Influence of Reinforcing Particle Size on Tribological Properties of AA6061-Titanium Carbide Microcomposites

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Abstract: *In the present work, the AA6061 alloy-titanium carbide metal matrix composites were manufactured. 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 AA6061 alloy-titanium carbide composites was investigated employing a pin-on-disc wear test rig. Results exposed that the wear rate increased with increasing size of titanium carbide particles. The mathematical modeling was validated with experimental results.*

Keywords: *Metal matrix composite, particle size, AA6061 alloy, titanium carbide, wear, sliding distance, normal load, speed.*

1. INTRODUCTION

Metal matrix composites have been extensively studied in terms of mechanical properties, but a particular material system may behave differently as particle size, morphology, composition, and distribution of the hardening phase varies. Matrix phases are generally chosen based upon their reactivity to the carbides of interest and the intrinsic properties of the matrix itself, including corrosion resistance and wear resistance, depending on the target application [1-16]. Wear resistance is one key aspect where the intrinsic properties of metal matrix composites may be exploited [17-25]. Often an amount of the hard particle constituent dissolves into the liquid metal matrix due manufacture of the metal matrix composites and then precipitates as either the same primary particle composition or as secondary particles. The effect of the composite particle dimension has been studied [26-30]. It was found that the material loss increased with increase of reinforced particle size. Rhee [31] 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.

In the current work, dry sliding wear of AA6061 alloy-titanium 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 [32, 33].

2. MATERIALS AND METHODS

AA6061 alloy-titanium carbide composites were fabricated by the stir casting process. The volume fraction of titanium carbide in the composites was 30%. The particle size of titanium carbide was varied at 100µm, 150 µm and 200 µm. The T8 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 AA6061 alloy-titanium carbide composite specimens against hardened ground steel (En32) disc (figure 1).

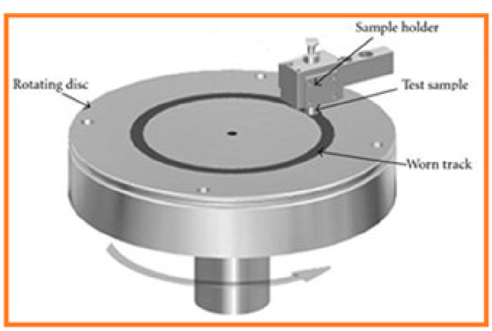

Figure 1: Tests carried out in the present work: (a) Pin-on-disc wear test and (b) Surface roughness test.

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 was attempted based on the following expression:

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

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 acceptable as they prove to Fisher's test at 90% confidence level. For variation in the wear rate, the percent contribution of titanium carbide particle size (A), normal load (B), sliding speed (C) and sliding distance (D) are, correspondingly, 83.20%, 8.18%, 4.05% and 4.58%. The R-squared values of %titanium carbide, normal load, sliding speed and sliding distance are, respectively, 0.9900, 0.9673, 0.9350 and 0.9618 as stated in figure 3. The resemblance of R-squared values is on par with 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	2.46E-02	4.16E-02	5.32E-02	1.38E-04	1	1.38E-04	1.28E+15	83.20
B	3.57E-02	3.90E-02	4.47E-02	1.36E-05	1	1.36E-05	1.26E+14	8.18
C	4.26E-02	4.04E-02	3.64E-02	6.73E-06	1	6.73E-06	6.21E+13	4.05
D	3.66E-02	5.16E-04	1.19E-01	7.62E-06	1	7.62E-06	7.03E+13	4.58
e				4.34E-19	4	1.08E-19	1.00	0.00
T	1.40E-01	1.21E-01	2.54E-01	1.66E-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 titanium carbide as shown in figure 3a. The observed wear-out trace testifies to a combination of abrasion wear and adhesion wear. The plastic deformation was observed on the wear-out trace edges. The decreased wear of the composite was detected with small size of reinforcing particles in the friction region. Figure 3b characterizes an increase in wear rate with increase of normal load. An increase in applied load increases the pressure on the pin resulting in an increase in the interfacial temperature, leading to the softening of the material and an increase in the plastic flow. When the loads are greater than transition load, severe wear occurs which leads to seizure of material. Probably due to poor bonding between particles and matrix and during wear, this has resulted in dislodging of titanium carbide particles hence, more wear rate. The wear loss of the AA6061 alloy-titanium carbide composites tended to decrease when the sliding speed was increased from 2 m/s to 4 m/s. Wear resistance increases when increasing the sliding speed at constant load regardless of size of titanium carbide particles. It can be observed form figure 3d that the wear of the AA6061 alloy-titanium carbide composites material increases as the sliding distance is increased.

