Experimental Validation of Dry Wear Formulation of AA7020/Zirconia Nanoparticle Metal Matrix Composites

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Abstract: *In the present work, the AA7020 alloy/zirconia metal matrix composites were manufactured at 10% and 30% volume fractions of zirconia. 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 wear formulation was successfully validated.*

Keywords: *Metal matrix composite, wear formulation, AA7020 alloy, zirconia, wear, sliding distance, normal load, speed.*

1. INTRODUCTION

Metal matrix composites reinforced by nano-particles are very promising materials, suitable for a large number of applications. The nano-particles can improve the base material in terms of wear resistance, damping properties and mechanical strength [1-16]. There was global need of reducing the wear in order to reduce the usage of material resources and wastage of energy. The effect of process parameters and the addition of reinforcement on the dry sliding wear of the composites were investigated vastly and explained that incorporation of hard secondary constituent in the matrix significantly improves the wear resistance [17-26]. The issue of wear equations and modeling is discussed on a regular but infrequent basis. Many papers have been written before on this topic but little concrete direction has arisen for developing good wear models. Rhee [27] 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 research work was to validate experimentally the wear formulation of AA7020/zirconia metal matrix composites. The wear tests were conducted on pin-on-disc equipment. The design of experiments was based on Taguchi techniques [28, 29].

2. MATERIALS AND METHODS

AA7020 alloy/zirconia composites were fabricated by the stir casting process. 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 AA7020 alloy/zirconia composite specimens against hardened ground steel (En32) disc (figure 1). Knoop microhardness was conducted before and after wear tests.

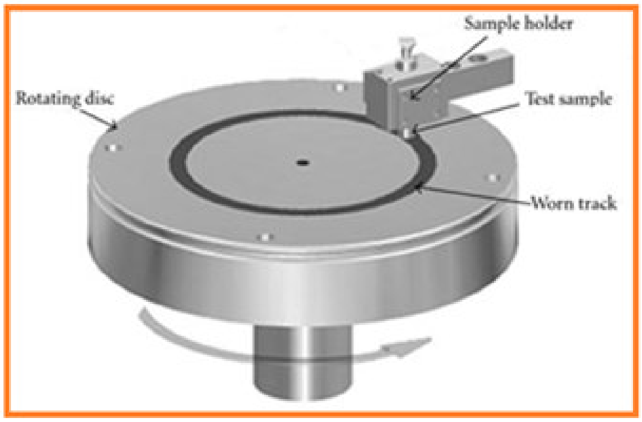

Figure 1: Tests carried out in the present work: (a) Pin-on-disc wear test and (b) Surface roughness test.

Table 1: Wear parameters and levels

Factor	Symbol	Level–1	Level–2	Level–3
Reinforcement, Vol.%	A	10	20	30
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:

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

where,
W is the wear rate in g/m
V_f is the volume fraction of reinforcement
F is the normal load, N
S is sliding speed, m/s
D is the sliding distance, m.
K, a, b, c and d are empirical constants.

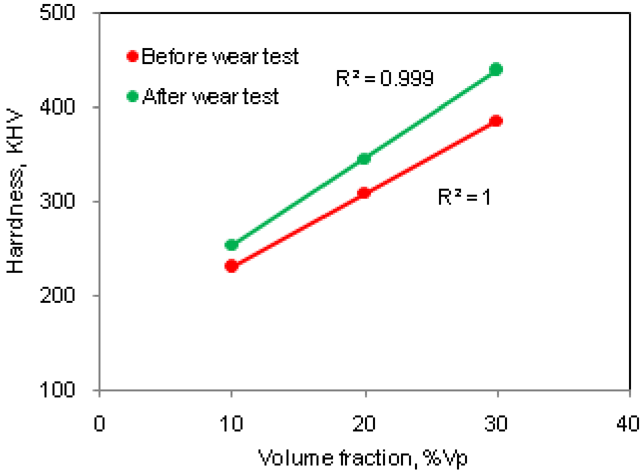

Figure 2: Microhardness of wear samples before and after wear tests.

