Sliding Wear by Hard and Micro-Particles of AA2024-Zirconium Carbide Metal Matrix Composites

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Abstract: *In the present work, the AA2024 alloy-zirconium carbide metal matrix composites were fabricated by stir casting practice. The test matrix varied particle* size *of 100µm, 150µm and 200µm. The design of experiments was carried out based on Taguchi's factorial techniques. Dry sliding wear behavior of AA2024 alloy-zirconium carbide composites was studied using a pin-on-disc wear test rig. Four different wear mechanisms were observed on the wear surfaces of the composite materials. They are (1) matrix wear, (2) particle wear, (3) particle fracture and (4) particle-matrix interfacial debonding. The mathematical modeling was validated with experimental results.*

Keywords: *Metal matrix composite, particle size, AA2024 alloy, zirconium carbide, wear, sliding distance, normal load, speed.*

1. INTRODUCTION

Composite materials with Al matrix are relatively new materials, the minimum specific weight and excellent mechanical and tribologcal properties of which make them unique for contact joints, especially for applications in aircraft and automotive industry. The mechanical properties such as hardness, tensile strength can be improved by adding fillers to the matrix [1-17]. Inclusion of particulates such as TiO_2 [18, 19], graphite [20, 21], carbon [22], ZrO_2 [23, 24], TiN [25], B_4C [26], ZrC [27], Si_3N_4 [28] and SiO_2 [29] into aluminum alloy matrix, improved the wear resistance. Abrasive wear is one type of wear where hard asperities on one surface move across a softer surface under load, which penetrate and removes material from the softer surface, leaving behind, and grooves. Abrasive wear can occur as two-body abrasion, three-body abrasion, or both [30].

The data regarding three-body abrasive wear of metal matrix composites is limited. In this regard, the aim of the paper was to model the effect of zirconium carbide particle size on the abrasive wear of AA2024-zirconium carbide composites. For this purpose AA2024-zirconium carbide metal matrix composites were fabricated with particle size varying from 100µm to 200µm. Dry sliding wear of AA2024 alloy- zirconium carbide composites with different particle sizes were studied under different combinations of sliding speed, normal load, sliding distance and particle size based on Taguchi techniques [31, 32].

2. MATERIALS AND METHODS

AA2024 alloy- zirconium carbide composites were fabricated by the stir casting process. The volume fraction of zirconium carbide in the composites was 30%. The particle size of zirconium carbide was varied at 100µm, 150 µm and 200 µm. The T6 heat-treated samples were machined to get cylindrical specimens of 10 mm diameter and 30 mm length for the dry wear tests. The levels chosen for the controllable wear parameters are précised in Table 1. The orthogonal array, L9 was ideal to carry out wear experiments (Table 2). A pin-on-disc wear monitor (ASTM G99) was employed to assess the wear behavior of AA2024 alloy- zirconium carbide composite specimens against hardened ground steel (En32) disc (figure 1).

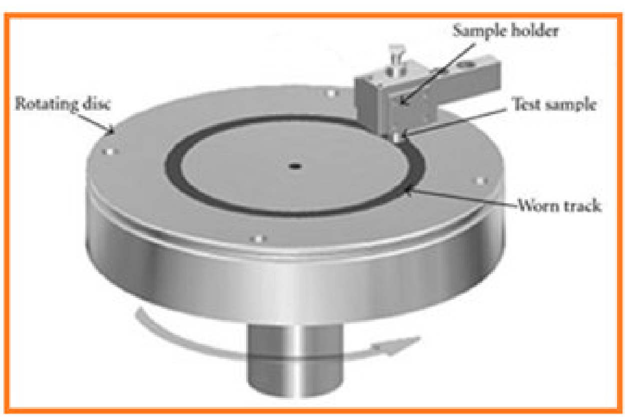

Figure 1: Tests carried out in the present work: (a) Pin-on-disc wear test and (b) Surface roughness test.

Table 1: Wear parameters and levels

Factor	Symbol	Level–1	Level–2	Level–3
Particle size, μm	A	100	150	200
Load, N	B	10	20	30
Speed, m/s	C	2	3	4
Sliding distance, m	D	500	750	1000

Table 2: Orthogonal array (L9) and control parameters

Treat No.	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

In the present work, the wear formulation [23, 25] was attempted based on the following expression:

$$W = K\,(d^a F^b S^c D^d) \quad (2)$$

where, W is the wear rate in g/m; d is the particle size of reinforcement, mm; F is the normal load, N; S is sliding speed, m/s D is the sliding distance, mm and; K, a, b, c and d are empirical constants.

