Significance of Testing Parameters on the Wear Behavior of AA1100/B_4C Metal Matrix Composites based on the Taguchi Method

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Abstract: *Aluminum Metal Matrix Composites (MMCs) have gained increasing commercial applications over the years. Aluminum alloys reinforced with different ceramic particles such as Alumina (Al_2O_3), Silicon carbide (SiC), Boron Carbide (B_4C), Titanium carbide (TiC), Titanium diboride (TiB_2) and Graphite show improved mechanical and tribological properties. Accordingly the properties of aluminum MMCs have been studied by many researchers in the past few years. In the present work, the AA1100-B_4C metal matrix composites were manufactured at 10% and 30% volume fractions of B_4C. The pin-on-disc wear test was conducted with different combinations of reinforcement, sliding distance, normal load, sliding speed. Based on the experimental results empirical models were established. The wear rate decreases with increase of vol.% B_4C in AA1100 alloy matrix. Three-body abrasive mechanism was predominant in the wear mechanisms of AA1100-B_4C metal matrix composites.*

Keywords: *AA1100, boron carbide, wear, sliding distance, normal load, sliding speed.*

1. INTRODUCTION

Composite materials permit other physical properties besides mechanical behavior such as: modulus, density, wear resistance, thermal conductivity, etc., to be custom designed to specific applications [1]. The development of Al based metal matrix composites is attracting a lot of interest from materials engineers in developing countries [2-10]. There are different types of reinforcement such as whiskers, particle, fiber and filament. Mainly particle reinforcement is preferred over the other types of reinforcement for synthesizing the metal matrix composite [11-17]. The tribological test are performed in different tribological testers such as pin-on-disk, block-on-ring, abrasive wear tester, etc. Mainly factors like applied load, sliding speed, sliding distance and temperature are varied during tribological testing to study the variation in wear rate and friction coefficient. The researchers have also carried out hardness and microstructure study of the materials to evaluate the hardness improvement and wear behavior of the materials.

In the current work, the wear behavior of boron carbide reinforced AA1100 matrix composites produced using step stir casting process was investigated. The variables for wear tests were volume fraction of reinforcement, applied load, sliding distance and sliding speed. The experiments were executed as per the Taguchi's design of experiments [18, 19].

2. MATERIALS METHODS

The matrix material was AA1100 alloy. The reinforcement material was boron carbide (B_4C) nanoparticles of average size 100nm. AA1100/B_4C composites were fabricated by the stir casting process and low pressure die casting technique with argon gas at 3.0 bar. The composite samples were given H18 heat 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, L9 was preferred to carry out wear tests experimentally (Table 2). A pin on disc type wear monitor (ASTM G99) was employed to evaluate the wear behavior of AA1100/B_4C composites against hardened ground steel (En32) disc. To determine hardness before and after wear test, the Knoop hardness was conducted. The worn surfaces were examined microscopically.

Table 1: Control parameters and levels

Factor	Symbol	Level–1	Level–2	Level–3
Reinforcement, vf	A	0.1	0.2	0.3
Load, N	B	10	20	30
Speed, m/s	C	1	2	3
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

3. RESULTS AND DISCUSSION

All process parameters are acceptable as they satisfy Fisher's test at 90% confidence level. The analysis of variance (ANOVA) is presented in Table 3. The percent contribution indicates that the volume fraction of B_4C, contributes 74.14%. The normal load gives 10.42% of variation in the wear rate. The sliding speed is insignificant. The sliding distance tenders 14.44% of the total variation in the wear rate. The R-squared values of %reinforcement, normal load, sliding speed and sliding distance are, respectively, 0.9200, 0.8138, 0.2474 and 0.8364. The trend of mean values obtained by Taguchi techniques is same as that of R-squared values.

Table 3: ANOVA summary of the wear rate

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	2.26E-02	2.01E-02	1.88E-02	2.47E-06	1	2.47E-06	6.08E+13	74.14
B	2.01E-02	2.00E-02	2.13E-02	3.47E-07	1	3.47E-07	8.55E+12	10.42
C	2.07E-02	2.04E-02	2.03E-02	3.34E-08	1	3.34E-08	8.20E+11	1.00
D	1.95E-02	1.42E-04	6.14E-02	4.82E-07	1	4.82E-07	1.18E+13	14.44
e				1.63E-19	4	4.07E-20	1.00	0.00
T	8.29E-02	6.07E-02	1.22E-01	3.34E-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.

The wear rate was decreased with increase in volume fraction of B_4C in AA1100 alloy matrix (figure 1a). This is due to high hardness of B_4C as compared to soft matrix. An increase in wear rate is with increase of normal load applied on the test specimen (figure 1b). This effect was due to adhesion and increase in plastic deformation at the surface layers. The wear rate was not influenced by the increase of speed (figure 1c). The wear rate increased with the sliding distance as shown in figure 1d.

The mathematical relation between wear and contact time is given by

$$W_{rp} = 0.0054{v_f}^{-0.1406} \quad (1)$$

$$W_{rf} = 0.0052F^{0.0952} \quad (2)$$

$$W_{rn} = 0.0069N^{0.0128} \quad (3)$$

$$W_{rd} = 0.0025d^{0.1561} \quad (4)$$

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.