3. RESULTS AND DISCUSSION

The knoop microhardness was determined of the wear specimens before and after wear tests. The microhardness was increased with volume fraction of zirconia nanoparticles in AA7020 alloy matrix as seen from figure 2. After wear test, the microhardness was further increased, as demonstrated in figure 2, due to strain hardening by the plastic deformation during wear. On account of strain hardening the wear specimens got strengthened. This strengthening was occurred because of dislocation movements and dislocation generation within the AA7020/zirconia composites.

The analysis of variance (ANOVA) is presented in Table 3. All process parameters are adequate as they satisfy Fisher's test at 90% confidence level. The contribution of zirconia volume fraction (A), normal load (B), sliding speed (C) and sliding distance (D) are, in that order, 29.52%, 7.67%, 2.74% and 60.33% of variation in the wear rate. The major significant variable is the sliding distance. The least important variable is the sliding speed. The R-squared values of %reinforcement, normal load, sliding speed and sliding distance are, respectively, 0.9497, 0.7508, 0.6998 and 0.9985 as mentioned in figure 3. The responsiveness 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	2.37E-02	2.23E-02	1.99E-02	2.52E-06	1	2.52E-06	6.20E+13	29.26
B	2.15E-02	2.13E-02	2.31E-02	6.61E-07	1	6.61E-07	1.63E+13	7.67
C	2.20E-02	2.26E-02	2.14E-02	2.36E-07	1	2.36E-07	5.81E+12	2.74
D	1.90E-02	1.66E-04	6.59E-02	5.20E-06	1	5.20E-06	1.28E+14	60.33
e				1.63E-19	4	4.07E-20	1.00	0.00
T	8.63E-02	6.63E-02	1.30E-01	8.62E-06	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.

