Experimental investigation on wear process parameters of magnesium metal matrix composites using Taguchi method

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Abstract : The present study examines the influence of wear parameters such as sliding speed, load applied and sintering temperature on dry sliding wear of silicon carbide (10 wt%) and alumina (10 wt%) particles reinforced magnesium metal matrix composites. The design of experiment approach was employed to acquire data using Taguchi technique in a controlled manner. The dry sliding wear test was carried out using a pin - on - disk apparatus., signal-to-noise ratio, orthogonal array and analysis of variance were used to determine the wear behavior of magnesium MMC's. It was determined that applied load was the most significant parameter influencing the wear rate followed by sliding and sintering temperature.

***Keywords* - Magnesium MMC's, Wear rate, Orthogonal Array, ANOVA, Taguchi Method.**

I. Introduction

Metal - matrix composites (MMCs) are increasingly being used in many of today's industries. In particular, the aluminum based mmc's are recommended their use in many components of automotive and aerospace due to the high specific strength and stiffness. Wear - resistant ceramic - reinforced Al MMCs were also used in automobile components such as, piston rings, brake rotors and cylinder liners. However, the persistent effort by the aerospace and automotive sectors to push performance limits consistently challenge the vital issue of weight reduction. Magnesium (Mg), which has a density of about two - thirds that of aluminum, is the lightest metal structural material. In the future, magnesium - based MMCs would provide attractive alternatives to Al MMCs.

The Taguchi technique is a powerful experimental tool designed to acquire data in a controlled manner and analyze the influence of process variable over certain specific variable that is unknown to these process variables and to design high-quality systems. Researchers successfully used this method in the study of wear behaviour of metal matrix composites. The objective of this technique is to make the products robust in terms of parameters influencing. Taguchi creates a standard orthogonal array to accommodate the effect on the target value of several factors and defines the experiment plan. To study the influence of parameters, the experimental results are analyzed using analysis of means and variance.

Magnesium metal matrix composites are designed to combine the important properties of ceramics and metals. However, the development of better quality of metal matrix composites has some restrictions. The achievement of an excellent bond between metal matrix and reinforcement particles is one of the major challenge.

II. Materials and Methods

In the present work, alumina (10 wt%) and silicon carbide (10 wt%) were added to magnesium metal. Powder metallurgy technique was employed for fabrication of composites. Basic steps in powder metallurgy process like blending of powders, compaction and sintering were carried out for each specimen. The composites were prepared from pure magnesium (99.7%) powder, high purity silicon carbide and alumina powders. powders were blended in a ball mill apparatus and poured into a die cavity. Then these powders are compacted in a universal testing machine at high pressure. the obtained green compacts were sintered in a furnace at a temperature 500°, 530° and 550°C. These composites were then cut into small pieces and machined for wear testing purposes to the required pin diameter of 10 mm and length of 30 mm. Using emery paper of 400, 600 and 1000 grade, polishing was done for all pins before wearing testing. The counter surface disc was cleaned with acetone before conducting the wear test. The pin samples obtained after being machined and polished have been cleaned with acetone and a digital weighing scale is used to weigh samples. Then the pin sample was held and pressed during the test against the rotating steel disk as shown in fig 1. The pin sample was weighed again at the end of each test.

The experiments were conducted as per the standard L9 orthogonal array for various parameters. The parameters selected for the experiment were Load in N, sliding speed in rpm and sintering temperature in °C. The each parameter was assigned three levels which are shown in Table 1. As shown in Table 2, the standard L9 orthogonal array consists of nine tests. The first column is assigned by applied load, second column was assigned by sliding speed and third column was assigned by sintering temperature. The response studied was wear in terms of grams with the goal of quality characteristic "smaller is the better" type.

