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Experimental Investigation on Dry Sliding Wear Behaviour of Hybrid Metal Matrix ($Al\text{-}Al_2o_3\text{-}B_4c$) Composite

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Abstract : Aluminium Metal Matrix Composites are being used in aerospace, marine and automotive industries since they give superior strength, stiffness and enhanced tribological behavior. In this investigation, Aluminium metal matrix composites reinforced with 5%wt. of Al_2O_3 and 5%wt. of B_4C particles was prepared by stir casting technology. Dry sliding wear behavior of the composite test was conducted by pin-on-disc testing apparatus. The most influence wear parameters such as applied load, sliding velocity and time period was selected. The Taguchi L27 (3^{13}) orthogonal array was selected for conducting the experiments. By using analysis of variance (ANOVA), the most influence parameters of wear rate of the composite was determined. It was found that the applied load as the most influencing the wear rate followed by the sliding velocity and time period.
Keywords: Dry sliding wear behaviour, Taguchi technique, Analysis of variance.

1. Introduction

Composite materials are materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct on a macroscopic level within the finished structure. Composite materials are formed by combining two or more materials that have quite different properties.

Wear is material removal from one surface of the component to another during relative motion between them. Prasad et al. [1] reported that adhesive wear occurs when two solid surfaces slide over one another under pressure, whereas abrasive wear may involve gouging, grooving, and plastic deformation caused by the penetration of hard abrasive reinforcement particles.

Gurcan and Baker [2] investigated the wear resistance of Al alloy-SiC composites and reported that the maximum wear resistance was observed in the composite containing 20wt. % of SiC particles. Mondal et al. [3] studied the effect of applied load, size and volume fraction of reinforcement on the abrasive wear behaviour of Al alloy–Al2O3composites. They observed that the wear rate of composite decreases linearly with increase in Al2O3 content. Fly ash particles into Al alloy showed lower wear rates compared to the Al alloy, and subsurface delamination is the main mechanism in both the Al alloy as well as in composites at higher loads. Sarkar et al. [4] concluded that the addition of magnesium increases the wettability which enhances wear resistance and mechanical properties such as hardness and tensile strength of Al-fly ash composites.

Sahin [5] conducted an abrasive wear test on Al2011 alloy with 5–10 wt% SiCp content with 32–64 lm reinforcement size. Factorial designs of experiments were used to assess the contribution of applied load, sliding distance and particle size. The abrasive wear was the response of the material running against SiCp and Al2O3 emery papers under different sliding conditions. He concluded that the wear rate of the matrix and the composite materials increased with increasing the abrasive size, applied load and sliding distance when SiC abrasive paper was used. However, the wear rate increased with increasing abrasive size and applied load and decreased with increasing sliding distance when the Al2O3 emery paper was selected.

Deuis et al. [6] In their study and discussion, the effect of reinforcement volume fraction and size, sliding distance, applied load, sliding speed, hardness of the counter face and properties of the reinforcement phase, that influences the dry sliding wear behaviour of this group of composites were examined in greater detail.

2. Experimental Details

A 900 gm of commercial aluminium (Grade: LM26) was melted in a resistance induction furnace. The melt was degassed by purging hexachloro ethane tablets when the melt temperature reached to 680º C. Simultaneously, 50 gm of boron carbide (150 µm) and 50 gm of alumina (150 µm) particles were preheated to 350º C with the aid of muffle furnace. Then the preheated silicon carbide particles and boron carbide particles were added with the melt and stirred using mild steel stirrer.The specimens were prepared from the castings for wear test analysis. The sample specimen (diameter 8mm and length 25mm) are shown in Fig. 1

3. Taguchi Technique

Taguchi method is an efficient problem solving tool, which can improve the performance of the product, process, design and system with a significant reduction in experimental time and cost. This method that combines the experimental design theory and quality loss function concept has been applied for carrying out robust design of processes and products and solving several complex problems in manufacturing industries.

The number of experiments generally increases with the increase of process parameters. To solve this complexity, Taguchi method uses a special design of orthogonal array to study the entire process parameter space with a small number of experiments only. Taguchi defines three categories of quality characteristics such as the lower-the-better, the larger-the-better and the nominal-the-best. The signal to noise (S/N) ratio for each parametric setting is computed. Regardless of the category of the quality characteristics, a larger S/N ratio corresponds to better quality characteristic. Therefore, the optimal level of process parameters promotes highest S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) can be performed to see which process parameter is statistically significant for each quality characteristic. [7]

In order to observe the influencing process parameters in wear, three process parameters namely applied load, sliding velocity and time period each at three levels were considered as listed in Table 1. A three level L27 (3^3) orthogonal array with twenty seven experimental runs was selected. Wear characteristics was considered as quality characteristics with the concept of the "smaller the better". The S/N ratio used for these types of response is given in Eq. (1)

$$S/N(dB) = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} R_i^2\right) \quad (1)$$

Where i = 1, 2… n (here n = 4) and R_i is the response value for an experimental condition.

Table 1. Parameters and their levels

Parameter	Notation	Levels		
		1	2	3
Applied Load (N)	A	20	30	40
Sliding Velocity (m/s)	B	1.571	2.618	3.665
Time Duration (minutes)	C	4	6	8

4. Resut and Discussion

Dry sliding wear test was conducted using pin-on-disc wear testing rig Fig.1. The wear loss of the composite pin material was recorded with an accuracy of 1.0 µm by the LVDT which is provided in the wear testing apparatus. Cylindrical pins (8mm diameter and 25mm height) were prepared and loaded in a computer interfaced pin-on-disc wear testing rig Fig.2. Prior to testing, the surface of the specimens was polished by using emery paper.

