International Journal of Research in Advent Technology, Vol.7, No.4, April 2019
E-ISSN: 2321-9637
Available online at www.ijrat.org

Effect of Sintering Temperature, Load and Sliding speed on the Wear behavior of Mg–SiC-Al_2O_3 metal matrix Composites using Taguchi method

Satish J[1], K.G. Satish[2]
Department of Mechanical Engineering, SJMIT, Chitradurga[1]
Department of Mechanical Engineering, UBBDTCE, Davanagere[2]
Email: satish.j17@gmail.com[1]

Abstract- In the present study, Powder metallurgy method is used to fabricate Magnesium metal matrix composites (MMCs) having Silicon carbide (SiC) and Alumina (Al_2O_3) in 15 wt%. The dry sliding wear tests were carried out on composite material using a pin-on-disc wear testing apparatus with a normal pin load of 19.62N, 39.24N and 58.86N, and wear rate for each load is calculated for different sliding speeds. By using Taguchi's design of experiments (DOE) Analytical modelling of composite material is performed with L9 orthogonal array. Analysis of Variance (ANOVA) has been used to find out the design parameters that significantly affect the composite material's wear rate. A linear regression model has been developed based on the experimental results. The resulting regression equation establishes a relationship between the significant terms obtained from ANOVA, namely applied load, sliding speed, sintering temperature and their relations.

Index Terms- Magnesium; Metal matrix composites; Taguchi; Dry sliding; Wear;

1. INTRODUCTION

Many of our recent technologies have need of materials with unusual combinations of properties that cannot be met by the conventional metal, ceramics, alloys, and polymeric materials. This applies in particular to materials needed for applications in aerospace, underwater and transportation. Strong materials are often relatively dense; in addition, they generally increase strength or rigidity [1]. Generally speaking, a composite is measured to be any multi-phase material that exhibits a significant proportion of the property of both constituent phases in order to achieve a better combination of properties. According to this standard of combined action, improved property combinations are shaped by the sensible combination of two or more distinct materials [2].

In metal-matrix composites (MMCs) the matrix is a metal. These materials can be used at higher service temperatures than their base metal counterparts; in addition, reinforcement can improve specific strength, specific stiffness, creep resistance, wear resistance, dimensional stability and thermal conductivity [8]. The Purpose of manufacturing metal matrix composite is to combine the significant properties of metals and ceramics. The function of the reinforcement in a composite material is essentially one of increasing the mechanical properties of the neat resin system. All of the different fibres / particulates used in composites have different properties and so affect the properties of the composite in various ways [12].

In this experimental work, magnesium metal matrix composites have been prepared by utilizing powder metallurgy process having 15 wt% SiC and 15 wt% Al_2O_3 and wear performance was examined with three process variables viz. applied load, sliding speed and sintering temperature in accordance with taguchi orthogonal array.

2. DEVELOPMENT OF MG - MMC'S

In this experimental work, magnesium is used as a base metal available in the form of a powder. Silicon carbide (SiC) and Alumina (Al_2O_3) was used as a reinforcement for the fabrication of composite. Silicon carbide and alumina are very hard and strong material and were used in many applications as an abrasive. The powder metallurgy process has been utilized for the development of magnesium metal matrix composites. The composites were prepared from powdered pure magnesium, high purity silicon carbide and powdered alumina. In a ball milling machine, powders were mixed and poured into a die cavity. These powders are then compacted at high pressure in a universal testing machine as shown in fig 1. The green compacts obtained were sintered in a furnace at 500 ° C, 530 ° C and 550 ° C. Wear tests on composite specimens were performed on the pin-on-disk wear testing machine in dry sliding states. The circular pin type test samples of size diameter 10mm and length 30mm were pressed against the counter rotating disc. Before wear examination began, the samples to be examined were finely polished to make a flat face and grabbed against the rotating counter-face disc. In accordance with the taguchi L9 orthogonal array design matrix, the composite specimens were subjected to dry sliding wear tests at room temperature. After each run, the samples and the rotating disk were polished to acquire error free data. The experiments were conducted for different parameters according to the standard L9 orthogonal array. Load in N, sliding speed in rpm and sintering temperature in ^oC were the parameters selected for the experiment. Three levels have been assigned to each parameter that are shown in Table 1.

Fig 1 Compaction of powders using UTM

Table 1 Process Parameters and their Levels

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

3. RESULTS AND DISCUSSIONS

For acquiring data in a controlled manner, the Taguchi technique is a dominant design of experimental tool and analyzing process variable influence over some specific variable that is an unknown function of these process variables and designing high-quality systems. Many researchers used this method successfully in the study of the wear behavior of metal matrix composites. The main advantage of this technique is to find out the possible interaction between the parameters [10]. The Taguchi technique is designed to optimize processes and to identify the optimum combination of factors for a given response [13]. In the study, the wear rate of the composite materials is predicted by selecting applied load (L), sliding speed (S) and sintering temperature (T) as control variables. Table 2 shows wear rate for the control variables.

