Tribological Investigation of Particle Size Effect on Wear Rate of Zirconium Oxide Microcomposites

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Abstract: *In the present work, the AA1100 alloy/zirconium oxide metal matrix composites were manufactured. The test matrix varied particle* size *of 100µm, 150µm and 200µm zirconium oxide. The composite samples were tested in dry sliding against a steel counterface.* The *AA1100/zirconium oxide composites have experienced severe wear. The wear rate initially is very low, rising steeply with wear distance, and then gradually decaying at longer wear distance.*

Keywords: *Metal matrix composite, particle size, AA1100 alloy, zirconium oxide, wear, sliding distance, normal load, speed.*

1. INTRODUCTION

Metal matrix composites continue to show significant improvements in wear resistance with the addition of ceramic particles. Matrix is adhesive binder that holds the particulates and transfers the load to the particulates. The bond in the particle and matrix is as often as possible solid in metal matrix composites; the most extreme interfacial shear apprehension is normally constrained by the yield strength of matrix material up [1-16]. Tribological utilizations of metal matrix composites have recognized for applications, for example, gears, brakes and so forth. Reinforcement particles can enhance the wear resistance depending on the characteristics such as their shape and size. The impacts of ceramic particles on the wear of particulate metal matrix composites under dry sliding condition are explored utilizing pin-on-disc apparatus. Three mechanisms have been proposed: (a) change in mechanical properties (modulus, strength and toughness), (b) change in morphology and (c) a direct effect of ceramic particles on the wear mechanism. The micro-particles had an independent effect on the wear rate. The point of including the hard ceramic particles to the soft aluminum is to build the hardness of the material and abatement the wear rate [17-28]. In some cases, localized surface melting reduces shear strength and friction drops to a low value determined by viscous forces in the liquid layer. Rhee [29] found that the total wear of a polymer-matrix is a function of the applied load *F*, speed *V* and sliding time *t* according to

$$\Delta W = KF^aV^bt^c \quad (1)$$

where ΔW is the weight loss of the friction material and *K, a, b* and *c* are empirical constants.

The objectives of this paper were as follows:

1. To fabricate the particulate metal matrix composite with zirconium oxide as reinforcement.
2. To perform wear test by shifting the parameters, for example, particle size, normal load, sliding speed and sliding distance under dry conditions. The design of experiments was based on Taguchi techniques [30, 31].
3. The wear test results are used to develop mathematical model using power laws.

2. MATERIALS AND METHODS

AA1100 alloy/zirconium oxide composites were fabricated by the stir casting process. The volume fraction of zirconium oxide in the composites was 30%. The particle size of zirconium oxide was varied at 100µm, 150 µm and 200 µm. The H18 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 AA1100 alloy/zirconium oxide composite specimens against hardened ground steel (En32) disc (figure 1).

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

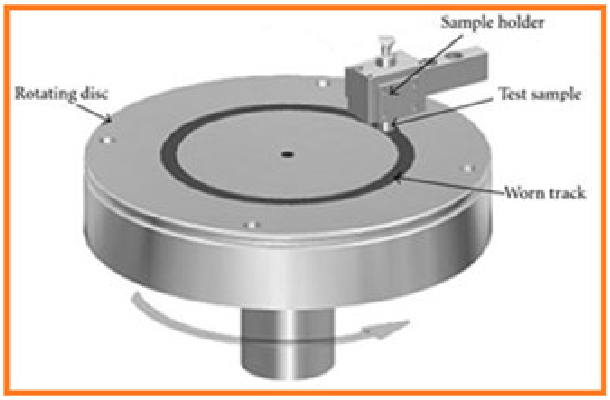

Figure 1: Tests carried out in the present work: (a) Pin-on-disc wear test and (b) Surface roughness test.