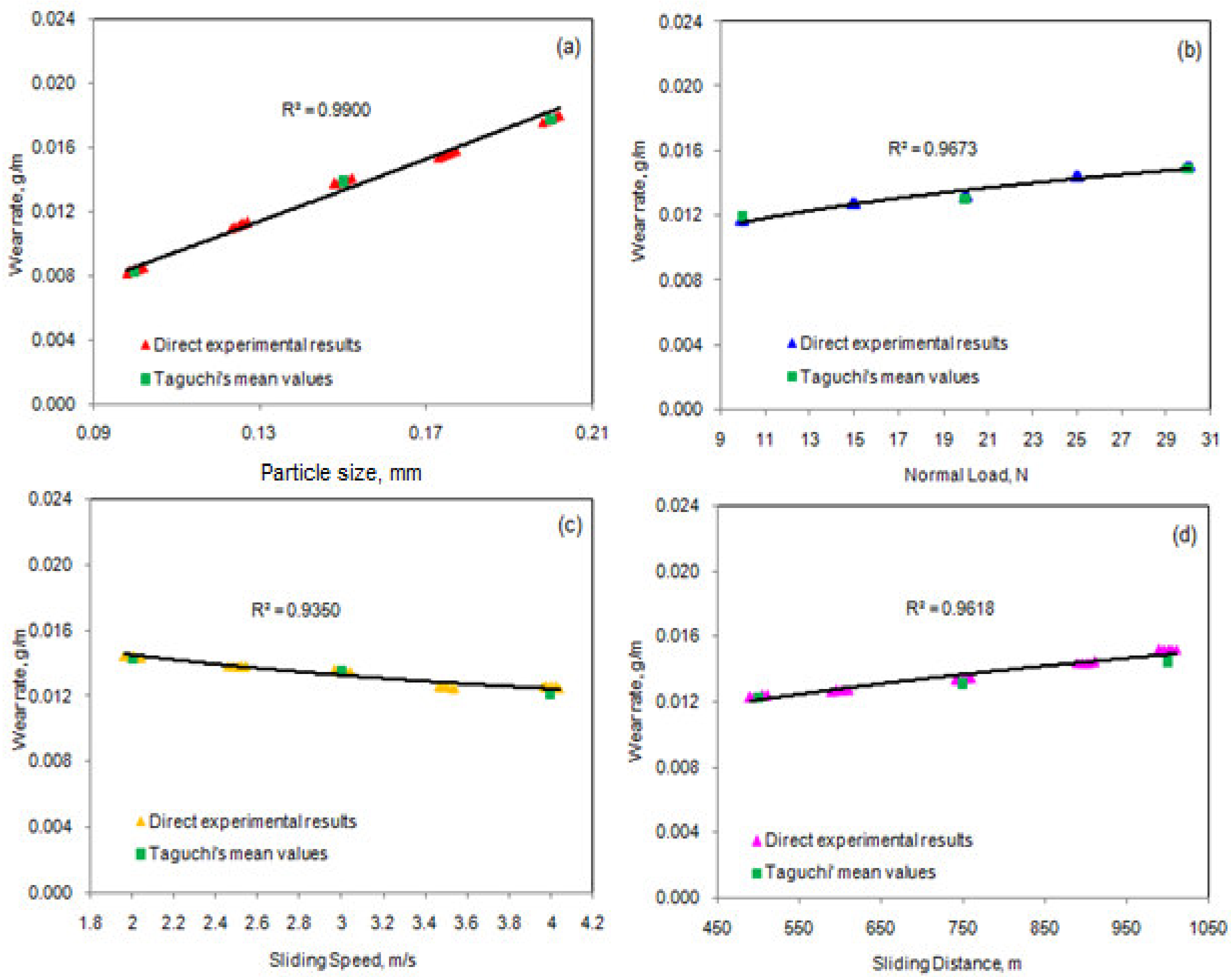

Figure 3: Wear rate as a function of (a) particle size, (b) applied load, (c) sliding speed and (d) sliding distance.

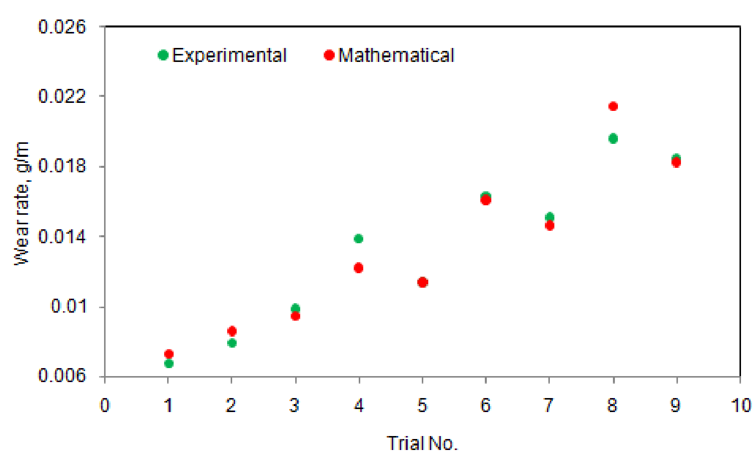

Figure 5: Validation of mathematical modeling with experimental results.

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:

$$W = 1.40 \times 10^{-2}\ (d^{1.0889} F^{0.2237} S^{-0.2237} D^{0.2386}) \quad (3)$$

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 AA6061 alloy-titanium 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 tolerable limits of experimental results as seen from figure 4. For this rationale, the mathematical modeling is rich enough to describe the severity of wear of AA6061-titanium carbide metal matrix composites.

4. CONCLUSIONS

The effect of micro-size particles on the severity of wear was modeled and validated with experimental results of AA6061 alloy-titanium carbide composites. The AA6061 alloy-titanium carbide composites have experienced severe wear due to plastic deformation and seizure of material during wear tests.

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