Wear performance of AA4015/Boron Carbide Metal Matrix Composites

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Abstract: *In the present work, the AA4015-B_4C metal matrix composites were manufactured at 10% and 30% volume fractions of B_4C. The composites were wear tested at different levels of normal load, sliding speed and sliding distances. The microstructure of worn surfaces pertaining to AA4015 alloy/ B_4C composite reveals the detachment of B_4C particles from the matrix.*

Keywords: *Metal matrix composite, AA4015 alloy, boron carbide, wear, sliding distance, normal load, sliding speed.*

1. INTRODUCTION

Metal-particle-reinforced ceramic matrix composites are promising candidates for future high temperature applications. Experimental evidence and numerical results also demonstrated that the spatial distribution of the second phase particles played an important role on the mechanical properties and the damage mechanism of the composites. [1-16]. Dry sliding contacts often contain wear particles and mechanically mixed deformed layers (third bodies) whose behavior needs to be understood and modeled. it is desirable to have a material with improved properties with respect to self lubrication and wear resistance. 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 [17-32].

The present work is on the evaluation of wear characteristics and consequences of cast AA4015/B_4C composites. The design of experiments was based on Taguchi techniques [33-34].

2. MATERIALS METHODS

The matrix material was AA4015 alloy. The reinforcement material was boron carbide (B_4C) nanoparticles of average size 100nm. AA4015 alloy/ B_4C composites were fabricated by the stir casting process and low pressure casting technique with argon gas at 3.0 bar. The composite samples were given H14 solution treatment. The heat-treated samples were machined to get cylindrical specimens for the wear tests. The design of experiments was carried out as per Taguchi techniques. The levels chosen for the controllable process parameters are summarized in table 1. The orthogonal array (Table 2), L9 was used to carry out wear tests. A pin on disc type friction and wear monitor (ASTM G99) was employed to evaluate the friction and wear behavior of AA4015 alloy/B_4C composites against hardened ground steel (En32) disc. Scanning electron microscopy analysis was also carried out to find consequence of wear test AA3003/B_4C composite specimens. The microhardness was measured in terms of Knoop hardness number.

Table 1: Control 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	1	2	3
Sliding distance, m	D	500	1000	1500

Elastic modulus (was computed as follows:

The upper-bound equation is given by

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

The lower-bound equation is given by

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

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 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

The, elastic stiffness and knoop hardness were increased with volume fraction of B_4C as shown in figure 1. In table 2, the percent contribution indicates that the parameter A, vol.% of B_4C contributes nearly half (43.8%) of variation in the wear rate. The normal load (B) adds 21.58% of variation in the wear rate. The speed (C) tenders 15.17% of variation in the wear rate. The sliding distance (D) presents 19.45% of variation in the wear rate.

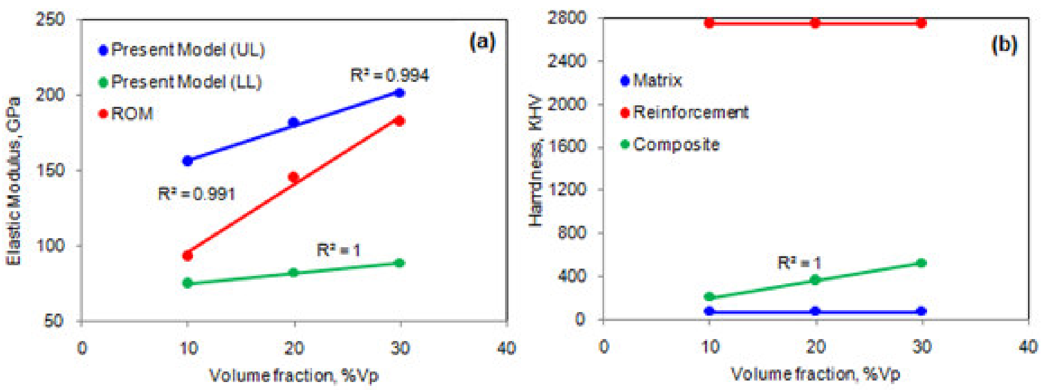

Figure 2: Mechanical Properties of AA4015/B_4C composites.

Table 3: ANOVA summary of the effective stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	19.90000	17.74000	15.91000	2.65940	1	2.6594	1.87E+14	43.8
B	16.34000	18.10000	19.11000	1.31007	1	1.3100667	9.22E+13	21.58
C	18.28000	18.75000	16.52000	0.92127	1	0.9212667	6.48E+13	15.17
D	17.21000	95.88053	53.55000	1.18087	1	1.1808667	8.31E+13	19.45
e				0.00000	4	0.0000	1.00E+00	0
T	71.73000	150.47053	105.09000	6.07160	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.