In the present work, the wear formulation 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 satisfying as they convince Fisher's test at 90% confidence level. For variation in the wear rate, the membership of particle size (A), normal load (B), sliding speed (C) and sliding distance (D) are, correspondingly, 85.87%, 4.77%, 1.52% and 7.84%. The important variable is the particle size of zirconium oxide. The unimportant variable is the sliding speed. The R-squared values of %reinforcement, normal load, sliding speed and sliding distance are, respectively, 0.9930, 0.99173, 0.4743 and 0.9803 as stated in figure 3. The tendency of R-squared values is same as that of mean values accomplished by Taguchi techniques.

Table 3: ANOVA summary of the effective stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	3.43E-02	6.45E-02	8.09E-02	3.72E-04	1	3.72E-04	1.72E+15	85.87
B	5.45E-02	5.97E-02	6.56E-02	2.07E-05	1	2.07E-05	9.54E+13	4.77
C	6.07E-02	5.65E-02	6.26E-02	6.57E-06	1	6.57E-06	3.03E+13	1.52
D	5.42E-02	1.11E-03	1.80E-01	3.40E-05	1	3.40E-05	1.57E+14	7.84
e				8.67E-19	4	2.17E-19	1.00	0.00
T	2.04E-01	1.82E-01	3.89E-01	4.33E-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.