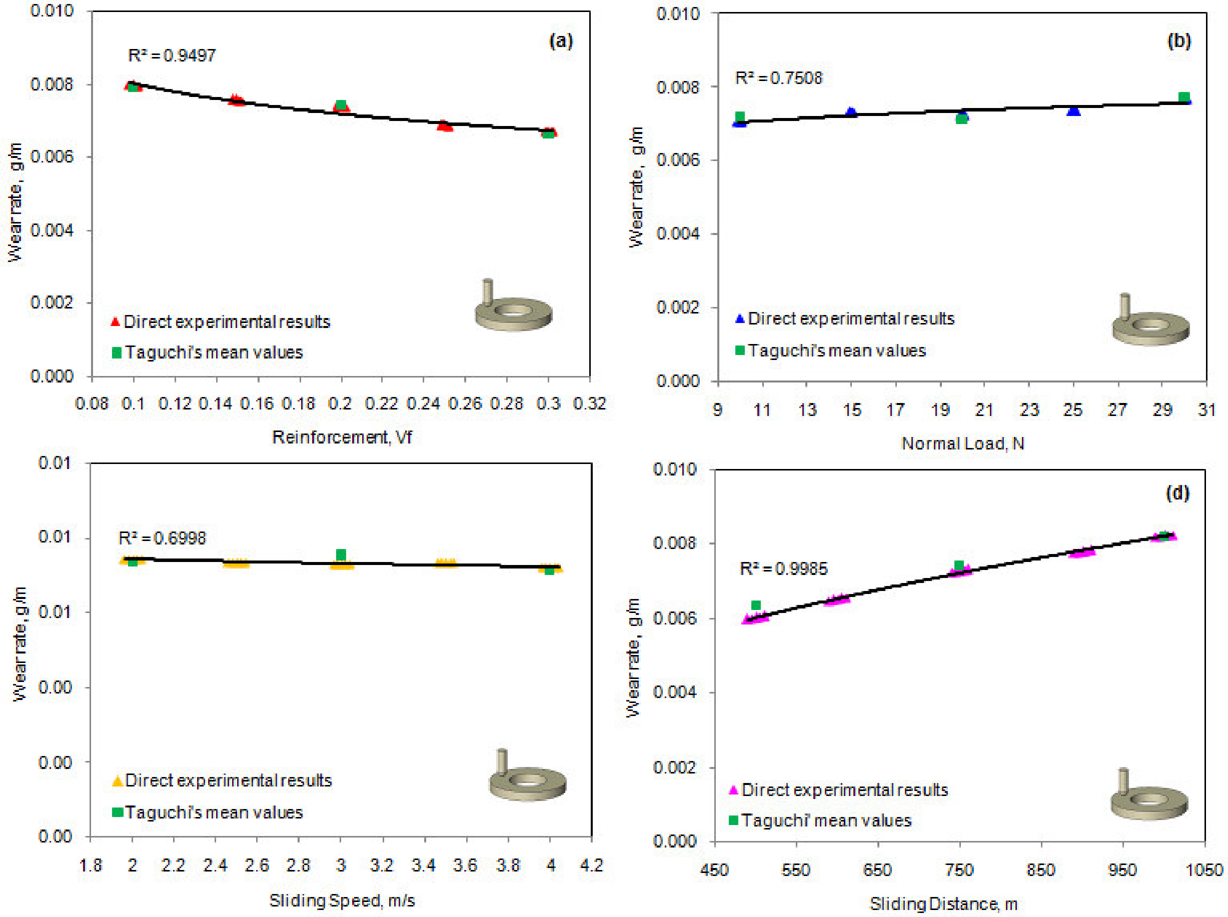

Figure 3: Wear rate as a function of (a) % reinforcement, (b) applied load, (c) sliding speed and (d) sliding distance.

The wear rate was decreased with increase in volume fraction of zirconia in AA7020 alloy matrix as shown in figure 3a. The strain hardening was high in AA7020/10% zirconia composites compared to AA7020/30%zirconia composites. Hence, the detachment of wear fragments decreases with increasing content of zirconia in the AA7020 alloy matrix. Figure 3b represents an increase in wear rate with increase of normal load. Due to increased applied load, the deformed AA7020 alloy matrix disengages from the pin's surface. The detached matrix material adheres to the steel disc surface, accordingly elevate the wear rate. The sliding speed was insignificant for composites reinforced with zirconia nanoparticles (figure 3c). The wear rate increases with sliding distance as shown in figure 3d. For long sliding distances, the shear stress at the interface between pin and steel disc exceeds the shear strength of the nanoparticle-matrix interface resulting particle debonding. Disintegration of the surface layers from the composite pin in consequence proceeds at faster rates 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:

$$\mathrm{W} = 2.52 \times 10^{-4} \left(\mathrm{V_f}^{-0.0158}\mathrm{F}^{0.0632}\mathrm{S}^{-0.0394}\mathrm{D}^{0.4483}\right) \tag{3}$$

Archard interpreted K factor as a probability of forming wear debris from asperity encounters [30]. Typically for mild wear, $K \approx 10^{-8}$, whereas for severe wear, $K \approx 10^{-2}$. As the value of $K \approx 10^{-4}$, the wear of AA7020/zirconia composites is moderate. The wear rate values computed by the Equation (3) are within the permissible limits of experimental results as seen from figure 4. Hence, the mathematical modeling is adequate to represent the wear mechanism of AA7020/zirconia metal matrix composites.

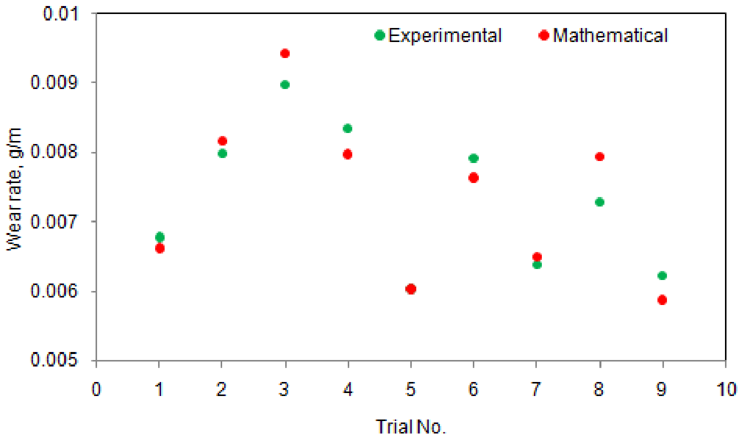

Figure 4: Validation of mathematical modeling with experimental results.

4. CONCLUSIONS

The wear formulation was successfully validated with experimental results of AA7020/zirconia composites. The AA7020/zirconia composites have experienced moderate wear because of nanoparticles reinforced in aluminum alloy matrix.

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