Unlubricated Sliding of AA4015/TiB_2 Metal Matrix Composites

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Abstract: *In the present work, the AA4015/TiB_2 metal matrix composites were manufactured at 10% and 30% volume fractions of TiB_2. 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 resistance increases with increase of vol.% TiB_2 in AA4015 alloy matrix. Combined effect of adhesion and abrasions were predominant in the wear mechanisms of AA4015-TiB_2 metal matrix composites.*

Keywords: *AA4015, titanium boride, wear, sliding distance, normal load, sliding speed.*

1. INTRODUCTION

Metal matrix composites have added advantages compared to the base material due to the presence of the reinforcements. Aluminum has a good thermal conductivity, less density and a high strength to weight ratio. Upon adding the material, the strength, stiffness, density and thermal/electrical conductivity of the composites improve considerably [1-19]. From the various studies on dry sliding wear of aluminum composites, effects of reinforcement size, volume fractions and morphology on the wear rate can be observed. Similarly, effects of various operation parameters on the dry sliding wear have been discussed in previous studies [20-27].

The objective of the present work was to evaluate the dry sliding wear behavior of AA4015/TiB_2 composites over a range of loads, sliding distances and sliding speeds.

2. MATERIALS METHODS

The matrix material was AA4015alloy. The reinforcement material was titanium boride (TiB_2) nanoparticles of average size 100nm. AA4015 alloy/ TiB_2 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 H16 heat treatment. The heat-treated samples were machined to get cylindrical specimens for the wear tests.

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

The design of experiments was carried out as per Taguchi techniques [27, 28]. The levels chosen for the controllable process parameters are summarized in Table 1. Each of the process parameters was deliberated at three levels. The orthogonal array (OA), L9 was preferred to carry out wear tests experimentally (Table 2). A pin on disc type friction and wear monitor (ASTM G99) was employed to evaluate the friction and wear behavior of AA4015 alloy/ TiB_2 composites against hardened ground steel (En32) disc.

Elastic modulus is 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.

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 stiffness and hardness properties of AA4015/ TiB_2 composites are shown in figure 1. The elastic stiffness and knoop hardness were increased with volume fraction of TiB_2.

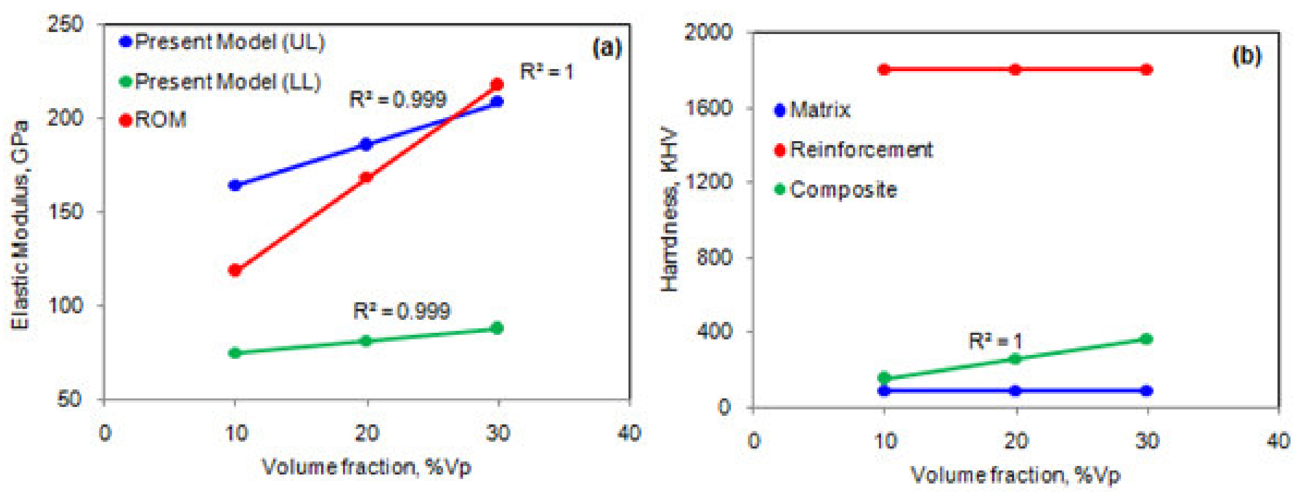

Figure 1: Mechanical Properties of AA4015/TiB_2 composites.

