Tribological Behavior of AA8090/SiC Composites

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Abstract: For structural application of moving components, the tribological properties are considered to be one of the major factors controlling the performance. In the present study, AA8090 was used as a matrix material. Particulate silicon carbide was used as a reinforcing material. This investigation was carried out to understand tribological properties of SiC reinforced AA8090 metal matrix composites. Dry sliding wear tests were conducted pin-on-disc machine. Addition of hard SiC to AA8090 results in enhancement in the hardness of the composites. Increased hardness leads to lowering of wear loss and seizing. The optimum wear rate of 0.03259 mg/m can be achieved with the volume fraction of SiC should be 30%.

Keywords: Metal matrix composites, wear rate, volume fraction, applied load, sliding distance, sliding speed, silicon carbide.

1. INTRODUCTION

Particulate metal matrix composites consist of metal based materials reinforced with particulates. The metal matrix composites have substantiated to replace a number of conventional materials being used in automotive, aerospace and defense industries. Aluminum matrix composites are the encouraging materials owing to their excellent specific mechanical properties [1-4]. Metal matrix composites possess superior wear resistance compared with unreinforced aluminum alloy. A lot of research on the dry sliding wear behavior of MMCs have been reported. Tribological behavior of materials depends on many factors such as properties of material combinations, experimental condition and type of wear tester [5-11].

The present study emphases on determining the weight loss functions and wear rate of AA8090/silicon carbide metal matrix composites. The theoretically predicted wear rate values have been compared with the experimental values. In order to predict optimum wear rate based on weight loss functions and the probability statistical tests were performed.

2. MATERIALS AND METHODS

Aluminum alloy 8090 was used as matrix material. Silicon carbide (SiC) of laboratory grade was used as a reinforcing material. SiC reinforced AA8090 composites were produced using stir casting technique. The composite specimens were subjected to T-6 heat treatment standards. In order to characterize the dry-sliding wear behavior of the test specimens, wear tests were performed using a pin-on-disc machine. Circular pins of diameter 8 mm and height 30 mm were used as test specimens. The test specimen was gripped in the wear testing machine to avoid rolling during the test. The wear parameters chosen for the experiment were: volume fraction of SiC, applied load, sliding speed and sliding distance. The wear rate was studied as a function of volume fraction of SiC, applied load, sliding speed and sliding distance. Each experiment was repeated twice as per the design experiments as per Taguchi techniques [12]. The levels chosen for the controllable process parameters are summarized in Table 1. The orthogonal array, L9 was preferred to carry out wear tests experimentally (Table 2).

Table 1: Control parameters and levels

Factor	Symbol	Level–1	Level–2	Level–3
Reinforcement, vf	A	0.1	0.2	0.3
Load, N	B	10	20	30
Speed, m/s	C	1	2	3
Sliding distance, m	D	500	750	1000

. **Table 2:** Orthogonal array (L9) and control parameters

Treat N	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

The total wear of a metal matrix composite is modeled mathematically as a function of reinforcement volume fraction, applied load, sliding speed and sliding distance according to

$$W = K{v_f}^a F^b V^c S^d \quad (1)$$

where a, b, c and d are power law coefficients of reinforcement volume fraction (vf), applied load (F), sliding speed (V) and sliding distance (S), respectively. K is the empirical constant.

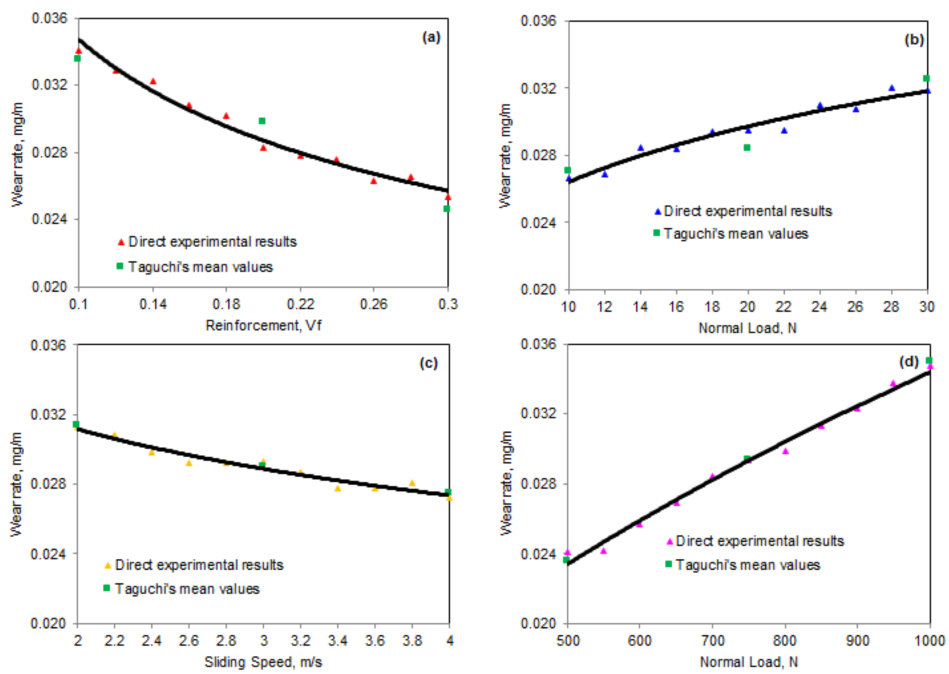

Figure 1: Influence of process parameters on wear rate.

