Inference of Macro-particles on Wear Rate of AA6061/TiO_2 Metal Matrix Composites

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Abstract: *In the present work, the AA6061 alloy/titanium oxide metal matrix composites were manufactured with particle size of 100μm, 150μm and 200μm titanium oxide. The pin-on-disc wear test was carried out with different combinations of reinforcement, sliding distance, normal load, sliding speed. Based on the experimental results the inference of macro sized particles on the severity of wear was effectively envisaged for AA6061/titanium oxide metal matrix composites.*

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

1. INTRODUCTION

The size parameters characteristic of a composite microstructure can exert a strong influence on its mechanical properties. For instance, strengthening of a metallic matrix by particles; lattice dislocations are forced by the microstructural constraint to distort out or stack up [1-16]. The case of strengthening in particle reinforced metal matrix composites has been extensively researched in the past; however no consensus has been reached regarding wear mechanism. The current work is interested on the size dependence of wear in particle reinforced composites. Defects such as clusters, agglomerates, and segregation of graphite particles play a dominant role in accelerating the fracture process. The variation of friction and wear rate depends on interfacial conditions such as normal load, geometry, relative surface motion, sliding speed, surface roughness of the rubbing surfaces, type of material, system rigidity, temperature, stick slip, relative humidity, lubrication and vibration. Among these factors sliding distance and normal load are the two major factors whose play significant role for the variation of friction and wear rate. High normal pressures and high sliding distances can result in high interface (flash) temperatures that can significantly reduce the strength of most materials [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

$$\Delta W = KF^a V^b t^c \quad (1)$$

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

The purpose of this paper was to estimate severity of particle size on the dry sliding wear of AA6061/titanium oxide metal matrix composites. The wear tests were conducted on pin-on-disc equipment. The design of experiments was based on Taguchi techniques [30, 31].

2. MATERIALS AND METHODS

AA6061alloy/titanium oxide composites were fabricated by the stir casting process. The volume fraction of titanium oxide in the composites was 30%. The particle size of titanium oxide was varied at 100μm, 150 μm and 200μm. 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 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

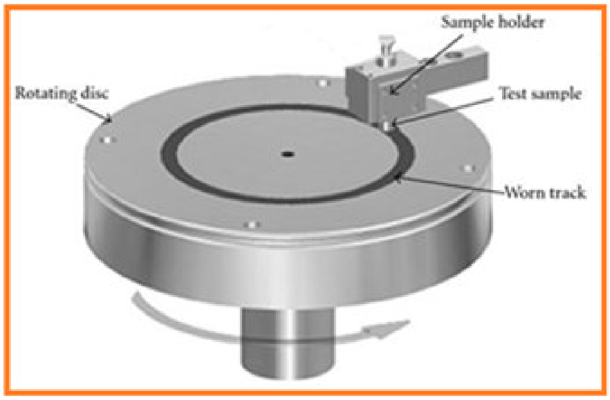

Figure 1: Tests carried out in the present work: (a) Pin-on-disc wear test and (b) Surface roughness test.

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 agreeable as they satisfy Fisher's test at 90% confidence level. For variation in the wear rate, the involvement of particle size (A), normal load (B), sliding speed (C) and sliding distance (D) are, in that order, 85.71%, 6.33%, 0.57% and 7.39%. The noteworthy variable is the particle size of titanium oxide. The slightest considerable variable is the sliding speed. The R-squared values of %reinforcement, normal load, sliding speed and sliding distance are, respectively, 0.9958, 0.8708, 0.4405 and 0.9838 as stated in figure 3. The compassion of R-squared values is same as that of mean values attained by Taguchi techniques.

Table 3: ANOVA summary of the effective stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	3.26E-02	6.51E-02	8.33E-02	4.39E-04	1	4.39E-04	1.35E+15	85.71
B	5.63E-02	5.63E-02	6.84E-02	3.24E-05	1	3.24E-05	9.97E+13	6.33
C	6.04E-02	5.82E-02	6.24E-02	2.90E-06	1	2.90E-06	8.92E+12	0.57
D	5.33E-02	1.18E-03	1.81E-01	3.79E-05	1	3.79E-05	1.16E+14	7.39
e				-1.30E-18	4	-3.25E-19	1.00	0.00
T	2.03E-01	1.81E-01	3.95E-01	5.12E-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.

