Role of Reinforcing Particle Size in the Wear Behavior of AA6061-Titanium Nitride Composites

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

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

1. INTRODUCTION

Metal matrix composites are increasingly becoming attractive materials for advanced aerospace applications because their properties can be tailored through the addition of selected reinforcements. In particular, particulate reinforced metal matrix composites have recently found special interest because of their specific strength and specific stiffness at room or elevated temperatures. Addition of hard reinforcements can improve hardness, strength and wear resistance of the composites [1-17]. A majority of publications concerning the tribological properties of composite materials refer to aluminum alloys reinforced with hard ceramic particles 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]. Aluminum alloy 6061 is typically characterized by properties such as fluidity, castability, corrosion resistance and high strength-weight ratio. Modeling wear and friction is the ultimate goal of practical tribologists. The empirical approach of a model involves characterization of surfaces, collection of tribological data in laboratory tests, correlation of data with field tests, and sorting out of data to build an empirical model [30].

In the present work attempt has been made to study the influence of titanium nitride microparticles on the severity of wear on AA6061/titanium nitride metal matrix composites. For this purpose AA6061/titanium nitride metal matrix composites were fabricated with particle size varying from 100µm to 200µm. Dry sliding wear of AA6061 alloy-titanium nitride 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

AA6061 alloy-titanium nitride composites were fabricated by the stir casting process. The volume fraction of titanium nitride in the composites was 30%. The particle size of titanium nitride 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 nitride composite specimens against hardened ground steel (En32) disc (figure 1).

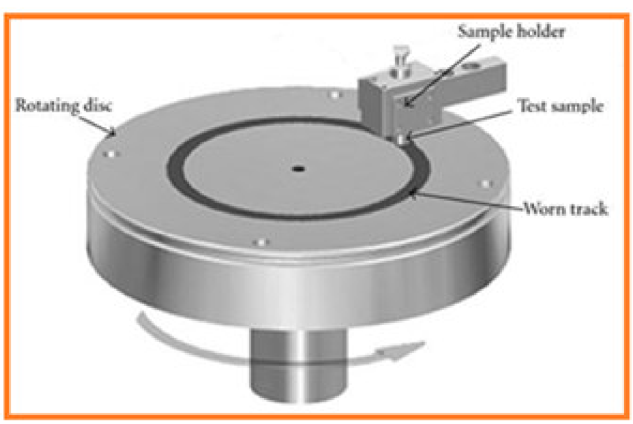

Figure 1: Tests carried out in the present work: (a) Pin-on-disc wear test and (b) Surface roughness test.

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 titanium nitride particle size (A), normal load (B), sliding speed (C) and sliding distance (D) are, correspondingly, 91.28%, 3.71%, 1.63% and 3.38%. The R-squared values of %titanium nitride, normal load, sliding speed and sliding distance are, respectively, 0.9929, 0.9813, 0.7617 and 0.9789 as stated in figure 3. The similitude 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	2.50E-02	4.82E-02	6.23E-02	2.37E-04	1	2.37E-04	1.09E+15	91.28
B	4.24E-02	4.36E-02	4.95E-02	9.63E-06	1	9.63E-06	4.44E+13	3.71
C	4.81E-02	4.36E-02	4.38E-02	4.24E-06	1	4.24E-06	1.95E+13	1.63
D	4.10E-02	7.46E-04	1.35E-01	8.78E-06	1	8.78E-06	4.05E+13	3.38
e				8.67E-19	4	2.17E-19	1.00	0.00
T	1.56E-01	1.36E-01	2.91E-01	2.60E-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 nitride as shown in figure 3a. Reinforcement particles have a tendency to associate themselves with porosity and give rise to particle-porosity clusters. During the microstructural investigation, agglomerations of titanium nitride particles were also noticed. The increased particle size reduced the bonding strength with the matrix. During wear test, the large particles dislodge from the pin surface promoting high wear rate. The hard titanium nitride particles outcropped and formed an impediment for the contact between the composite surface and the steel disc. Hence, the dispersion of large titanium nitride particles, the hard phase in the soft aluminum matrix, tends to increase the wear loss. Figure 3b signifies 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 frictional temperature, leading to the softening of the material and an increase in the plastic flow. When the loads are greater than interfacial strength between reinforced particle and matrix, severe wear occurs which leads to seizure of material. The wear loss of the AA6061 alloy-titanium nitride composites leaned to decrease when the sliding speed was increased from 2 m/s to 4 m/s. The wear of the AA6061 alloy-titanium nitride composites increases with the sliding distance as shown in figure 3d. This excessive material loss might be owing to brittle nature of titanium nitride and the dominant cutting wear mechanism.