3. RESULTS

The wear rate was decreased with increase in volume fraction of SiC in AA8090 matrix (figure 1a). This is due to high hardness of SiC as compared to soft AA8090 matrix. An increase in wear rate is with increase of normal load applied on the test specimen (figure 1b). This effect was due to increase in plastic deformation [13]. The wear rate was decreased with the increase of sliding speed (figure 1c). An increase of the surface temperature is also found with the increasing sliding speed, which is ascribed to frictional heating at high sliding speeds [14]. The wear rate increased with the sliding distance as shown in figure 1d. This is due to increase in the deformation and fracture of asperities of the softer surface [15].

All process parameters are acceptable as they satisfy Fisher's test at 90% confidence level. The analysis of variance (ANOVA) is presented in Table 3. The percent contribution indicates that the volume fraction of SiC, contributes 31.02%. The normal load gives 12.56% of variation in the wear rate. The sliding speed responds to 5.98% of variation in the wear rate. The sliding distance tenders 50.31% of variation in the wear rate.

Table 3: ANOVA summary of the wear rate

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	2.01E-01	1.79E-01	1.47E-01	2.42E-04	2	1.21E-04	1145.69	31.02
B	1.62E-01	1.70E-01	1.95E-01	9.79E-05	2	4.90E-05	463.96	12.56
C	1.88E-01	1.74E-01	1.65E-01	4.66E-05	2	2.33E-05	220.90	5.98
D	1.41E-01	1.76E-01	2.10E-01	3.92E-04	2	1.96E-04	1857.75	50.31
e				9.50E-07	9	1.06E-07		0.00
T	6.92E-01	6.99E-01	7.17E-01	7.80E-04	17			100.00

Note: SS is the sum of square, v is the degrees of freedom, V is the variance, F is the Fisher's ratio, P is the percentage of contribution and T is the sum squares due to total variation.

The mathematical relation between wear and contact time is given by

$$W_{rp} = 0.0185{v_f}^{-0.2736} \tag{2}$$

$$W_{rf} = 0.0179F^{0.1697} \tag{3}$$

$$W_{rn} = 0.0355N^{-0.1880} \tag{4}$$

$$W_{rd} = 0.0007S^{0.5550} \tag{5}$$

where,
W_{rp} is the wear rate due to vol.% of reinforcement (v_f),mg/m
W_{rf} is the wear rate due to normal load (F), mg/m
W_{rn} is the wear rate due to speed (N), mg/m
W_{rd} is the wear rate sliding distance (d), mg/m.

The values of power law coefficients a, b, c and d are, respectively, -0.2736, 0.1697, -0.1880 and 0.5550 from "equations (2) to (5)". By substituting the representative values of Vf, F, N and S and their corresponding power law coefficients on the right side of "equation (1)" and substituting the experimentally obtained wear rates on the left side of "equation (1)", the value of K is determined. The over-all wear rate (mg/m) equation for AA3003/TiN composites is given by

$$W = 4.718 \times 10^{-5}\left(v_f^{\,-0.7044} F^{0.1632} V^{-0.2437} S^{0.4496}\right) \quad (6)$$

There is a good agreement between the experiment results and theoretical results obtained from "equation (6)" as shown in figure 2. The discrepancies between the theoretical and experimental war rates are due porosity in the stir cast composites.

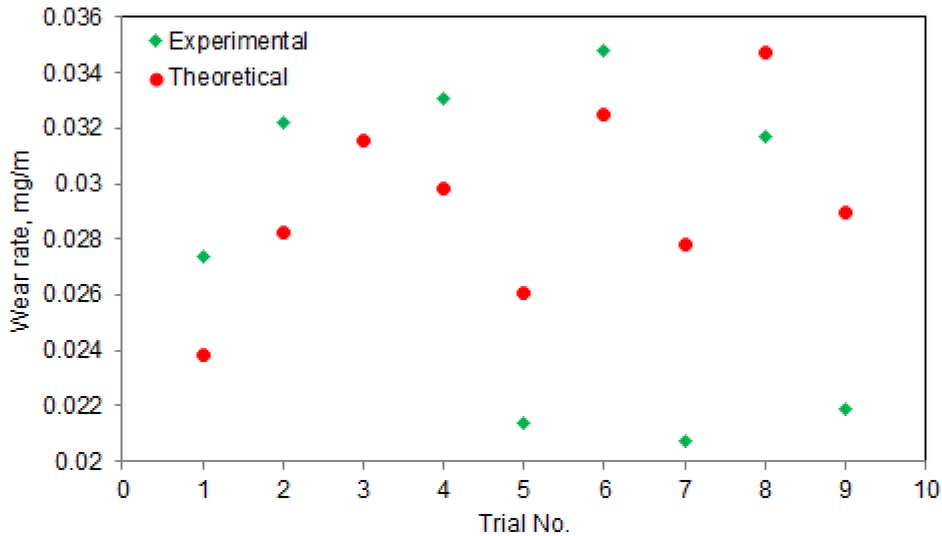

Figure 2: Validation of theoretical results.