3. RESULTS AND DISCUSSION

The analysis of variance (ANOVA) is presented in Table 3. All process parameters are adequate as they establish Fisher's test at 90% confidence level. For variation in the wear rate, the percent contribution of zirconium carbide particle size (A), normal load (B), sliding speed (C) and sliding distance (D) are, correspondingly, 92.62%, 3.86%, 0.79% and 2.73%. The R-squared values of particle size, normal load, sliding speed and sliding distance are, respectively, 0.9923, 0.9792, 0.6442 and 0.9772 as stated in figure 3. The trend equivalence of R-squared values is same as that of mean values obtained by Taguchi techniques.

Table 3: ANOVA summary of the effective stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	2.42E-02	4.15E-02	5.86E-02	1.97E-04	1	1.97E-04	9.11E+14	92.62
B	3.92E-02	3.96E-02	4.55E-02	8.24E-06	1	8.24E-06	3.80E+13	3.86
C	4.32E-02	4.09E-02	4.02E-02	1.67E-06	1	1.67E-06	7.72E+12	0.79
D	3.81E-02	5.99E-04	1.24E-01	5.82E-06	1	5.82E-06	2.68E+13	2.73
e				8.67E-19	4	2.17E-19	1.00	0.00
T	1.45E-01	1.23E-01	2.69E-01	2.13E-04	8			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 wear rate was increased with increase in particle size of zirconium carbide as shown in figure 3a. Figure 3b indicates an increase in wear rate with increase of normal load. The wear loss of the AA2024 alloy- zirconium carbide composites inclined to decrease when the sliding speed was increased from 2 m/s to 4 m/s. The wear of the AA2024 alloy- zirconium carbide composites increases with the sliding distance as shown in figure 3d. The wear rate strongly depends on the particle size of zirconium carbide for all the composites. This is due to the fact that the apparent contact area is greatly decreased at higher particle sizes. Since there is a decrease in contact area, it allows to have reduced interfacial bonding with the matrix material. Due to the poor adhesion between the filler and matrix in zirconium carbide filled composites, volume loss is increased.

