Study of Factors Influencing Sliding Wear Behavior of Hexagonal Boron Nitride Reinforced AA6061 Metal Matrix Composites

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Abstract: *This paper deals with the dry sliding wear of AA6061 in the presence of hexagonal boron nitride. The AA6061 alloy-BN 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 conducted based on Taguchi's factorial techniques. Dry sliding wear behavior of AA6061 alloy-BN composites was studied using a pin-on-disc wear test rig. The ploughing of particles due to wear and hard asperities were observed on the surfaces of 200µm particle reinforced composites. The mathematical modeling was validated with experimental results.*

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

1. INTRODUCTION

In the past few years, the demand for lighter weight materials with increased specific strength for the automotive and aerospace industries has caused the development and usage of aluminum alloy based composites. Aluminum metal matrix composites reinforced with ceramic particles are gaining wide popularity as high performance material because of their improved strength, high elastic modulus and increased wear resistance, their ability to exhibit superior strength-to-weight and strength-to-cost ratio over conventional base alloy [1-17]. Al alloy based metal matrix composites are presently used in several applications such as pistons, pushrods, cylinder liners and brake discs. Metal composite self-lubricating composites are among the materials that are currently of great scientific interest. Self-lubricating composites have also been developed for engineering applications, including gears, bearings, bushings and cams. Erosive and abrasive wear may both be viewed as surface damage resulting from the relative motion with another body. Where the two forms of wear diverge involves the nature of the relative motion. Numerous reports are available on the subject of the fabrication and wear studies of the metal matrix composites. Ceramic materials 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] provide wear resistance and mechanical strength.

Superior lubricating properties of hexagonal boron nitride (h-BN) make it a best available modern day in-situ solid lubricant and can be applied by direct means of impregnating in the metal or ceramic composite subjected to high temperature and wear applications. The aim of this paper was to model the effect of boron nitride (BN) particle size on the sliding wear of AA6061-BN composites. For this purpose AA6061-BN metal matrix composites were manufactured with particle size varying from 100µm to 200µm. Dry sliding wear of AA6061 alloy-BN 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-BN composites were fabricated by the stir casting process. The volume fraction of BN in the composites was 30%. The particle size of BN 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 AA6061 alloy-BN 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

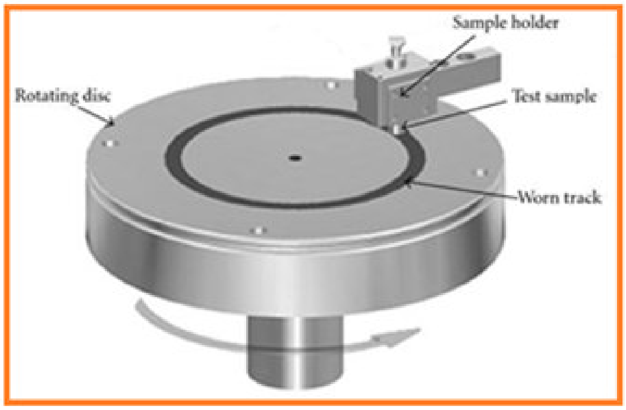

Figure 1: Tests carried out in the present work: (a) Pin-on-disc wear test and (b) Surface roughness test.