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

The analysis of variance (ANOVA) is presented in Table 3. The percent contribution indicates that the parameter A, vol.% of TiB_2, contributes 50.40%. The normal load (B) shares 14.11% of variation in the wear rate. The speed (C) dispenses 7.14% of variation in the wear rate. The sliding distance (D) affords 28.35% of the total variation in the wear rate. The R-squared values of %reinforcement, normal load, sliding speed and sliding distance are, respectively, 0.949, 0.803, 0.653 and 0.946. The trend of mean values obtained by Taguchi techniques is same as that of R-squared values. The influence of vol.% of TiB_2 on wear rate is shown in figure 2a. It can be seen that the wear rate was decreased with increase in volume fraction of TiB_2 in AA4015 alloy matrix. This is owing to high hardness of TiB_2 as compared to soft matrix. An increase in wear rate is with increase of normal load applied on the test specimen (figure 2b). The increase in the load causes rise in friction. This effect results in adhesion and increases the deformation at the surface layers, leading to loss of the metal. The wear rate was decreased with increase of speed (figure 2c). The wear rate was proportional to the sliding distance as shown in figure 2d. This might be due to the delamination and chipping out of the TiB_2 particles from the matrix.

Table 3: ANOVA summary of the effective stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	20.14	19.69	18.70	0.36	1.00	0.36	1.27E+13	50.40
B	19.28	19.29	19.96	0.10	1.00	0.10	3.56E+12	14.11
C	19.68	19.66	19.19	0.05	1.00	0.05	1.80E+12	7.14
D	18.99	126.10	58.53	0.20	1.00	0.20	7.16E+12	28.35
e				0.00	4.00	0.00	1.00	0.00
T	78.09	184.74	116.38	0.72	8.00			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.