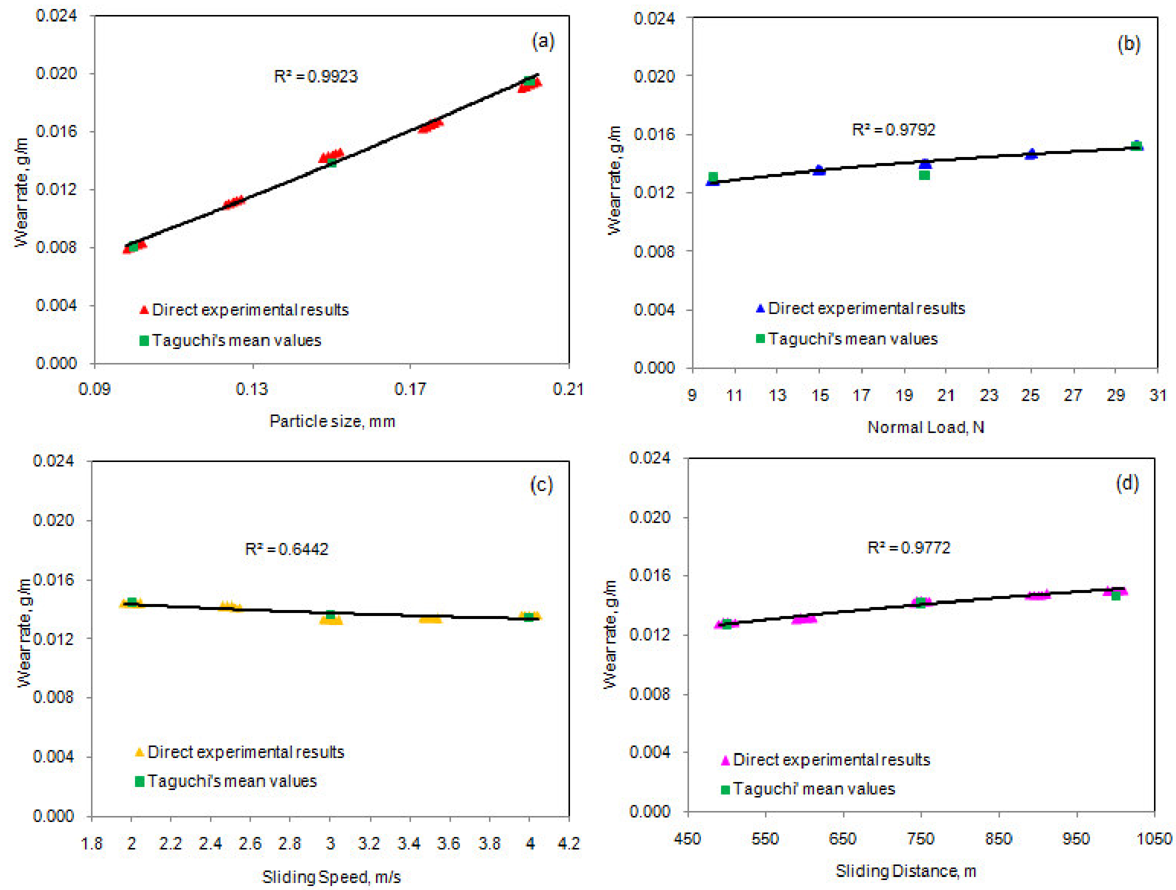

Figure 3: Wear rate as a function of (a) particle size, (b) applied load, (c) sliding speed and (d) sliding distance.

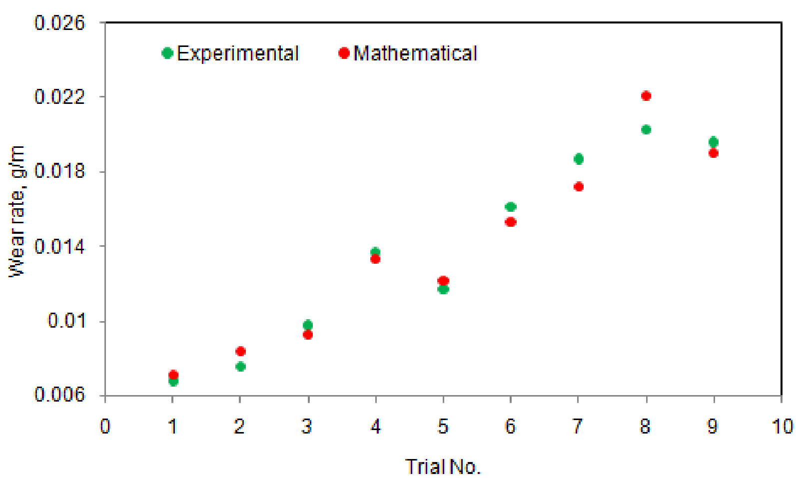

Figure 4: Validation of mathematical modeling with experimental results.

The mathematical relation between wear and volume fraction of reinforcement, applied load, sliding speed and sliding distance were obtained by curve fitting in terms of power laws as follows:

$$W = 2.07 \times 10^{-2} \left(d^{1.2398} F^{0.1528} S^{-0.1052} D^{0.2428}\right) \quad (3)$$

Four different wear mechanisms were observed on the wear surfaces of the composite materials. They are (1) matrix wear, (2) particle wear, (3) particle fracture and (4) particle-matrix interfacial debonding. During experiments on wear tests, it was observed that the matrix debris concentrated at certain regions; and the remaining regions are dominated by the presence of broken particles. Matrix layer removal, debonding and pull-out of zirconium carbide particles were also observed. Archard interpreted *K* factor as a probability of forming wear debris from asperity encounters [33]. Typically for mild wear, $K \approx 10^{-8}$, whereas for severe wear, $K \approx 10^{-2}$. As the value of $K \approx 10^{-2}$, the wear of AA2024 alloy- zirconium carbide composites is severe because the composite was made of micro-sized reinforced particles. The wear rate values determined by the Equation (3) are within the acceptable limits of experimental results as seen from figure 4. With this underlying principle, the mathematical modeling is at ease to identify the severity of wear of AA2024- zirconium carbide metal matrix composites.

4. CONCLUSIONS

The influence of micro-size particles on the severity of wear was modeled and validated with experimental results of AA2024 alloy- zirconium carbide composites. The AA2024 alloy- zirconium carbide composites have experienced rigorous wear due to plastic deformation and seizure of material during wear tests.

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