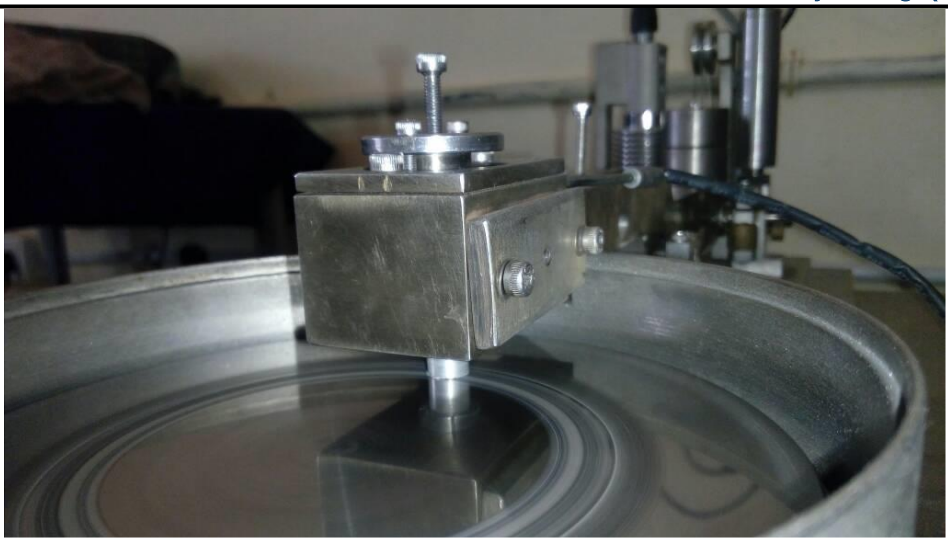

Figure 1: Specimen held and pressed during the test against the rotating steel disc in the wear testing machine

Table 1 Selection of Process Parameters and their Levels

Process parameters	Level 1	Level 2	Level 3
Load (N)	19.62	39.24	58.86
Speed (rpm)	200	400	600
Sintering Temperature (^{0}C)	500	530	550

Table 2 Orthogonal array for wear test

Sl. No.	Load (N)	Speed (Rpm)	Sintering Temperature (^{0}C)	Volumetric Wear rate (mm^3/m)
1	19.62	200	500	0.0001033
2	19.62	400	530	0.0008139
3	19.62	600	550	0.0009102
4	39.24	200	530	0.0008843
5	39.24	400	550	0.0038664
6	39.24	600	500	0.0046444
7	58.86	200	550	0.0047973
8	58.86	400	500	0.0069189
9	58.86	600	530	0.0086279

III. RESULTS AND DISCUSSIONS

3.1 S/N Ratios Analysis

The Signal to Noise ratio response analysis was used to evaluate the influence of control parameters such as applied load (L), sliding speed (S), and sintering temperature (T) on wear rate. Process parameter settings with the highest S/N ratio always provide the optimum quality with minimum variance. The selected characteristic of sliding wear quality was smaller is the better type and the same type of response was used for the ratio of signal to noise given below.

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

The S/N ratio response was analyzed with the above Equation for all nine experiments and presented in Table 3. Response table for S/N ratio were presented in table 4, where delta values were used to verify the most affecting process parameter on the wear rate. From the table 4, it is found that wear rate is higher influenced by the applied load, followed by sliding speed and sintering temperature. Fig 2 and 3 shows main effects plot for means and s/n ration of wear rate graphically. From the figures it is evident that the wear rate increases with the increasing the applied load and sliding temperature. wear rate decreases with the increasing of sintering temperature.

Table 3 Orthogonal array for wear test

L9 Array	S/N ratio (db)
1	79.7180
2	61.7886
3	60.8173
4	61.0680
5	48.2539
6	46.6614
7	46.3801
8	43.1993
9	41.2819

Table 4 Response table for S/N ratio of wear rate

Levels	Factors		
	Load (A)	Speed (B)	Sintering Temperature (C)
1	67.44	62.39	56.53
2	51.99	51.08	54.71
3	43.62	49.59	51.82
Delta	23.82	12.80	4.71
Rank	1	2	3