Fig. 1. Pin-on- disc wear testing apparatus

Fig. 2. Wear test specimen

Table 2. Experiments and S/N ratios

Exp. No.	Applied load (N) (A)	Sliding Velocity (m/s) (B)	Time Duration (minutes)	Wear rate	
				Measured value	Signal/noise ratio
1	20	1.571	4	78	-37.8419
2	20	1.571	6	84	-38.4856
3	20	1.571	8	65	-36.2583
4	20	2.618	4	91	-39.1808
5	20	2.618	6	84	-38.4856
6	20	2.618	8	80	-38.0618
7	20	3.665	4	104	-40.3407
8	20	3.665	6	91	-39.1808
9	20	3.665	8	98	-39.8245
10	30	1.571	4	71	-37.0252
11	30	1.571	6	61	-35.7066
12	30	1.571	8	49	-33.8039
13	30	2.618	4	80	-38.0618
14	30	2.618	6	74	-37.3846
15	30	2.618	8	67	-36.5215
16	30	3.665	4	86	-38.69
17	30	3.665	6	84	-38.4856
18	30	3.665	8	92	-39.2758
19	40	1.571	4	51	-34.1514
20	40	1.571	6	51	-34.1514
21	40	1.571	8	47	-33.442
22	40	2.618	4	67	-36.5215
23	40	2.618	6	60	-35.563
24	40	2.618	8	52	-34.3201
25	40	3.665	4	76	-37.6163
26	40	3.665	6	71	-37.0252
27	40	3.665	8	69	-36.777

Table 3. Average S/N ratio response

	A	B	C
Level1	-38.63	-35.65	-37.71
Level2	-37.22	-37.12	-37.16
Level3	-35.51	-38.58	-36.48
Max-Min	3.12	2.93	1.24
Rank	1	2	3
Optimum level	A3	B3	C3

The S/N ratio for each parameter is found by averaging the S/N Ratio at the corresponding level. The most influence parameters such as applied load, sliding velocity and time duration on wear rate were analyzed. Measure value and S/N ratios are shown in Table 2. Ranking of parameters is shown in Table 3. The applied load is a dominant parameter on the wear rate followed by sliding velocity and time duration.

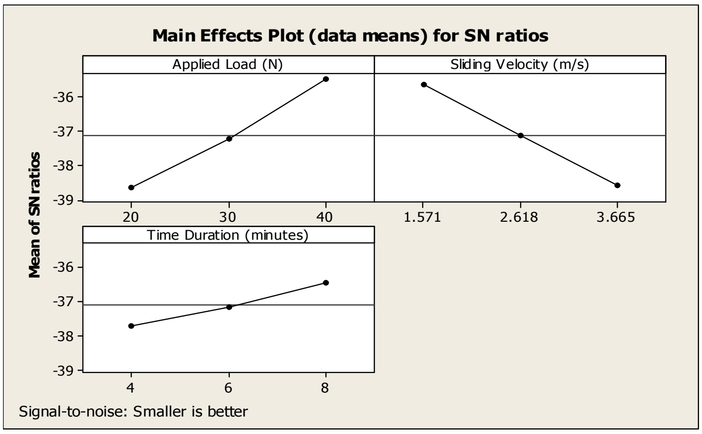

Fig. 3. Response diagram of S/N ratio

From the response diagram of S/N ratio in Figure 3, it was shown that the optimum parameters were 40 N of applied load, 1.571 m/s of sliding velocity and 8 minutes f time duration for the hybrid composites.

Table 4. ANOVA analysis for wear rate

Source	Dof	SS	MS	F Ratio	Percentage of Contribution
Applied load	2	2966.01	148305	62.99	46.42
Sliding Velocity	2	2550.22	1275.11	54.16	39.92
Time duration	2	401.56	200.78	8.53	6.30
Error	20	470.89	23.54		7.36
Total	26	6388.67			100

From the ANOVA table (Table 4), the maximum influence parameters on the wear rate were found. It can be observed that the applied load as 46.42% was the major influencing factor followed by sliding speed as 39.92% and time duration as 6.30% influencing the wear rate of hybrid composites.

The linear regression equation was developed for the wear rate of hybrid composite is given below:

$$W = 96.4 - 1.28 (A) + 11.4 (B) - 2.36 (C) \quad (2)$$

For this model, it was found that $r^2 = 0.925$ where r is correlation coefficient. The value of r^2 is indicates the closeness of the model representing the process. So, this model provides a reasonably good explanation of the relationship between the independent variables and output response (wear rate).

6. Conclusion

The following are the conclusions dawn based on the wear test conducted by pin-on-disc apparatus on hybrid metal matrix composite.

The results observe that applied load and sliding velocity were the most significant parameters followed by time duration on the wear rate. It was found that the optimum parameters for minimum wear rate were applied load 20 N, sliding velocity 1.571 m/s and time duration 8 minutes.

Form the ANOVA, applied load (46.42%) has the highest influence on the wear rate followed by sliding velocity and time duration. A linear regression model was developed to predict the wear rate of the hybrid metal matrix composites. The closeness of the results of predictions based on calculated S/N ratios and measured values on the wear rate revealed that the taguchi robust design method can be used successfully for both parameter optimization and prediction on the wear rate of the composites.

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