Tribological Analogy of Cast AA2024/TiB_2 Composites

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Abstract: *In the current work, the AA2024/TiB_2 metal matrix composites were manufactured at 10% and 30% volume fractions of TiB_2. The composites were wear tested at different levels of normal load, sliding speed and sliding distances. The microstructure of worn surfaces pertaining to AA2024 alloy/TiB_2 composite reveals the detachment of TiB_2 particles from the matrix.*

Keywords: *Metal matrix composite, AA2024 alloy, titanium boride, wear, sliding distance, normal load, sliding speed.*

1. INTRODUCTION

Modeling wear is essential for tribological applications of metal matrix composites. Even though mechanical characterization of composite materials has advanced significantly over the past decade, the definition of clear strategies for tribological behavior still remains challenging. It has been established that a proper selection of reinforce and matrix materials may help to widen the scope of metal matrix composites [1-17]. The wear characteristics of the composites depend upon the material morphology [18-22]. 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.

The present work is on the determination of wear characteristics and consequences of cast AA2024/titanium boride composites. The design of experiments was based on Taguchi techniques [23, 24].

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

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

2. MATERIALS METHODS

The reinforcement material was titanium boride (TiB_2) nanoparticles of average size 100nm. AA2024 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 heat treatment of T6. The heat-treated samples were machined to get cylindrical specimens of dimension 10 mm diameter and 30 mm length for the wear tests. A pin on disc type friction and wear monitor (ASTM G99) was employed to evaluate the friction and wear behavior of AA2024 alloy/ TiB_2 composites against hardened ground steel (En32) disc. 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 conduct experiments. An exploration has been carried out to study the effects of sliding speed, contact time, normal pressure, and volume fraction of TiB_2 on the wear characteristics. Scanning electron microscopy analysis was also carried out to find consequence of wear test AA2024/ TiB_2 composite specimens.

Elastic modulus is measure of the stiffness of a material and is a quantity used to characterize materials. Elastic modulus is the same in all orientations for isotropic materials.

The upper-bound equation is given by

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

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, $\delta = E_p/E_m$.

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.

The microhardness was measured in terms of Knoop hardness number. The Knoop indenter is a diamond ground to pyramidal form that produces a diamond shaped indentation having approximate ratio between long and short diagonals of 7:1. The depth of indentation is about 1/30 of its length. When measuring the Knoop hardness, only the longest diagonal of the indentation was measured and this was used in the formula mentioned in Eq. (5) with the load used to calculate KHN.

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.

3. RESULTS AND DISCUSSION

The elastic modulus (figure 1a) and knoop hardness (figure 1b) were increased with volume fraction of TiB_2. This is owing to higher stiffness and hardness of titanium boride nanoparticles than those of AA2024 alloy matrix. At 30% of TiB_2 the elastic stiffness values of AA2024/TiB_2 composites were nearly same as computed by the present model and by Rule of Mixtures (ROM). There is a lot discrepancy at low volume fraction of TiB_2. This may be due to the ignorance of the effects of porosity and clustering of nanoparticles in the ROM model.

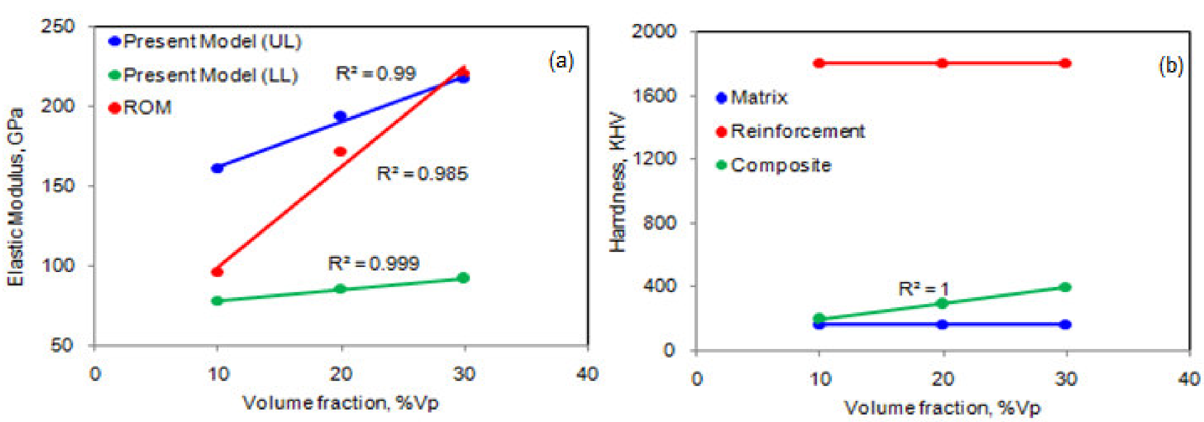

Figure 1: Elastic modulus and hardness of AA2024/TiB_2 composites.