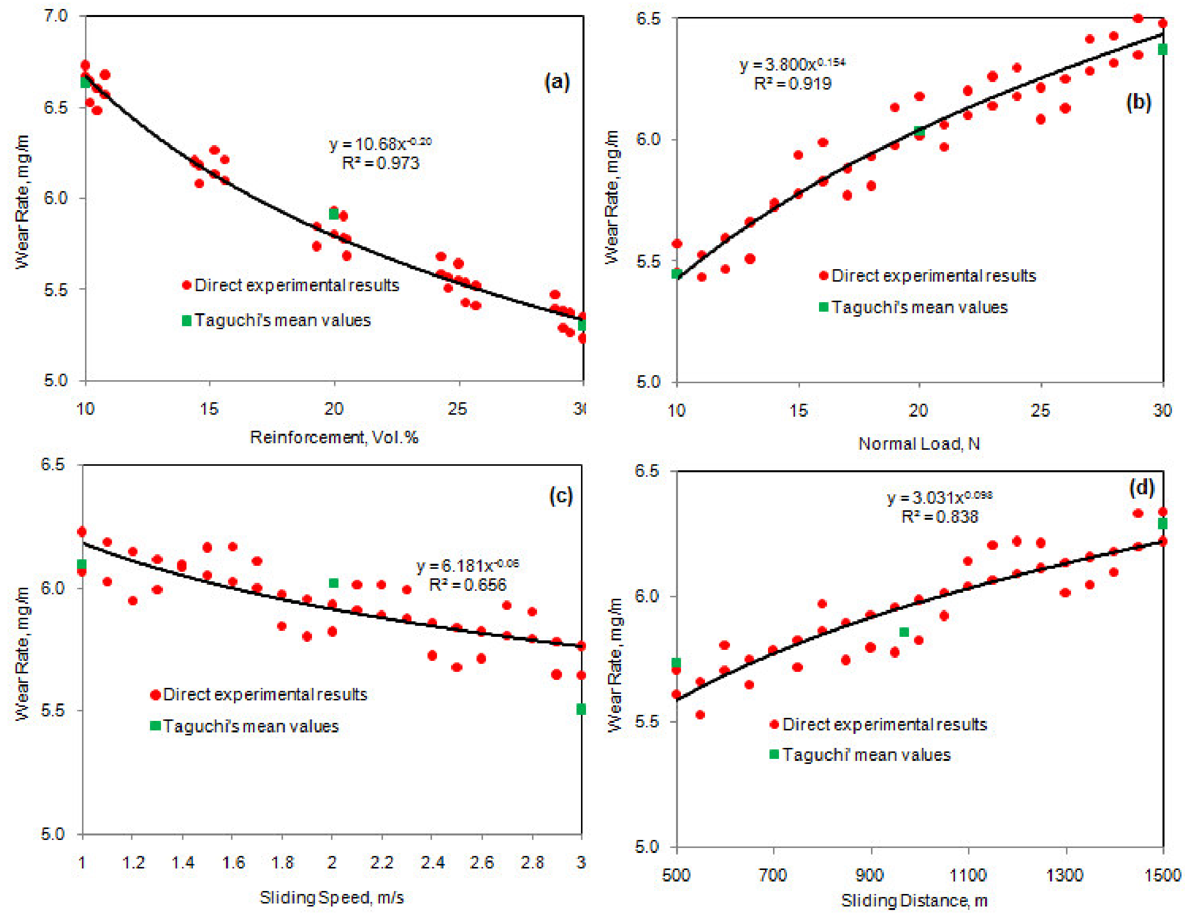

Figure 2: Influence of process parameters on wear rate.

The tested specimens are shown in figure 2. It gives the information about the number specimens at each composition and also variation in the composition of the composites due to melting and pouring of metal at different intervals. The wear rate was decreased with increase in volume fraction of B_4C in AA4015 alloy matrix (figure 2a). This is owing to high hardness of B_4C as compared to soft AA4015 alloy matrix. The wear rate was increased with load regardless of composition of the composites as shown in figure 2b. The wear rate was decreased with increase of sliding speed (figure 2c). Increasing the sliding speed made it increasingly difficult for surface damage by plastic deformation. From figure 2d it is observed that the wear rate was increased with the sliding distance. During sliding, as the sliding distance increases the time of contact between the surfaces were also increased. Hence more volume loss will be there. The mathematical relations between wear and vol.% of reinforcement, normal load, speed and sliding distance are given by