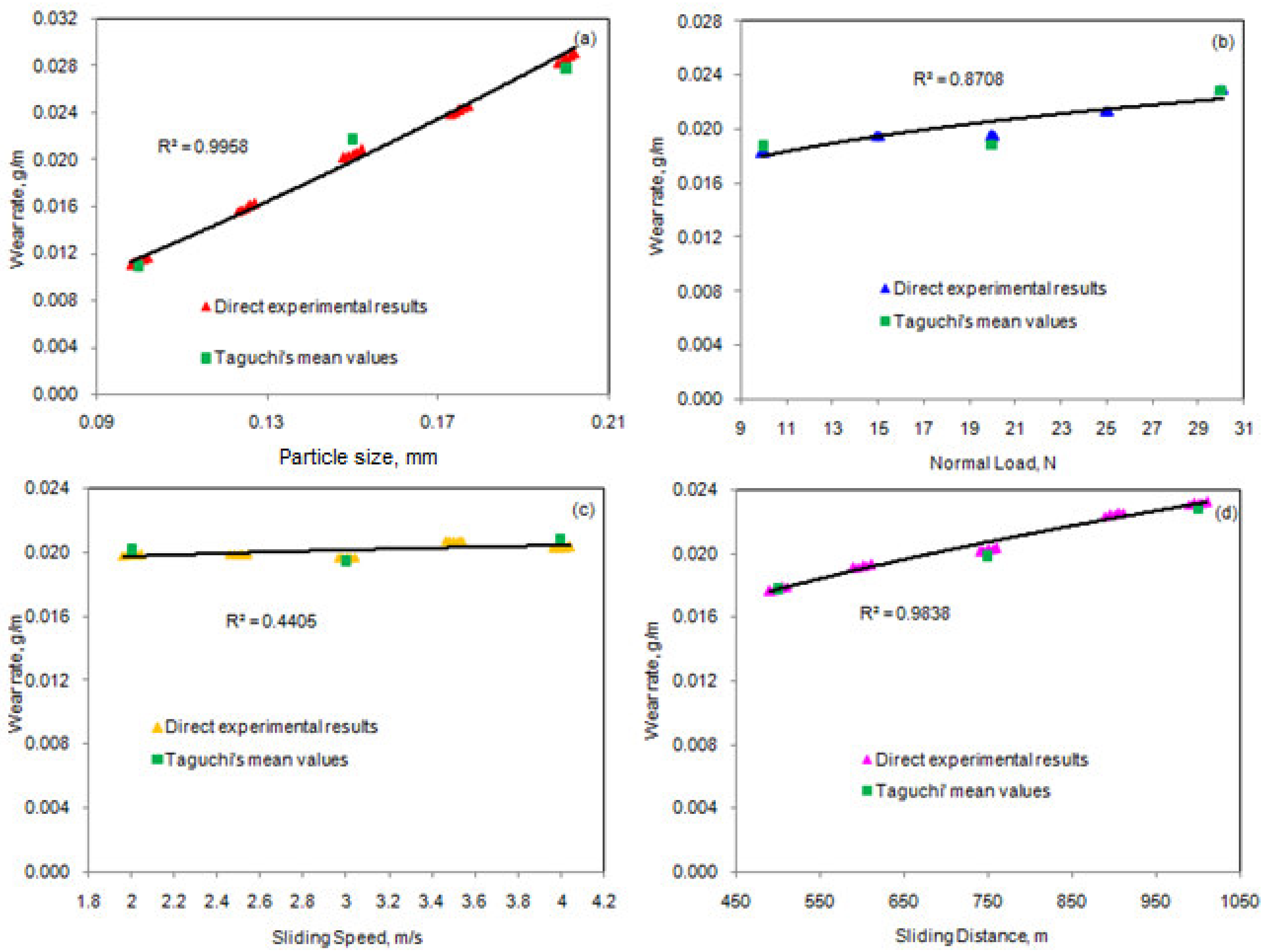

Figure 3: Wear rate as a function of (a) particle size, (b) applied load, (c) sliding speed and (d) sliding distance.

The wear rate was increased with increase in particle size of titanium oxide as shown in figure 3a. In case of composites with small size particle, for the same mass percentage, the number of reinforcement particles is larger. In case of large number of smaller particles, contact area between the matrix and the reinforcement phases will more and so is the interface between the two phases. This increased interface region would result in better stiffening and increased strength of the composite structure resulting in reduced wear of the material. Also, when the particulates get dislodged during the process of wear, they get entrapped between the mating surfaces, causing three body type abrasion. Figure 3b characterizes an increase in wear rate with increase of normal load. At higher loads (20-30N), the asperities get worn out faster, thereby increasing the contact area between the mating surfaces, as well as strain hardening of the surface because of increased dislocation density, this result in relatively higher rates of wear loss. The sliding speed was insignificant on the wear rate (figure 3c). The wear rate increases with sliding distance as shown in figure 3d. Breakdown of the surface layers from the composite pin promotes the loss of material with increasing sliding distance.

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:

$$\mathrm{W} = 1.79 \times 10^{-2} \left(\mathrm{d}^{1.3334}\mathrm{F}^{0.1924}\mathrm{S}^{0.0502}\mathrm{D}^{0.331}\right) \quad (3)$$

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/titanium oxide composites is severe because the composite was made of large reinforced particles. The wear rate values computed by the Equation (3) are within the acceptable limits of experimental results as seen from figure 4. Hence, the mathematical modeling is sufficient to represent the severity of wear of AA6061/titanium oxide metal matrix composites.

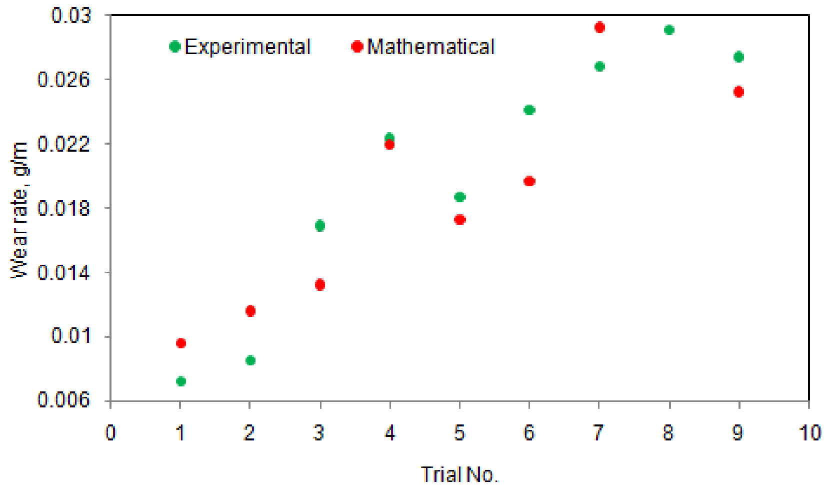

Figure 4: Validation of mathematical modeling with experimental results.

4. CONCLUSIONS

The inference micro-size particles on the severity wear was effectively modeled and confirmed with experimental results of AA6061/titanium oxide composites. The AA6061/titanium oxide composites have undergone severe wear because of macro size particles reinforced in aluminum alloy matrix.

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