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. In Table 3, the percent contribution indicates that the parameter A, assigns 63.41% of variation in the wear rate. The parameter B accords 19.38% of variation in the wear rate. The parameter C contributes 2.02% of variation in the wear rate. The parameter D presents 15.19% of variation in the wear rate.

Table 3: ANOVA summary of the effective stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	23.01	21.34	20.21	1.32	1	1.32	3.10E+13	63.41
B	20.64	21.80	22.12	0.40	1	0.40	9.48E+12	19.38
C	21.68	21.65	21.23	0.042	1	0.042	9.90E+11	2.02
D	21.31	146.44	64.56	0.31	1	0.31	7.43E+12	15.19
e				0.00	4	0.00	1.00E+00	0
T	86.64	211.23	128.12	2.086	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.

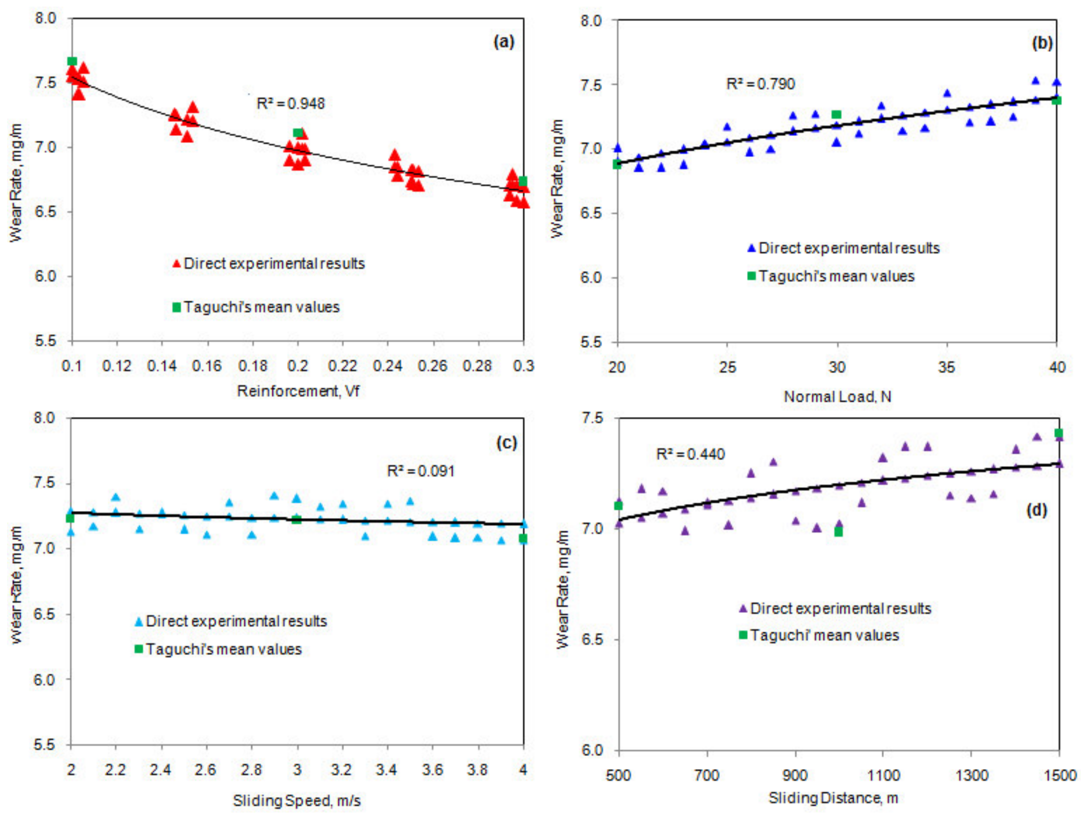

Figure 2: Influence of process parameters on wear rate.