$$W_{rp} = 10.68 \times {v_f}^{-0.20} \quad (6)$$

$$W_{rf} = 3.80 \times F^{0.154} \quad (7)$$

$$W_{rn} = 6.181 \times N^{-0.06} \quad (8)$$

$$W_{rd} = 3.031 \times d^{0.098} \quad (9)$$

where,

W_{rp} is the wear rate due to vol.% of reinforcement (v_f), mm^3/m
W_{rf} is the wear rate due to normal load (F), mm^3/m
W_{rn} is the wear rate due to speed (N), mm^3/m
W_{rd} is the wear rate sliding distance (d), mm^3/m.

The R-squared values, which are attributable to vol.% reinforcement, normal load, sliding speed and sliding distance, are 0.973, 0.919, 0.656 and 0.838, respectively. This trend is similar to the percent contributions of process parameters obtained from Taguchi techniques. The percent contributions of vol.% reinforcement, normal load, sliding speed and sliding distance are 43.8%, 21.58%, 15.17% and 19.45% respectively.

The amount of metal loss depends upon the strength of the variables. It is necessary to distinguish the consequence of wear in AA4015/B_4C composites. The change in hardness of the worn specimens is shown in figure 3. 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 strain hardening mainly due to influence of vol.% B_4C. The microstructures of worn specimens are revealed in figure 4. In the composites having 10%B_4C, the matrix material softening and spreading over the worn surface was observed. When the reinforcement increased from 10 to 30 vol.% the scratches were also increased due to dragging of detached B_4C nanoparticles on the surface.

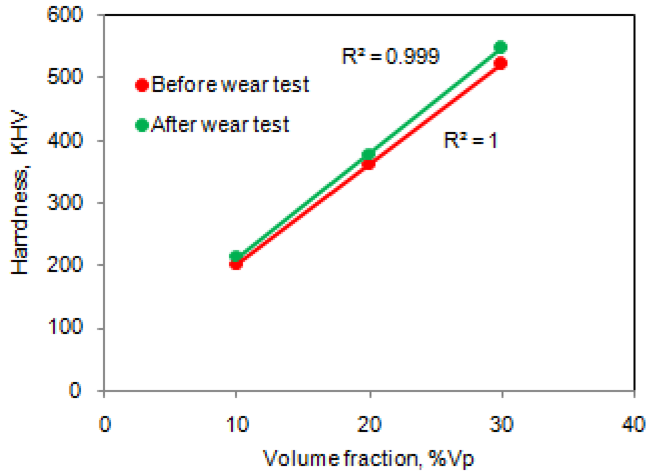

Figure 3: Harness of AA4015/B_4C composites after wear test.

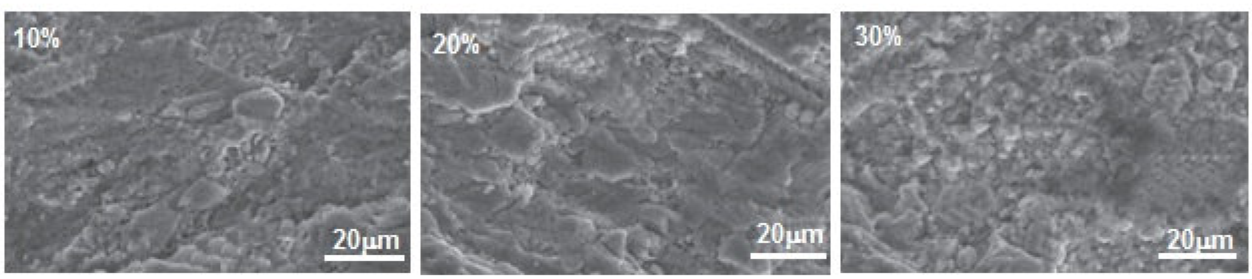

Figure 4: SEM images of worn surfaces of AA4015/B_4C composites: (a) 10 vol.% B_4C (b) 20 vol.% B_4C and (c) 30 vol.% B_4C.

4. CONCLUSION

The investigation on the wear behavior of the composites as the function of vol.% of reinforcement, load, speed and sliding distance using Taguchi's design of experiments was carried out successfully. The following are drawn from the present work as follows:

1. The wear loss decreases with increase of vol.% B_4C in AA4015 alloy matrix.
2. The wear loss increases with increase in normal load and sliding distance.
3. The wear loss decreases with increasing speed.

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