Tribological Performance of AA3003/B_4C Metal Matrix Composites

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Abstract: *In the present work, the AA3003-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 AA3003 alloy/ B_4C composite reveals the detachment of B_4C particles from the matrix.*

Keywords: *Metal matrix composite, AA3003 alloy, boron carbide, wear, sliding distance, normal load, sliding speed.*

1. INTRODUCTION

Aluminum matrix composites reinforced with ceramic particles exhibit high strength, high elastic modulus, and improved resistance to wear, creep and fatigue compared to unreinforced metals which make them promising structural materials for aerospace and automobile industries. [1-14]. Friction, wear and contact problems are subjects of numerous experimental and theoretical studies. The very complex nature of tribological phenomena is a reason that many problems of contact mechanics are still not solved. Similar to the wear of metal, composite wear is affected by several factors that may be broadly divided into three groups: mechanical, environmental, and thermal [15-27]. This classification of composite wear includes fatigue wear, chemical wear, delamination wear, fretting, erosion, abrasion, and transfer wear. The modeling of friction and wear can be carried out not only with the aid of laboratory tests but using also mathematical models and computer simulations.

There is still a need for efficient and reliable computational procedures of contact problems taking into account complex phenomena of friction and wear. Wear is a process of gradual removal of a material from surfaces of solids. The detached material becomes loose wear debris. Nowadays, wear particles are the subject of intensive studies. The present work is on the assessment of wear characteristics and consequences of cast AA3003/B_4C composites. The design of experiments was based on Taguchi techniques [28, 29].

2. MATERIALS METHODS

The matrix material was AA3003 alloy. The reinforcement material was boron carbide (B_4C) nanoparticles of average size 100nm. AA3003 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. Each of the process parameters was deliberated at three levels as mentioned in Table 1. The orthogonal array, L9 was preferred to carry out wear tests (Table 2). A pin on disc type friction and wear monitor (ASTM G99) was employed to evaluate the friction and wear behavior of AA3003 alloy/B_4C composites against hardened ground steel (En32) disc.

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

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

The lower-bound equation is given by

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

where, $\delta = E_p/E_m$. 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.

The microhardness was measured in terms of Knoop hardness number. The Knoop hardness number KHN is the ratio of the load applied to the indenter, P (kgf) to the unrecovered projected area:

$$KHN = \frac{P}{CL^2} \quad (3)$$

where,
P = applied load in kgf
L = measured length of long diagonal of indentation in mm
C = 0.07028 = Constant of indenter relating projected area of the indentation to the square of the length of the long diagonal.

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 hardness properties of AA3003/B_4C composites are shown in figure 1. The elastic stiffness and knoop hardness were increased with volume fraction of B_4C.

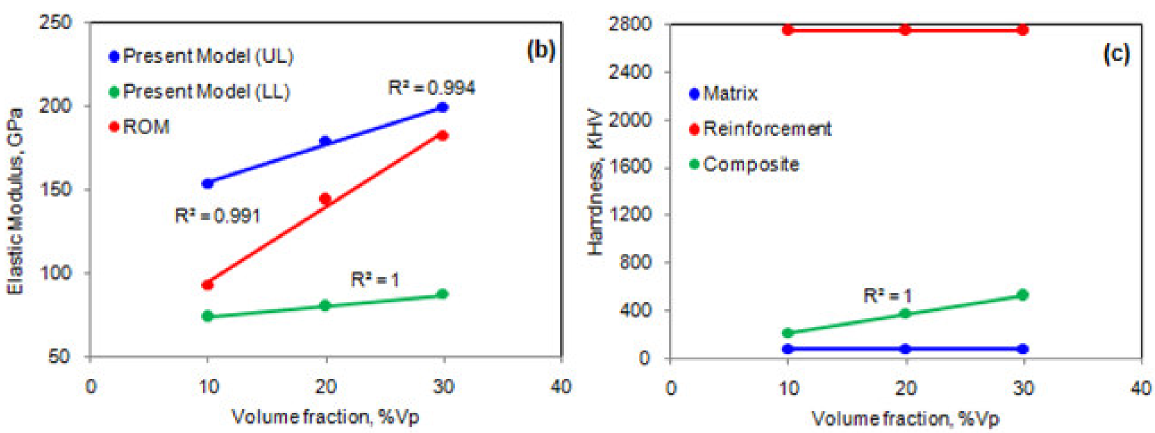

Figure 1: Elastic modulus and hardness properties of AA3003/B_4C composites.

