3/m)	Error (%)
1	19.62	200	10	0.002639	0.002830	6.74

In the table 7, comparison was made between regression wear rate values and the experimental wear rate values. It was found that the regression wear rate value is closely similar to the experimental wear rate value. The error between the experimental value and the regression model value was less. Hence, the developed regression model showed an effective approach to predict the wear rate of composites.

IV. Conclusion

Using powder metallurgy route, alumina and silicon carbide particles were successfully reinforced into a magnesium metal matrix to fabricate hybrid metal matrix composite. Taguchi method was used to analyze the wear process parameters and it was found that percentage of reinforcement (60.50%) has the highest influence on the dry sliding wear rate than the other parameters applied load (21.84%) and sliding speed (15.96%). From the main effects plot, it was found that L=19.62N, S=200rpm, R=10wt% gives minimum wear rate. The closeness of the results of experimental values and predicted values based on regression model shows that taguchi method provides a systematic and effective methodology for the optimization of the wear parameters.

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