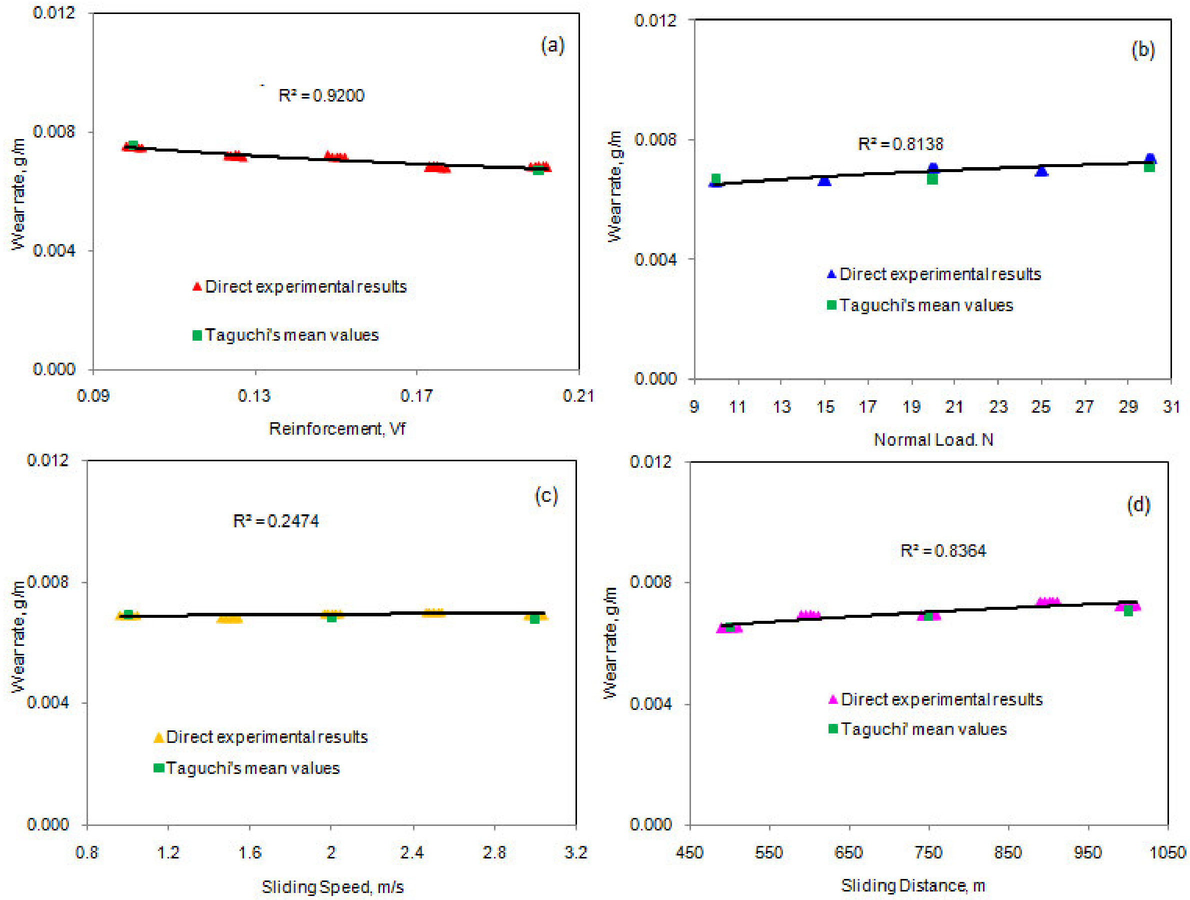

Figure 1: Influence of process parameters on wear rate.

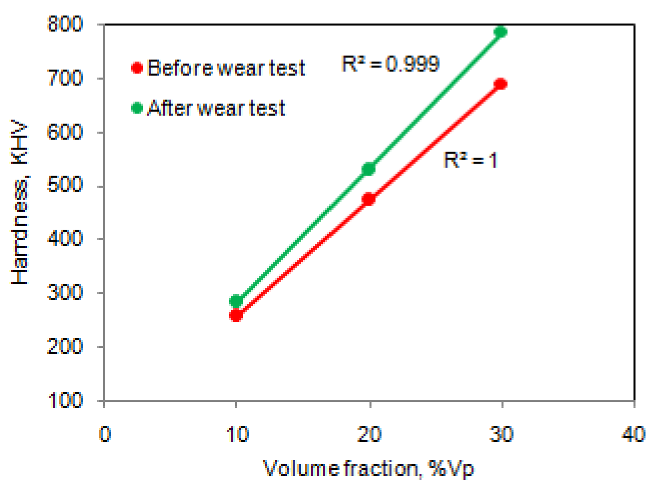

Figure 2: Hardness of AA1100/B_4C composites after wear test.

It is important to identify the consequence of wear in AA1100/B_4C composites. The change in hardness of the worn specimens is shown in figure 2. 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. When the load was increased, the plastic deformation would take place in the AA1100 alloy matrix which could adhere to the steel disc and consequently, resulting the conditions of adhesive wear. If the wear is caused by a hard particle (B_4C) trapped between the rubbing surfaces, the phenomenon is called three-body abrasive wear. The particle may be either free or partially entrenched into one of the mating materials.

4. CONCLUSION

The study on the wear behavior of AA1100/B_4C composites as the function of vol.% of B_4C, normal load, sliding speed and sliding distance using Taguchi's design of experiments was carried out successfully. The wear resistance increases with increase of vol.% B_4C nanoparticles in AA1100 alloy matrix. The wear rate increases with increase in normal load and sliding distance. The dominant mechanisms of adhesive wear and three-body abrasive wear.

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