Control of B_4C Reinforced Particulates on Dry Wear Resistance of AA2024/B_4C Composites

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Abstract: *In the present work, the AA2024/B_4C metal matrix composites were manufactured at 10% and 30% volume fractions of B_4C. The pin-on-disc wear test was carried out with different combinations of reinforcement, sliding distance, normal load, sliding speed. Matrix fracture was observed in the composites having low volume fraction of B_4C; whereas particle removal and its fracture was examined in the composites having high volume fraction of B_4C.*

Keywords: *AA2024, boron carbide, dry wear, sliding distance, normal load, sliding speed.*

1. INTRODUCTION

In most basic wear studies, the so-called dry friction has been investigated to avoid the influences of fluid lubricants. During dry wear tests, the debris from worn surface may cause contamination. Reinforcement by particles or short fibers has proved to be especially advantageous since it offers composite materials having virtually isotropic properties at low cost [1-16]. A considerable amount of research is carried out on the dry sliding wear behavior of aluminum metal matrix composites [17-27]. Abrasion is the principle wear mechanism for the composites at low sliding speeds and loads. At higher loads, the wear mechanism changes to delamination.

The aim of the present work was to estimate wear rate and its consequences on cast AA2024/boron carbide composites. The design of experiments was based on Taguchi techniques [28, 29].

2. MATERIALS METHODS

Elastic modulus is computed considering isotropic behavior. The upper-bound equation is given by

$$\frac{E_c}{E_m} = \left(\frac{1-v_v{}^{2/3}}{1-v_v{}^{2/3}+v_v}\right) + \frac{1+(\delta-1)v_p{}^{2/3}}{1+(\delta-1)(v_p{}^{2/3}-v_p)} \quad (3)$$

The lower-bound equation is given by

$$\frac{E_c}{E_m} = 1 + \frac{v_p - v_p}{\delta/(\delta-1)-(v_p+v_v)^{1/3}} \quad (4)$$

where, $\delta = E_p/E_m$.

where, v_v and v_p are the volume fractions of voids/porosity and nanoparticles in the composite respectively and E_m and E_p is elastic moduli of the matrix and the particle respectively.

Table 1: Control parameters and levels

Factor	Symbol	Level–1	Level–2	Level–3
Reinforcement, Vol.%	A	10	20	30
Load, N	B	20	30	40
Speed, m/s	C	2	3	4
Sliding distance, m	D	500	1000	1500

AA2024 alloy/ B_4C composites were fabricated by the stir casting process and low pressure casting technique with argon gas at 3.0 bar. The average size of reinforcement material was 100nm. The composite samples were given T6 heat treatment. The heat-treated samples were machined to get cylindrical specimens for the wear tests as per ASTM standards. The wear tests were carried out according to the Taguchi's design of experiments. Each of the process parameters was chosen at three levels as given in Table 1. The orthogonal array, L9 was preferred to carry out experiments (Table 2). A pin on disc type friction and wear monitor (ASTM G99) was employed to evaluate dry wear behavior of AA2024 alloy/ B_4C composites against hardened ground steel (En32) disc. The wear teat variables were sliding speed, contact time, normal pressure, and volume fraction of B_4C. Knoop harness test was conducted on the composite specimens before and after wear test. Scanning electron microscopy analysis was also carried out to find consequence of wear test AA2024/B_4C composite specimens.

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

3. RESULTS AND DISCUSSION

Before conducting wear test, the elastic stiffness and hardness of AA2024/B_4C were estimated. The elastic stiffness and knoop hardness were increased with volume fraction of B_4C as shown in figure 1.