The wear test results are shown in figure 2. Owing to high hardness of TiB_2, the wear rate was decreased with increase in volume fraction of TiB_2 in AA2024 alloy matrix (figure 2a). 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). The plastic deformation decreases with increasing the sliding speed. From figure 3d it is observed that the wear rate was increased with the sliding distance. The mathematical relations between wear and vol.% of reinforcement, normal load, speed and sliding distance are given by

$$W_{rp} = 5.817 \times v_f^{-0.11} \quad (6)$$

$$W_{rf} = 5.042 \times F^{0.104} \quad (4)$$

$$W_{rn} = 7.37 \times N^{-0.01} \quad (5)$$

$$W_{rd} = 5.769 \times d^{0.032} \quad (6)$$

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 mathematical expressions were fit into power-law function. In statistics, a power law is a functional relationship between two quantities, where a relative change in one quantity results in a proportional relative change in the other quantity, independent of the initial size of those quantities. One attribute of power laws is their scale invariance. The R-squared values, which are attributable to volume fraction of reinforcement, normal load, sliding speed and sliding distance, are 0.948, 0.790, 0.091 and 0.440, respectively. This trend is similar to the percent contributions of process parameters obtained from Taguchi techniques.

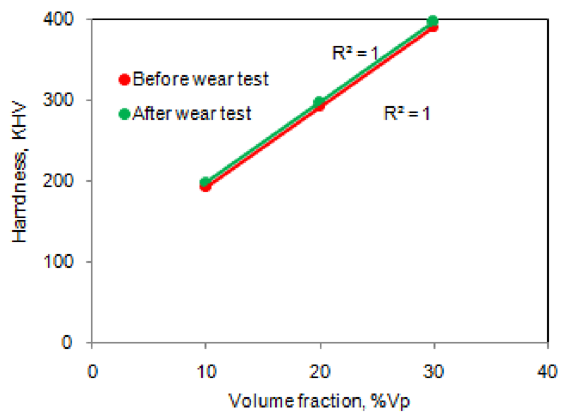

Figure 3: Harness of AA2024/ TiB_2 composites after wear test.

3.2 Consequence of Wear in AA2024/ TiB_2 Composites

It is important to settle on the corollary of wear in AA2024/ 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 mainly due to influence of volume fraction of TiB_2 and load applied on the wear specimens. The microstructures of worn specimens are revealed in figure 4. When the reinforcement increased from 10% to 30% the scratches and detachment of particles were also increased. The scratches are more in the matrix dominated composites due to its softness; whereas the detachment of nanoparticles is predominant in the reinforcement (i.e., high volume fraction) subjugated composites.

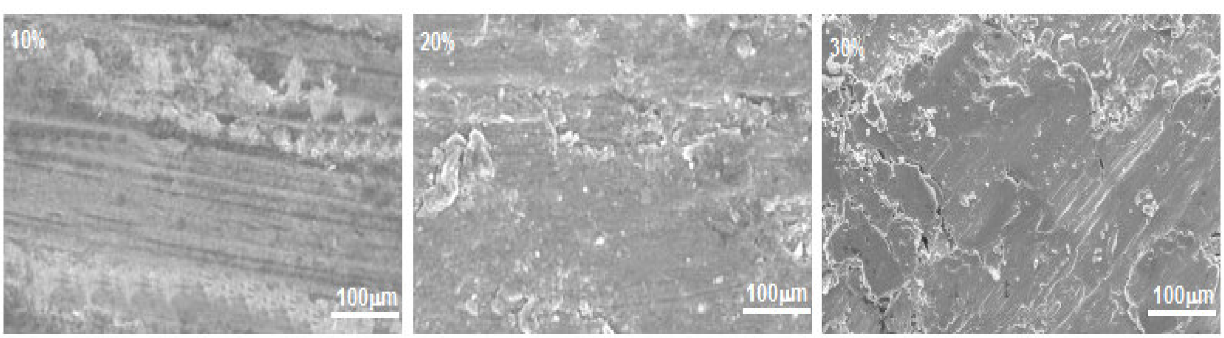

Figure 6: SEM images of worn surfaces of AA2024/ TiB_2 composites: (a) 10 vol.% TiB_2 (b) 20 vol.% TiB_2 and (c) 30 vol.% TiB_2.

3. CONCLUSION

The exploration on the wear behavior of the composites as the function of volume fraction of reinforcement, load, sliding speed and sliding distance using Taguchi's design of experiments was carried out lucratively. The wear loss decreases with increase in volume fraction of TiB_2 in AA2024 alloy matrix; while it increases with load applied on the wear specimens.

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