Wear Resistant Titanium Boride Metal Matrix Composites

A. Chennakesava Reddy

Associate Professor, Department of Mechanical Engineering, Vasavi College of Engineering, Hyderabad, India
dr_acreddy@yahoo.com

Abstract: According to ASTM G40, abrasive wear is degradation 'due to hard particles or hard protuberances forced against and moving along a solid surface;' whereas erosive wear is defined as 'the progressive loss of original material from a solid surface due to mechanical interaction between that surface and a fluid, a multi-component fluid, or impinging liquid or solid particles.' In this paper, AA3003/TiB_2 metal matrix composites were prepared by the stir casting technique. 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 increases due to damage and degradation to the surface result from a conversion and transfer of kinetic energy of the hard particles. The wear resistance was improved with increasing volume fraction of titanium boride in the composites.

Keywords: AA3003, titanium boride, wear, sliding distance, normal load, sliding speed.

1. INTRODUCTION

Metal matrix composites (MMCs) provide significantly enhanced properties over conventional monolithic materials, such as higher strength, stiffness, and weight savings [1-7]. A large amount of work has been conducted in an effort to characterize the mechanical behavior of particle reinforced metal matrix composites. In metal matrix composites, the reinforcing phase typically is much stiffer than the matrix [8-15].

Numerous reports are available on the subject of the fabrication and wear studies of the SiC reinforced composites [16]. Ultra-hard materials are commonly used for Wear-resistant applications and also for advanced cutting tools. Such materials are needed in many applications such as earth moving, mining, abrasive slurry transport, rock drilling etc. where they experience sliding or impacting interaction with abrasive particles [17]. The ceramic is super abrasive, and in most instances exhibits a hardness of 30 GPa or greater. This research relates to new compositions involving the use of Al alloy and titanium boride (TiB_2) as a strengthening reinforcement to provide composites of extremely high abrasive wear resistance.

In the present work, the wear behavior of TiB_2 reinforced AA3003 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 AA3003 alloy. The reinforcement material was titanium boride (TiB_2) nanoparticles of average size 100nm. AA3003/TiB_2 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 H14 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 AA3003/TiB_2 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

The analysis of variance (ANOVA) is presented in Table 3. The percent contribution indicates that the volume fraction of TiB_2, contributes 63.03%. The normal load gives 15.60% of variation in the wear rate. The sliding speed influences 3.31% of variation in the wear rate. The sliding distance supplies 18.06% of variation in the wear rate. The R-squared values of %reinforcement, normal load, sliding speed and sliding distance are, respectively, 0.8612, 0.8210, 0.4191 and 0.8461. 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	2.12E-02	1.96E-02	1.84E-02	1.31E-06	1	1.31E-06	2.41E+13	63.03
B	1.94E-02	1.92E-02	2.05E-02	3.23E-07	1	3.23E-07	5.96E+12	15.60
C	2.00E-02	1.97E-02	1.94E-02	6.85E-08	1	6.85E-08	1.26E+12	3.31
D	1.88E-02	1.34E-04	5.91E-02	3.74E-07	1	3.74E-07	6.90E+12	18.06
e				-2.17E-19	4	-5.42E-20	1.00	0.00
T	7.94E-02	5.87E-02	1.17E-01	2.07E-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 TiB_2 in AA3003 matrix (figure 1a). This is due to hardness values of constituents of the composites. The knoop hardness values of TiB_2 and AA3003 are, respectively, 1800 and 70. Within an increase in the percentage addition of TiB_2, the resulting scratch width decreased, suggestive of improved wear resistance. An increase in wear rate is with increase of normal load applied on the test specimen (figure 1b). This is reflective of the fact that wear rates are proportional to the depth of embedment of abrasive particles into the material surface. The wear rate decreases with the increase of sliding speed (figure 1c). With an increase in speed, the temperature rise at the interface becomes significant so that the action of the abrasive particles involves more plowing and gouging than cutting. The wear rate increased with the sliding distance as shown in figure 1d.

The mathematical relation between wear and contact time is given by

$$W_{rp} = 0.0056{v_f}^{-0.1008} \tag{1}$$

$$W_{rf} = 0.0053F^{0.0814} \tag{2}$$

$$W_{rn} = 0.0067N^{-0.0183} \tag{3}$$

$$W_{rd} = 0.0028d^{0.1324} \tag{4}$$

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.