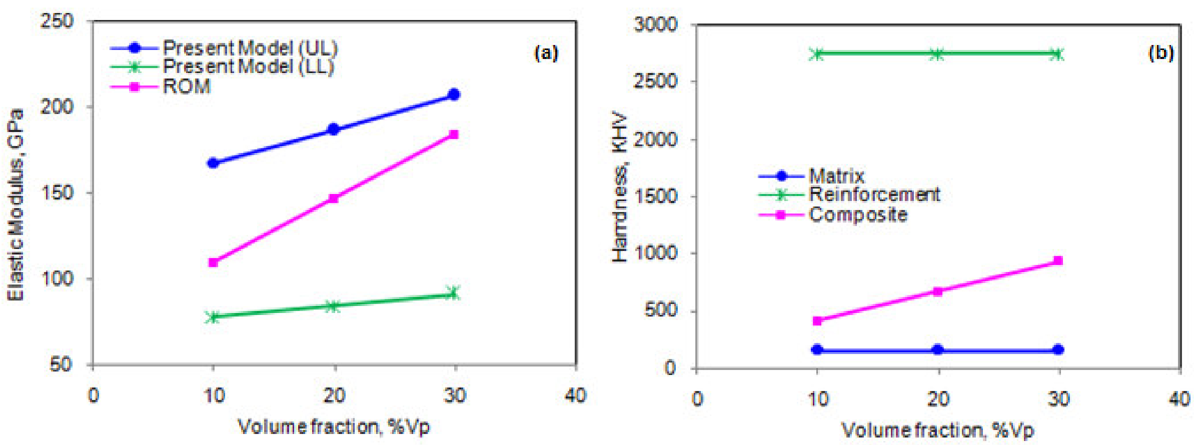

Figure 1: Elastic modulus and hardness of AA2024/B_4C composites.

Table 3: ANOVA summary of the effective stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	17.25000	12.87000	9.28000	10.62149	1	10.621489	1.49E+15	81.63
B	11.64000	13.39000	14.37000	1.27509	1	1.2750889	1.79E+14	9.8
C	13.72000	13.44000	12.24000	0.41209	1	0.4120889	5.80E+13	3.17
D	12.33000	54.44280	39.40000	0.70269	1	0.7026889	9.89E+13	5.4
e				0.00000	4	0.0000	1.00E+00	0
T	54.94000	94.14280	75.29000	13.01136	8			100

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.

3.1 Effect of volume fraction, Normal Load, Sliding Speed, Sliding distance on Wear Rate

In Table 3, the percent contribution indicates that the parameter A, all by itself (81.63%) contributes the most toward the variation in the wear rate. The normal load (B) affords a one-tenth of variation (9.8%) observed in the wear rate. The sliding distance (D) confers 5.4% of variation in the wear rate. The speed (C) grants 3.17% only of variation in wear rate. It was observed that five results were higher than the average wear rate. Hence, only one parameter could influence the wear rate. It can be seen from figure 2a that the wear rate was decreased with increase in volume fraction of B_4C in AA2024 alloy matrix. This is owing to high hardness of B_4C as compared to soft matrix. Composites produced by low volume fraction of B_4C, wear out faster than those produced by high volume fraction of B_4C. It is also observed that a general trend of increase in wear rate is with increase in normal load applied on the test specimens (figure 2b). The wear rate was decreased with increase of speed (figure 2c). It is also observed from figure 2d that the wear rate was proportional to the sliding distance. The R-squared values are in the range of 0.880 to 0.999. These values indicate the parameter influence on wear rate and the best fit of the trend.