Table 2 Orthogonal array for wear test

Load (N)	**Speed (rpm)**	**Sintering Temperature (^{0}C)**	**Volumetric Wear rate (mm^3/m)**
19.62	200	500	0.0006105
19.62	400	530	0.0007069
19.62	600	550	0.0016273
39.24	200	530	0.0095380
39.24	400	550	0.0055962
39.24	600	500	0.0039834
58.86	200	550	0.0125400
58.86	400	500	0.0131250
58.86	600	530	0.0138826

The first column of the L9 orthogonal array was assigned to applied load (L), the second column to sliding speed (S), the third column to sintering temperature (T), and the response variable to be studied is wear rate which as shown in table 2. The experimental results have been transformed into Signal-to-Noise (S/N) ratios. In the presence of noise factors, the S / N ratio shows the degree of predictable performance of a product or process. The wear rate S / N ratio is calculated using the characteristic "smaller the better," which can be calculated as a logarithmic transformation of the loss function shown in table 3. The control parameter with the strongest influence was find out by the difference in the mean of S / N ratios between the maximum and minimum value. The greater the difference between the mean S / N ratios, the more the control parameter was influential. The S / N ratio response analysis presented in Table 4 shows that the most influential and significant parameter among all factors was applied load, followed by sintering temperature and sliding speed. Figure 2 shows graphically the mean wear rate and Figure 3 shows the plot of main effects for wear rate means of S / N ratio. It can be inferred from the analysis of these results that the combination of parameters L= 19.62 N, S= 400 rpm and T= 500^{o}C gave the minimum wear rate for the range of parameter tested.

Table 3 Orthogonal array for wear test

L9 Array	**S/N ratio (db)**
1	64.2863
2	63.0128
3	55.7706
4	40.4109
5	45.0421
6	47.9949
7	38.0340
8	37.6380
9	37.1506

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

Levels	**Factors**		
	Load (A)	**Speed (B)**	**Sintering Temperature (C)**
1	61.02	47.58	49.97
2	44.48	48.56	46.86
3	37.61	46.97	46.28
Delta	23.42	1.59	3.69
Rank	1	3	2

Fig 2 : Main Effects Plot for mean of Wear rate

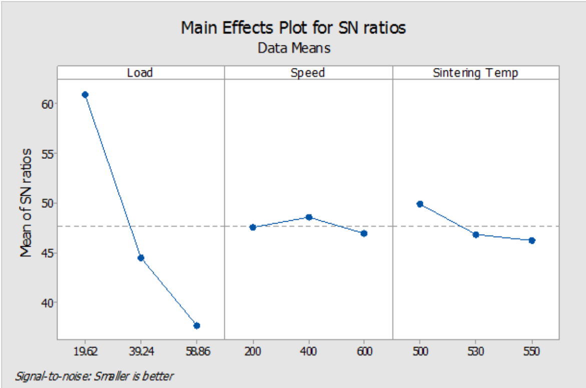

Fig 3: Main Effects Plot for S/N ratio of Wear rate

Analysis of Variance (ANOVA) be used to find out the design parameters extensively influencing the wear rate (response). From the results obtained, it can be observed that load was the most important parameter with the highest statistical influence (92.56 %) on composite dry sliding wear followed by sintering temperature (2.89 %) and sliding speed (0.82 %) which as shown in table 5.

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

	DF	Adj SS	Adj MS	F	P	Contribution (%)
A	2	0.000224	0.000112	26.68	0.036	92.56
B	2	0.000002	0.000001	0.28	0.784	0.82
C	2	0.000007	0.000004	0.85	0.541	2.89
Error	2	0.000008	0.000004			3.30
Total	8	0.000242				

By fitting a linear equation to the observed data, a linear regression analysis attempts to model the correlation between two or more predictor variables and a response variable (wear rate). Linear regression model have been developed using MINITAB 17 based on the experimental results The resulting regression equations establish a correlation between the important terms obtained from ANOVA, namely, load, sintering temperature, sliding speed and their interactions. The wear rate equation developed for regression is:

$$\text{Wear rate} = -0.0139 + 0.000311\,L - 0.000003\,S + 0.000018\,T$$

Where, L is applied load in N, S is sliding speed in rpm, T is the Sintering temperature in ^{o}C.

The above equations can be used to forecast the wear rate of the magnesium metal matrix composites. The coefficient associated with applied load (L) in the above regression equation is positive, indicating that as the load increases, the composite's wear rate also increases. The sintering temperature (T) coefficient in the regression equation is also positive, suggesting that the composite's wear rate increases with increasing sintering temperature. It can be inferred from the negative value of the coefficient associated with sliding speed (S) in the regression equation that as the sliding speed increases, wear rate of the composite decreases.

4. CONCLUSIONS

Using the Powder metallurgy technique, silicon carbide and alumina particles can be successfully introduced in the magnesium metal matrix to fabricate hybrid metal matrix composite material. Tests were performed successfully to examine the wear performance of hybrid metal matrix composite at different levels of load applied, sliding speed and sintering temperature using taguchi optimization method and it was found that applied load is the major parameter influencing the wear rate of the composite material and contributing 92.56% towards the response parameter, while factors sintering temperature and sliding speed has very less contribution towards the response parameter wear rate. A linear regression model was developed and it can be used to forecast the wear rate of the hybrid composites.

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