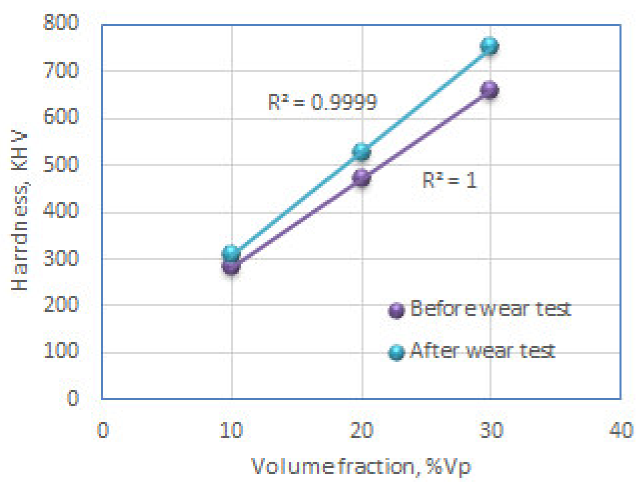

Figure 3: Hardness of AA8090/SiC composites after wear test.

4. DISCUSSION

It is important to identify the consequence of wear in AA8090/SiC composites. The change in hardness of the worn specimens is shown in figure 3. It can be seen that the hardness values increase after wear test. The increase in hardness in the worn specimens may be attributed to the work hardening and the frictional temperature. When the load was increased, the plastic deformation would take place in the AA8090 alloy matrix which could adhere to the steel disc and consequently, resulting the conditions of adhesive wear. If the wear is caused by a hard particle (TiC) trapped between the rubbing surfaces, the phenomenon is called three-body abrasive wear.

The particle may be either free or partially entrenched into one of the mating materials.

The 87th percentile is used as a benchmark for the probability analysis. The probability plots were created for each treatment by fitting with normal distributions and also estimated the 87th percentile for each population as shown in Fig.9. The estimated 87th percentiles for each population are:

- 0.03259 for the volume fraction of SiC,
- 0.03155 for the sliding speed,
- 0.03049 for the applied load and
- 0.03331 for sliding distance.

The estimated 87th percentiles indicate the merit of the factors A, B, C and D on the wear rate. This order is also same as that obtained from ANOVA. To withstand the wear rate of 0.03259 mg/m, the volume fraction of SiC should be 30%. The wear rate is within this limit for all the levels of applied load and sliding speed in the present work. The sliding distance has to be restricted to 750 m from its levels chosen in the present work.

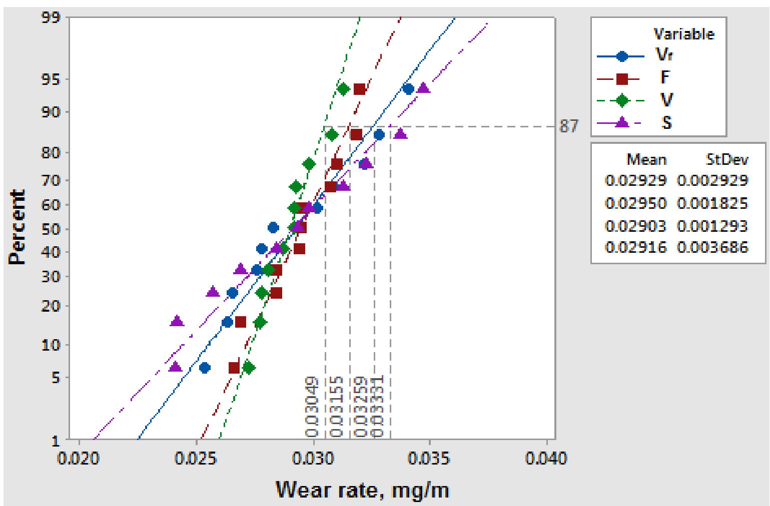

Figure 4: Weight loss functions: (a) reinforcement, (b) applied load, (c) sliding speed and (d) sliding distance.

5. CONCLUSION

The study on the wear behavior of AA8090/SiC composites as the function of vol.% of SiC, normal load, sliding speed and sliding distance using Taguchi's design of experiments was carried out successfully. The wear resistance increases with increase of vol.% SiC nanoparticles in AA8090 matrix. The wear rate increases with increase in normal load and sliding distance. The optimum wear rate of 0.03259 mg/m can be achieved with the volume fraction of SiC should be 30%.

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