Figure 2: Main Effects Plot for mean of Wear rate

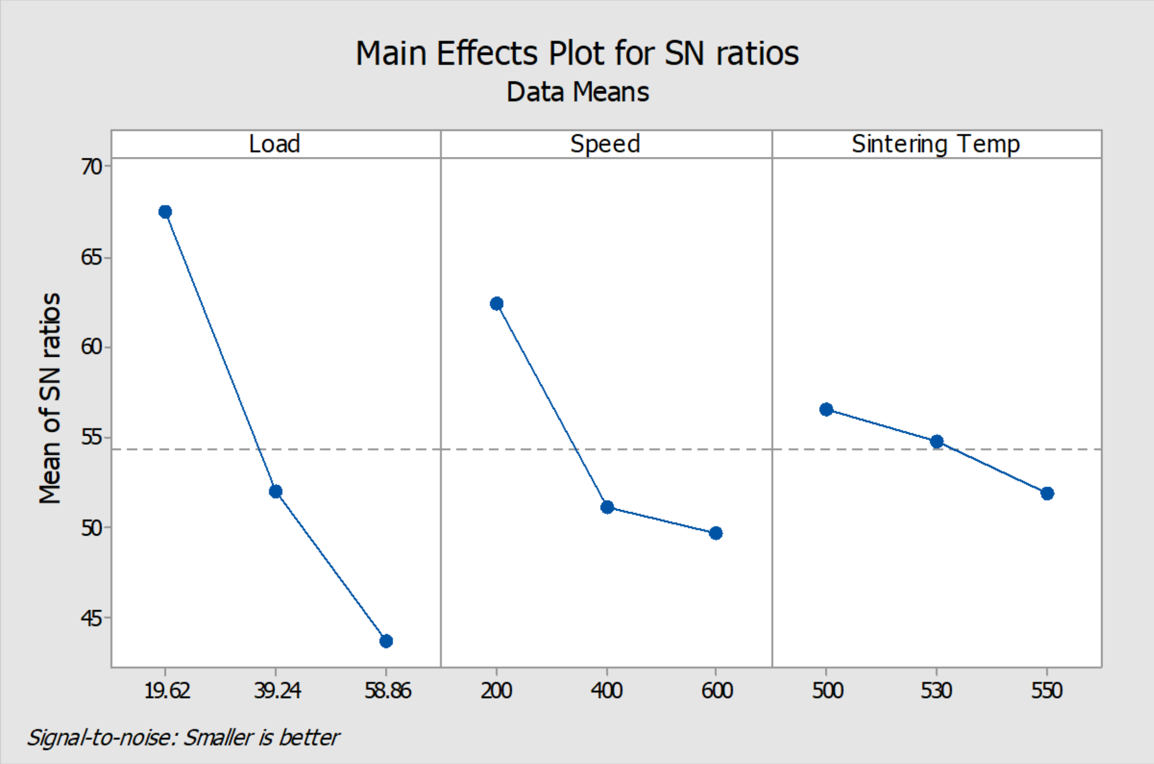

Figure 3: Main Effects Plot for S/N ratio of Wear rate

3.2 ANOVA Analysis

The analysis of variance (ANOVA) has been used to analyze the influence of parameters like applied load, sliding speed and sintering temperature. The ANOVA determines the relative significances of parameters in terms of their percentage contribution to the response. Table 5 show the results of ANOVA analysis. it is observed from ANOVA analysis table that influence of applied load, sliding speed and sintering temperature on wear rate of magnesium metal matrix composites. The last column of Table 5 shows the percentage contribution of each parameter to the total variation showing their degree of impact on the outcome. One can observe from the ANOVA Table that the applied load (79.45%) and sliding speed (16.43%) have great influence on the wear of the composite material.

Table 5 Response table for S/N ratio of wear rate

Source	**DF**	**Adj SS**	**Adj MS**	**F**	**P**	**Contribution (%)**
Load (A)	2	0.000058	0.000029	22.66	0.042	79.45
Speed (B)	2	0.000012	0.000006	4.84	0.171	16.43
Sintering Temperature (C)	2	0.000001	0.000000	0.29	0.773	1.36
Error	2	0.000003	0.000001			4.10
Total	8	0.000073				

3.2 Regression Analysis and Confirmation Test

A linear regression equation was developed through the use of statistical software from MINITAB. This analysis tries to determine the correlation between the response variable and the predicted variable. The equation of regression for wear rate of composite is as follows.

$$\text{Wear rate} = 0.00192 + 0.000157\,L + 0.000007\,S - 0.000014\,T$$

Where, L is applied load in N, S is sliding speed in rpm, T is the sintering temperature in °C.

Comparison of regression wear rate values with experimental wear rate values was made in Table 6. The regression wear rate value was found to be closely similar to the wear rate value of the experiment. There was less error between the experimental value and the value of the regression model. Therefore, the regression model developed demonstrated an effective approach to predicting composite wear rates.

Table 6 Results for Confirmation Experiment

Test No.	**Load**	**Speed**	**Sintering Temperature**	**Experimental Wear rate (mm^3/m)**	**Regression Wear rate (mm^3/m)**	**Error (%)**
1	39.24	200	500	0.0023539	0.00248068	5.11

IV. CONCLUSIONS

Alumina and silicon carbide particles were successfully reinforced into a matrix of magnesium metal to fabricate hybrid metal matrix composite using the powder metallurgy technique. The DOE technique is successfully used to dry sliding wear behaviour of silicon carbide and alumina particles reinforced magnesium MMCs. The ANOVA analysis shows that the applied load (79.45 %) and sliding speed (16.43 %) have significant influence on wear of composites in dry condition. From the main effects plot, it was found that L=19.62N, S= 200rpm, T=530ºC gives minimum wear rate. A linear regression model was successfully developed to forecast the wear rate of the composites. The closeness of prediction results based on calculated S / N ratios and experimental values shows that the Taguchi experimental design technique can be used successfully for optimization as well as prediction. As a result, it is found that the Taguchi method's parameter design provides a effortless, systematic and efficient methodology for wear test parameters optimization.

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