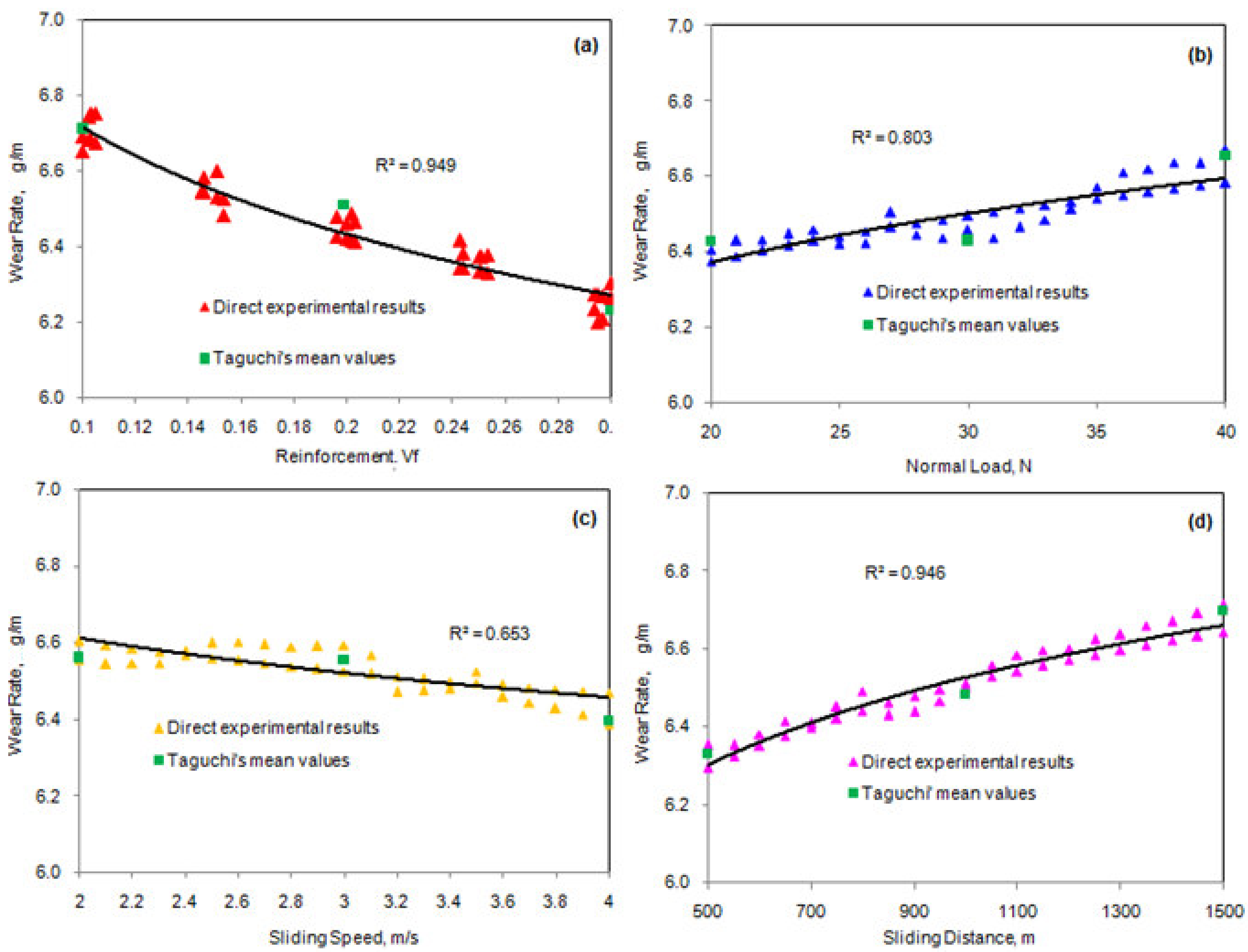

Figure 2: Influence of process parameters on wear rate.

The mathematical relation between wear and contact time is given by

$$W_{rp} = 5.817 {v_f}^{-0.06} \quad (3)$$

$$W_{rf} = 5.505 F^{0.048} \quad (4)$$

$$W_{rn} = 7.763N^{-0.03} \quad (5)$$

$$W_{rd} = 4.61d^{0.05} \quad (6)$$

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.

3.2 Consequence of Wear in AA4015/ TiB_2 Composites

It is essential to know the consequence of wear in AA4015/ TiB_2 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 work hardening and the frictional temperature. When the applied normal load increased, the plastic deformation would take place in the AA4015 alloy matrix which could adhere to the steel disc and consequently, resulting the conditions of adhesive wear as shown in figure 4. If the wear is caused by a hard particle (TiB_2) trapped between the rubbing surfaces it is called three body wear. The particle removal was higher in the composites having 30% TiB_2 than in the composites having 10% TiB_2.

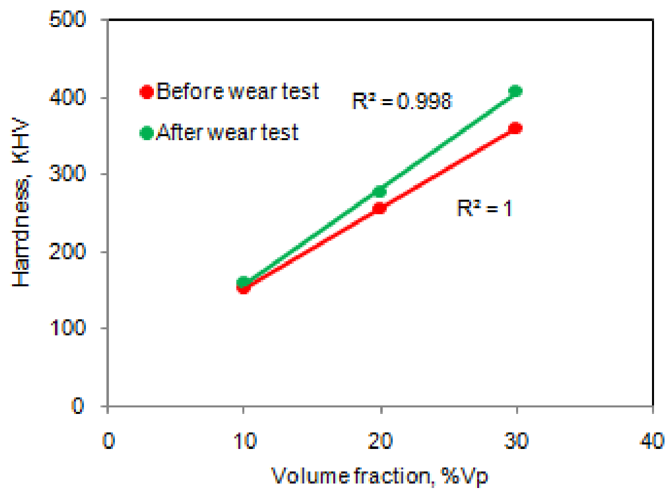

Figure 3: Hardness of AA4015/ TiB_2 composites after wear test.

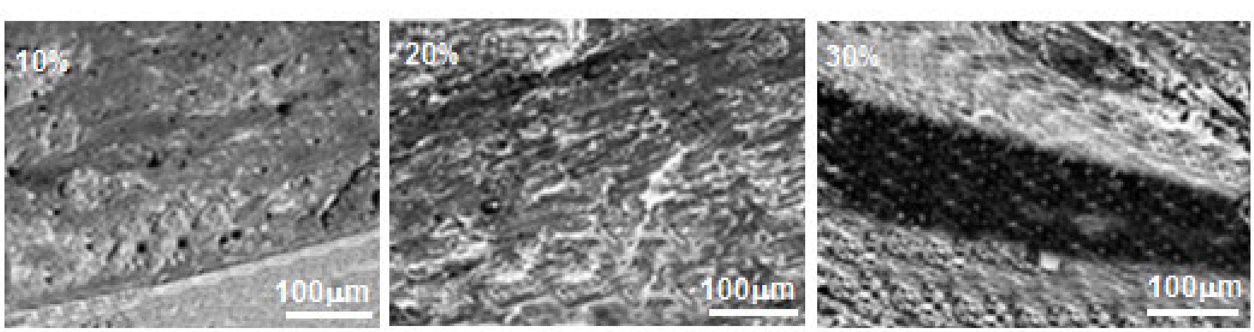

Figure 4: Adhesive and abrasive wear of AA4015/ TiB_2.

4. CONCLUSION

The study on the wear behavior of AA4015/TiB_2 composites as the function of vol.% of TiB_2, 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.% TiB_2 nanoparticles in AA4015 alloy matrix. The dominant mechanisms of wear were combination of adhesion and abrasion.

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