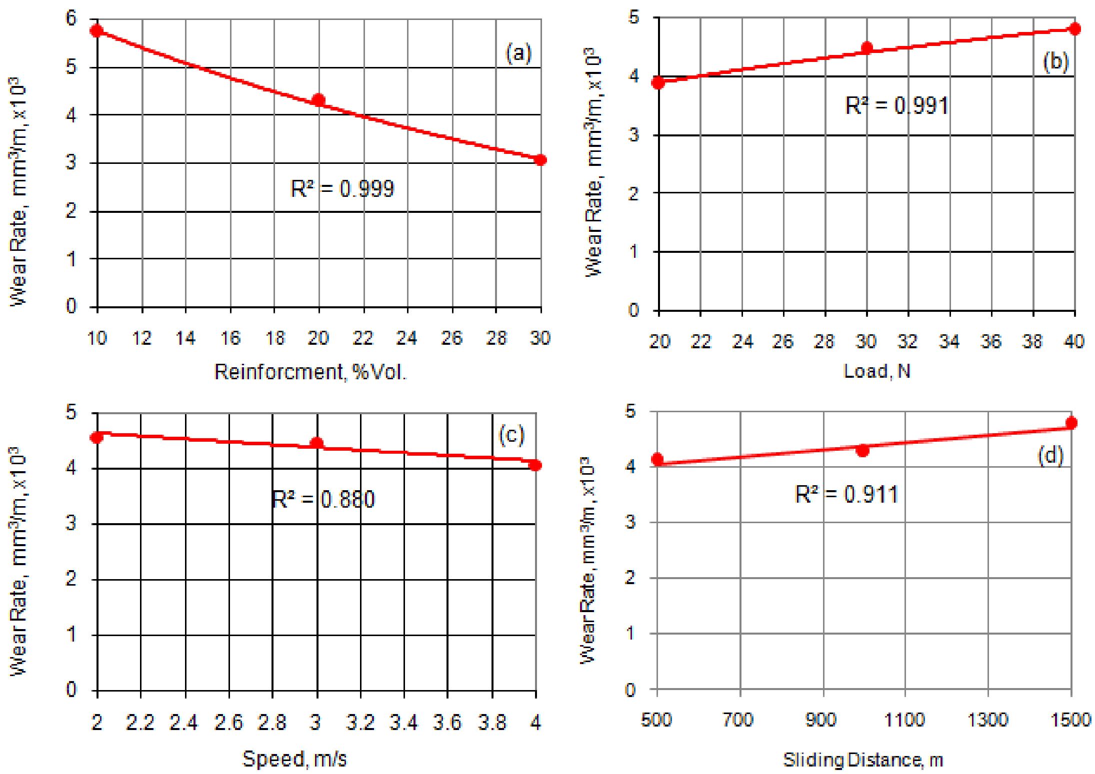

Figure 2: Influence of process parameters on wear rate.

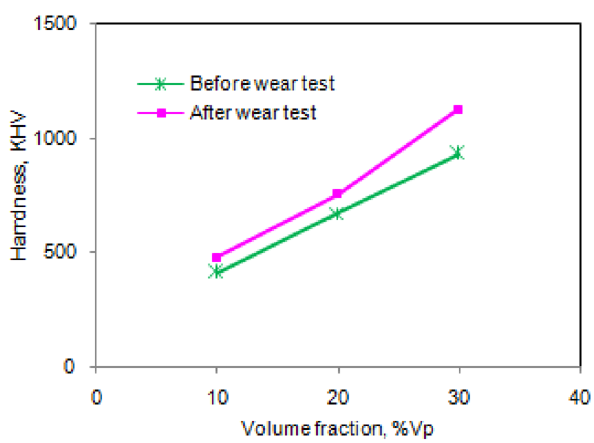

Figure 3: Harness of AA2024/B_4C composites after wear test.

3.2 Consequence of Wear in AA2024/B_4C Composites

It is crucial to know the consequence of wear in AA2024/B_4C composites. The worn specimens are not length enough for tensile testing to evaluate tensile strength and %elongation. Therefore, the worn specimens were tested for microhardness only. The change in hardness of the worn specimens is shown in figure3. It can be seen that the hardness values increase after wear test. The increase in hardness in the worn specimens may be attributed to the work hardening and the frictional temperature. The microstructures of worn specimens are revealed in figure 4. Since volume fraction of B_4C in AA2024 alloy matrix was found as the dominant parameter on the wear behavior, the transition in the state of the wear mechanism was detailed here for the increase in volume fraction of B_4C. When the reinforcement was increased to 30.%, a decrease in wear rate was detected. In the composites having 10 % of B_4C, a large amount of debris and fracture of AA2024 alloy matrix were observed (figure 4a). In the composites having 20 or 30 % of B_4C, removal of particles from the composite and rupture of B_4C particles were also observed (figure 4b-c). The particle removal and particle rupture were higher in the composites having 30% B_4C than in the composites having 10% B_4C.

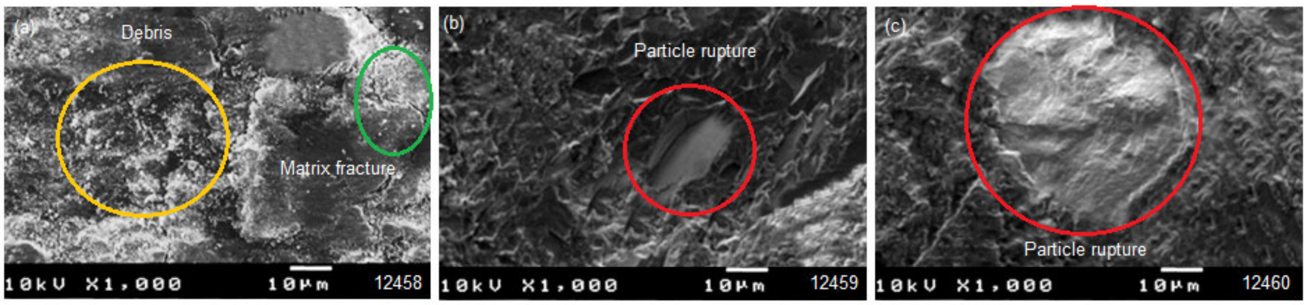

Figure 3: SEM images of worn surfaces of AA2024/B_4C composites: (a) 10%B_4C (b) 20%B_4C and (c) 30%B_4C.

4. CONCLUSION

The following are drawn from the present work as follows:

1. The wear resistance increases with increase of volume fraction of B_4C in AA2024 alloy matrix.
2. The wear loss increases with increase in normal load and sliding distance.
3. The wear loss decreases with increasing speed.
4. The consequences of wear were work hardening, matrix fracture and particle removal.

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