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

$$W = K\ (d^a F^b S^c D^d) \qquad (1)$$

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 support Fisher's test at 90% confidence level. For variation in the wear rate, the percent contribution of BN particle size (A), normal load (B), sliding speed (C) and sliding distance (D) are, correspondingly, 78.34%, 10.43%, 0.69% and 10.55%. The R-squared values of particle size, normal load, sliding speed and sliding distance are, respectively, 0.9936, 0.9813, 0.8028 and 0.9890 as stated in figure 3. The trend 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	1.47E-02	1.97E-02	2.23E-02	1.00E-05	1	1.00E-05	3.69E+14	78.34
B	1.76E-02	1.87E-02	2.04E-02	1.33E-06	1	1.33E-06	4.91E+13	10.43
C	1.85E-02	1.90E-02	1.92E-02	8.78E-08	1	8.78E-08	3.24E+12	0.69
D	1.74E-02	1.21E-04	5.66E-02	1.35E-06	1	1.35E-06	4.97E+13	10.55
e				1.08E-19	4	2.71E-20	1.00	0.00
T	6.81E-02	5.76E-02	1.18E-01	1.28E-05	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 BN as shown in figure 3a. This is highly related to the interfacial bonding between the larger size BN particle and matrix alloy. Due to weak interfacial debonding between larger BN particle and matrix alloy, the BN particles get detach from AA6061 alloy. The detached BN particle becomes a third body and promotes abrasive wear mechanism as shown in figure 4. Figure 3b indicates an increase in wear rate with increase of normal load. Major role of reinforcement is to carry the applied load, stresses and to avoid plastic deformation which leads to decrease in the wear rate. 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. The wear loss of the AA6061 alloy-BN composites increases with increase in the sliding speed. The increase in sliding speed causes the oxidation of the composite. The h-BN particle embedded in the surface easily gets squeezed out due to the higher intensity of subsurface deformation rate at higher sliding speeds. The wear of the AA6061 alloy-BN composites increases with the sliding distance as shown in figure 3d. During long sliding distances, the surfaces in contact at the disc surfaces were heated due to friction between the contact surfaces and also due the adhesion of flat regions of the sliding surfaces. It also shows the ploughing of particles due to wear and hard asperities were observed on the surfaces of 200μm particle reinforced composites (figure 4).