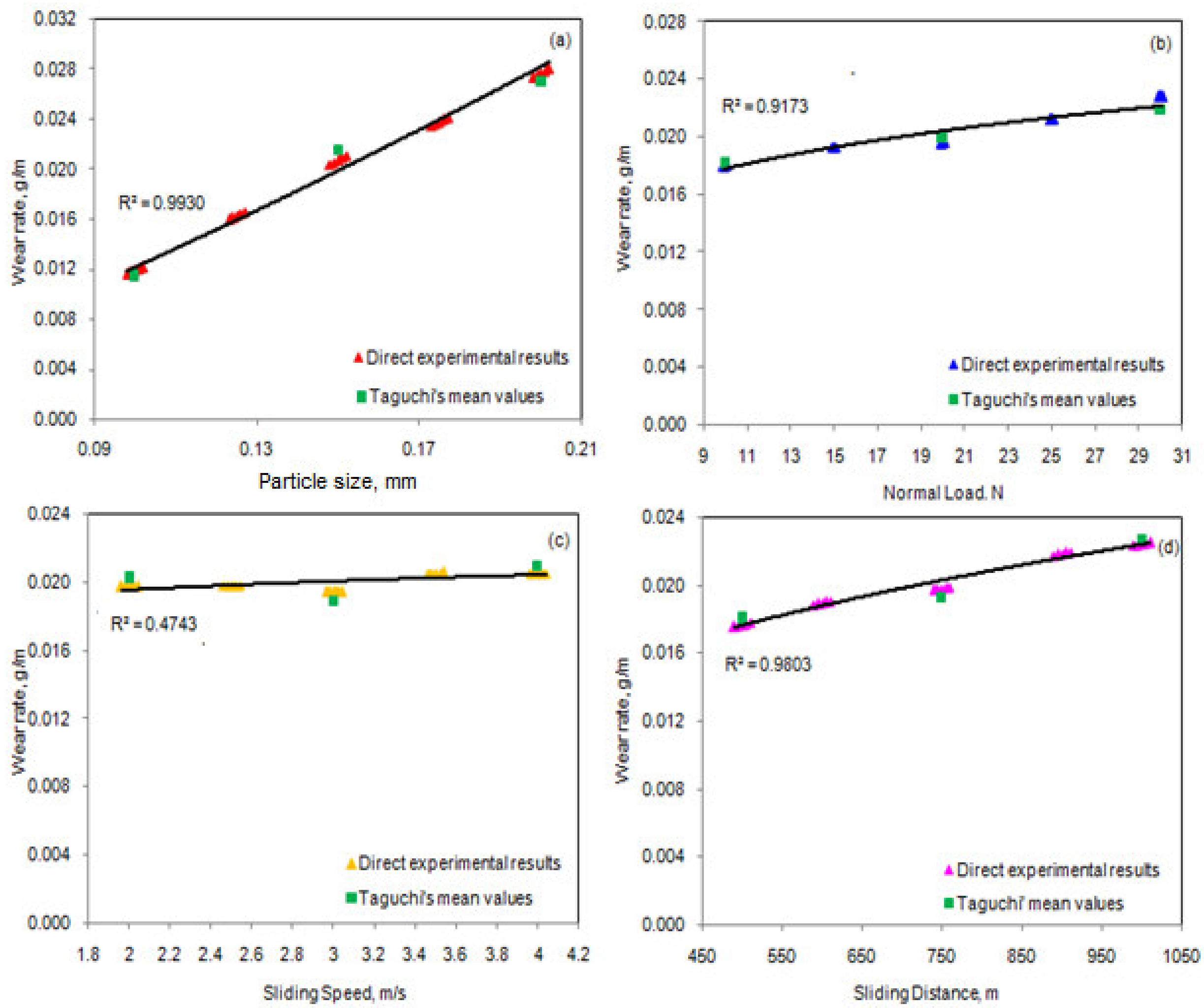

Figure 3: Wear rate as a function of (a) particle size, (b) applied load, (c) sliding speed and (d) sliding distance.

The wear rate was augmented with increase in particle size of zirconium oxide as shown in figure 3a. With the micro particles, the rougher striations are deeper and contain indications of severe ploughing and therefore abrasive wear effects. On the smooth areas, consisting of compacted wear debris, cracking phenomena of the latter lead to the detachment of large, plate-like units. Figure 3b characterizes an increase in wear rate with increase of normal load. The sliding speed had no influence on the wear rate (figure 3c). The wear rate increases with sliding distance as shown in figure 3d. The curves signify that the wear rate initially is very low, rising steeply with wear distance, and then gradually decaying at longer wear distance. This behavior is analogous to the wear rate obtained from respective material at various applied loads.

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:

$$W = 1.04 \times 10^{-2}\ (d^{1.2181}F^{0.201}S^{0.0818}D^{0.344}) \quad (3)$$

Archard interpreted K factor as a probability of forming wear debris from asperity encounters [32]. 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 AA1100/zirconium oxide 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 bearable limits of experimental results as seen from figure 4. For this reason, the mathematical modeling is abundant to describe the severity of wear of AA1100/zirconium oxide metal matrix composites.

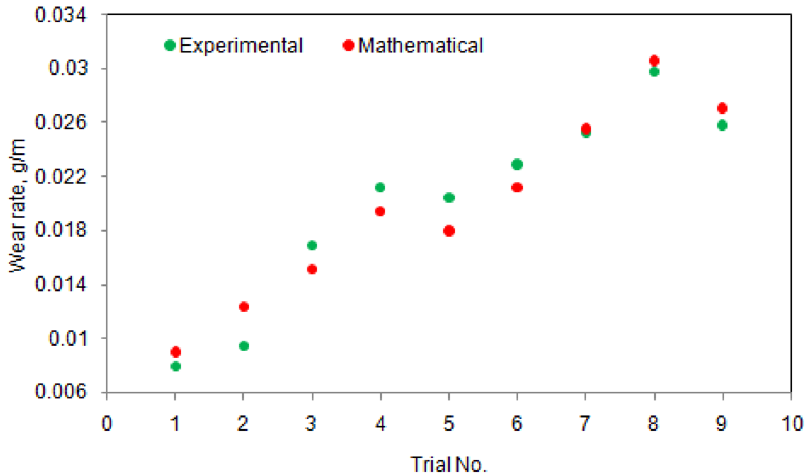

Figure 4: Validation of mathematical modeling with experimental results.

4. CONCLUSIONS

The effect of micro-size particles on the severity of wear was professionally modeled and validated with experimental results of AA1100/zirconium oxide composites. The AA1100/zirconium oxide composites have experienced severe wear. The wear rate initially is very low, rising steeply with wear distance, and then gradually decaying at longer wear distance.

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