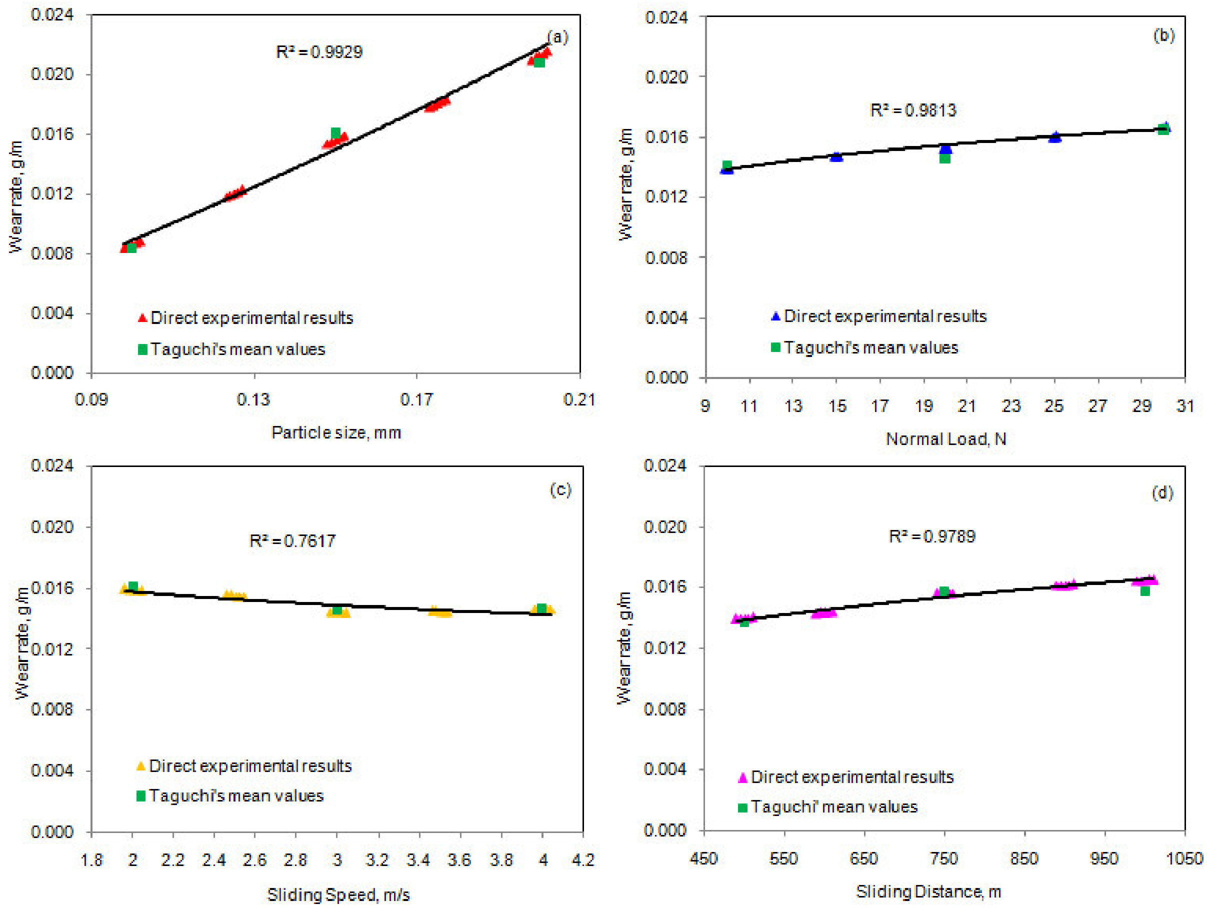

Figure 3: Wear rate as a function of (a) particle size, (b) applied load, (c) sliding speed and (d) sliding distance.

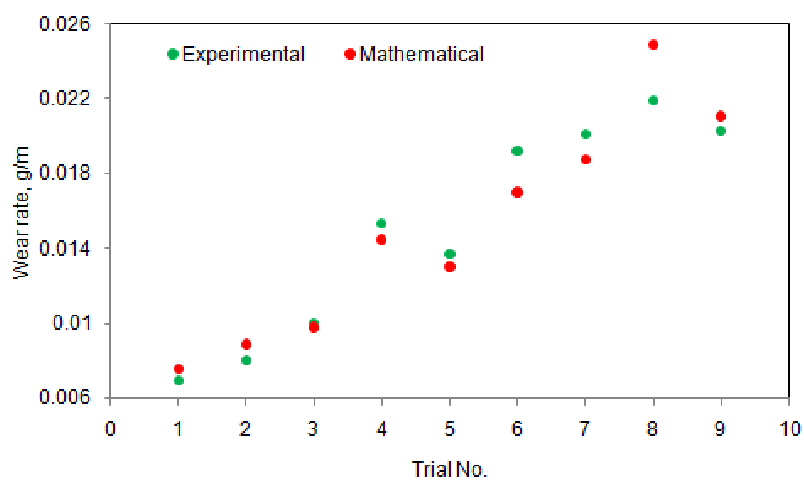

Figure 4: Validation of mathematical modeling with experimental results.

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:

$$W = 2.39 \times 10^{-2}\ (d^{1.2992}F^{0.1615}S^{-0.1398}D^{0.2525}) \qquad (3)$$

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 nitride 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 nitride metal matrix composites.

4. CONCLUSIONS

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

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