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

For the analysis of variance (ANOVA), all parameters qualify Fisher's test at 90% confidence level. The percent contribution indicates that the parameter A, contributes 56.81% of variation in the wear rate. The parameter, B adds 18.79% of variation in the wear rate. The parameter, C tenders 9.93% of variation in the wear rate. The parameter, D presents 14.48% of variation in the wear rate. The wear rate was decreased with increase in volume fraction of B_4C in AA3003 alloy matrix (figure 2a). This is owing to high hardness of B_4C as compared to soft AA3003 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. The wear rate was increased with the sliding distance as shown in figure 2d. During sliding, as the sliding distance increases the time of contact between the surfaces were also increased resulting more material loss.

Table 3: ANOVA summary of the effective stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	23.12000	20.98000	17.42000	5.52702	1	5.5270222	1.94E+14	56.81
B	18.82000	20.57000	22.13000	1.82802	1	1.8280222	6.43E+13	18.79
C	21.28000	21.12000	19.12000	0.96569	1	0.9656889	3.40E+13	9.93
D	19.48000	131.60563	61.52000	1.40869	1	1.4086889	4.96E+13	14.48
e				0.00000	4	0.0000	1.00E+00	0.00
T	82.70000	194.27563	120.19000	9.72942	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.

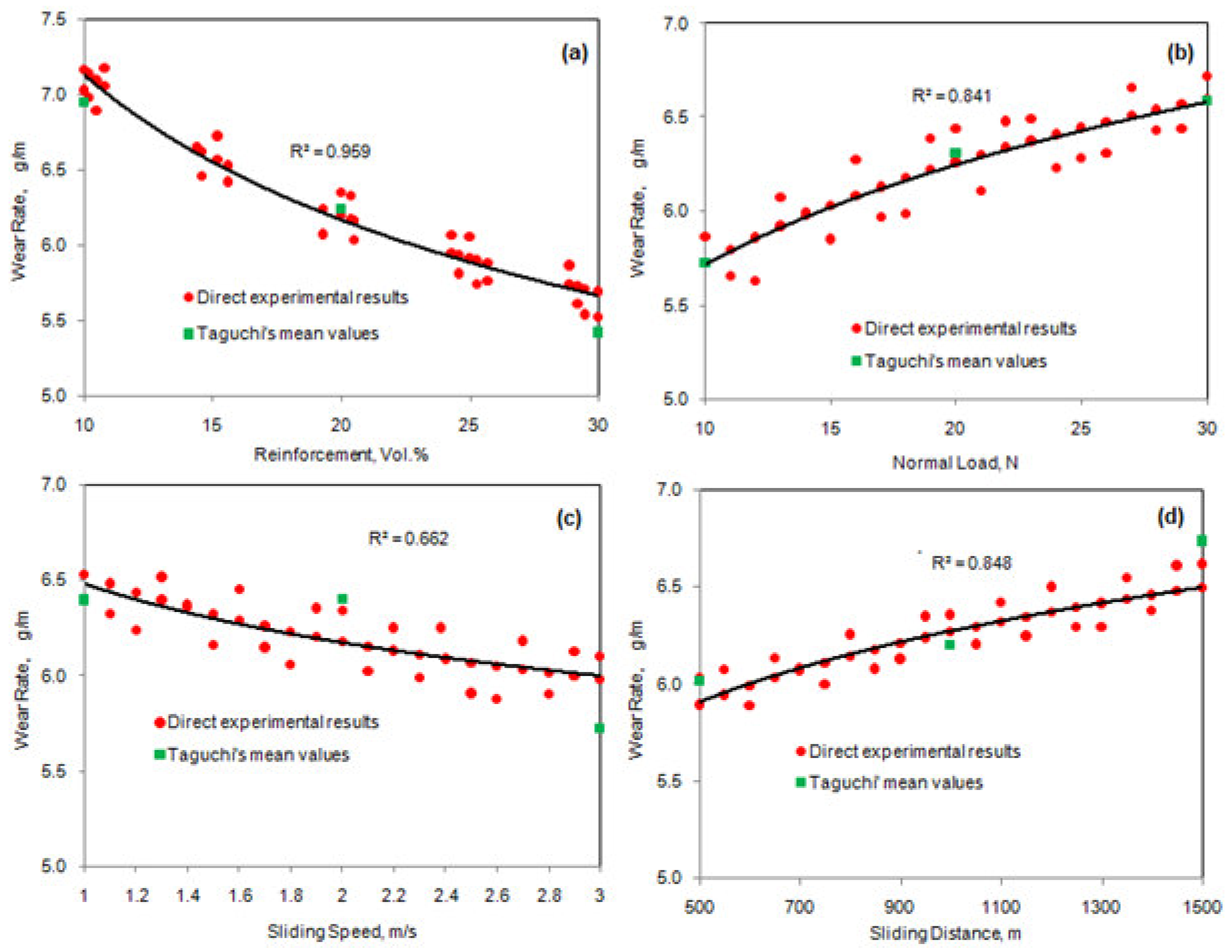

Figure 2: Influence of process parameters on wear rate.