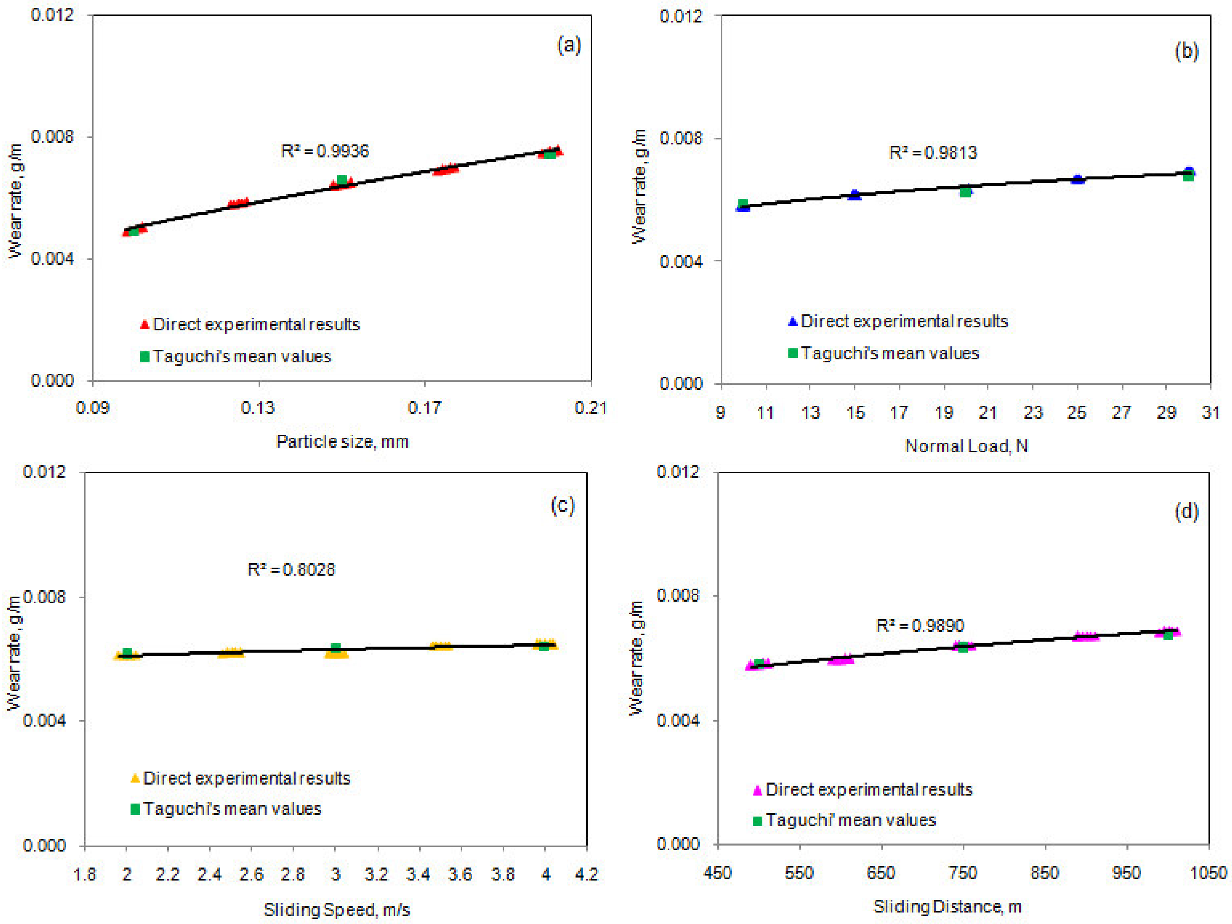

Figure 3: Wear rate as a function of (a) particle size, (b) applied load, (c) sliding speed and (d) sliding distance.

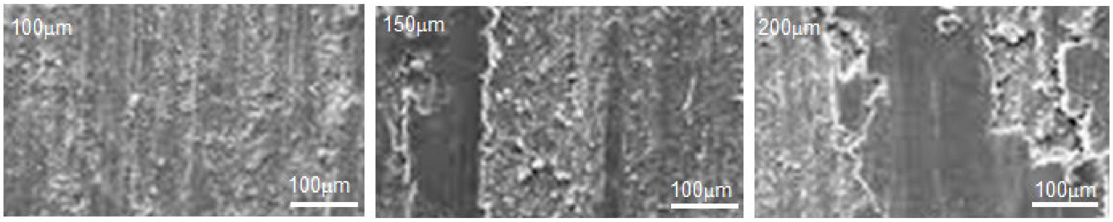

Figure 4: Micrographs of worn surfaces.

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:

$$W = 2.06 \times 10^{-3}\ (d^{0.58722} F^{0.1612} S^{0.0821} D^{0.2551}) \qquad (2)$$

Matrix layer removal, debonding and pull-out of BN particles were observed during wear tests on pin-on-disc setup. 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 $K \approx 10^{-3}$, the wear of AA6061 alloy-BN composites is moderate because the composite was made of micro-sized reinforced BN particles. The wear rate values determined by the Equation (2) are within the tolerable limits of experimental results as seen from figure 5. With this justification, the mathematical modeling is capable to evaluate the severity of wear of AA6061-BN metal matrix composites.

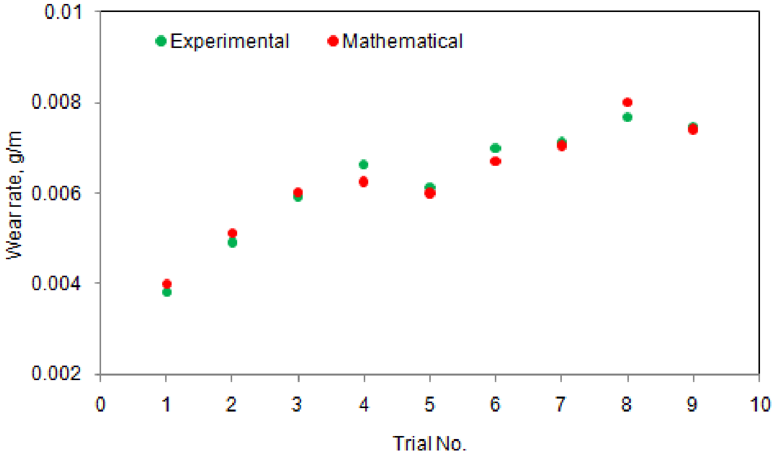

Figure 5: Validation of mathematical modeling with experimental results.

4. CONCLUSIONS

The impact of micro-size particles on the severity of wear was modeled and validated with experimental results of AA6061 alloy-BN composites. The ploughing of particles due to wear and hard asperities were observed on the surfaces of 200μm particle reinforced composites.

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