The mathematical relations between wear and vol.% of reinforcement, normal load, speed and sliding distance are given by

$$W_{rp} = 11.56 \times {v_f}^{-0.20} \quad (4)$$

$$W_{rf} = 4.254 \times F^{0.128} \quad (5)$$

$$W_{rn} = 6.475 \times N^{-0.08} \quad (6)$$

$$W_{rd} = 3.453 \times d^{0.086} \quad (7)$$

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

The R-squared values, which are attributable to vol.% reinforcement, normal load, sliding speed and sliding distance, are 0.968, 0.861, 0.741 and 0.819, respectively. This trend is similar to the percent contributions of process parameters obtained from Taguchi techniques.

3.2 Consequence of Wear in AA3003/Al_2O_3 Composites

The purpose of post-wear evaluation is to focus the changes that are brought in the worn specimens in terms of mechanical properties, microstructure, and worn-surface pattern. It can be seen from figure 3 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.

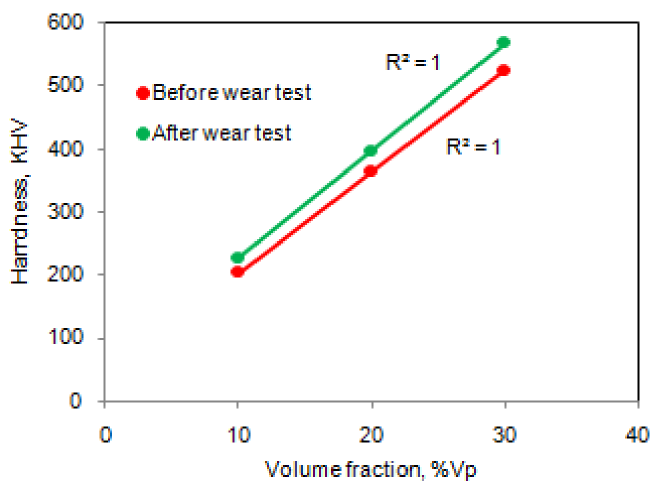

Figure 4: Harness of AA3003/B_4C composites after wear test.

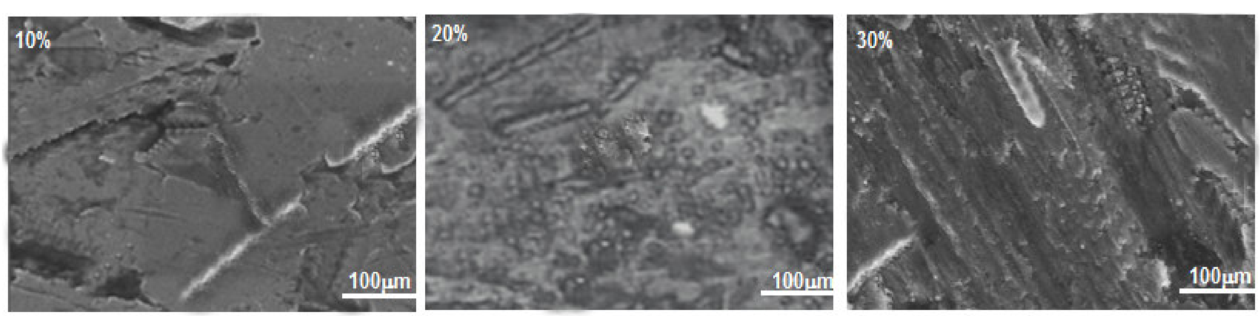

Figure 5: SEM images of worn surfaces of AA3003/B_4C composites (a) 10 vol.% B_4C (b) 20 vol.% B_4C and (c) 30 vol.% B_4C.

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 wear loss decreases with increase of vol.% B_4C in AA3003 alloy matrix. The wear loss increases with increase in normal load and sliding distance. The wear loss decreases with increasing speed.

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