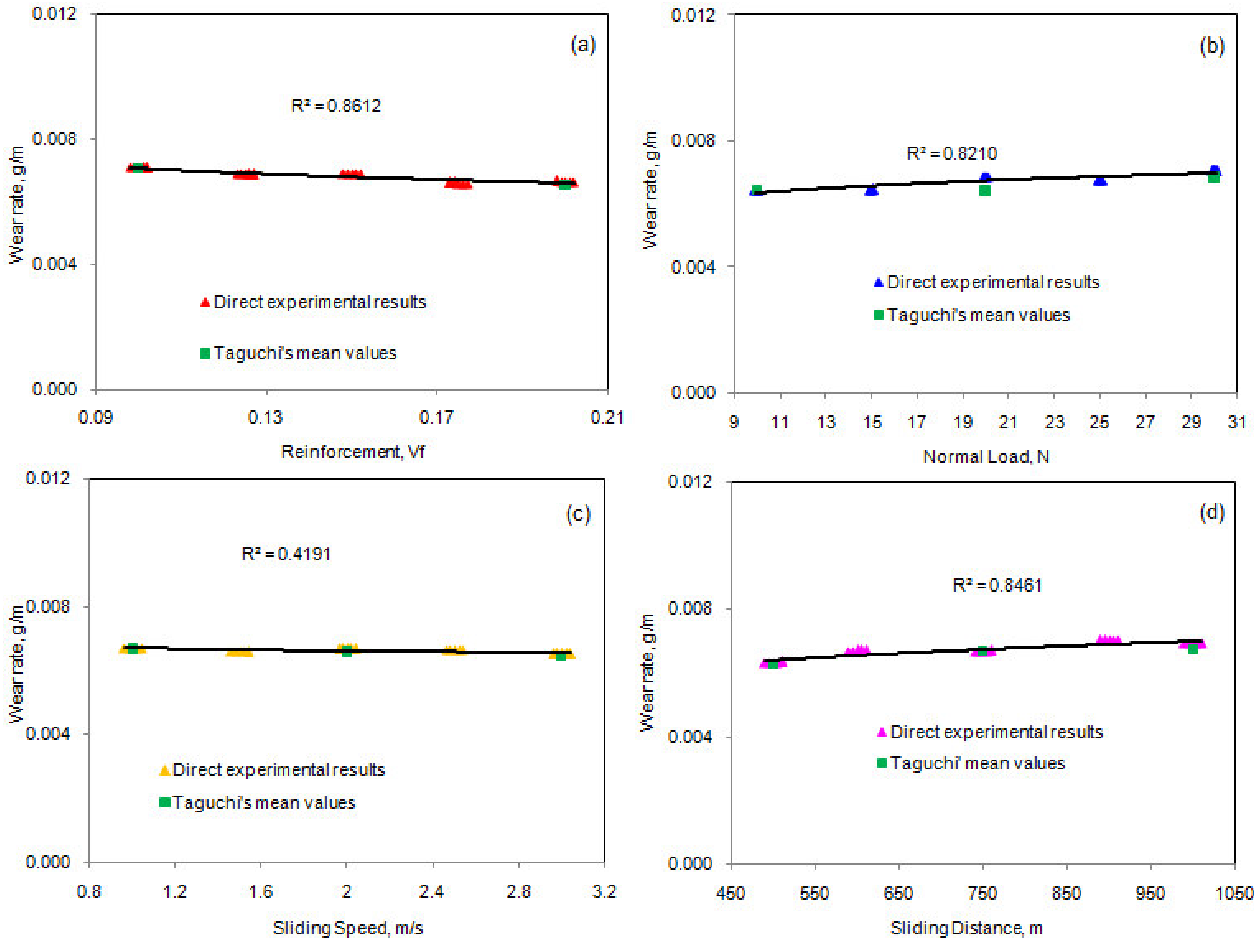

Figure 1: Influence of process parameters on wear rate.

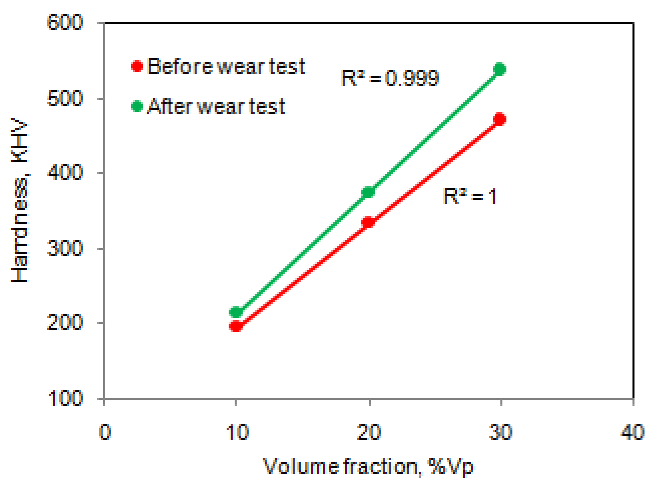

Figure 2: Hardness of AA3003/TiB_2 composites after wear test.

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. When the load was increased, the plastic deformation would take place in the AA3003 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 (TiB_2) trapped between the rubbing surfaces, the phenomenon is called three-body abrasive wear. Damage and degradation to the surface result from a conversion and transfer of kinetic energy of the hard particles. This energy can be dissipated in one of several forms: into the work of fracture (e.g., cohesive energy) of the surface and/or of the particle itself, or into thermal energy.

4. CONCLUSION

The study on the wear behavior of AA3003/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 AA3003 matrix. The wear rate increases due to damage and degradation to the surface result from a conversion and transfer of kinetic energy of the hard particles.

REFERENCES

1. A. Chennakesava Reddy, Evaluation of Debonding and Dislocation Occurrences in Rhombus Silicon Nitride Particulate/AA4015 Alloy Metal Matrix Composites, 1st National Conference on Modern Materials and Manufacturing, Pune, India, 19-20 December 1997, pp. 278-282.
2. A. Chennakesava Reddy, Interfacial Debonding Analysis in Terms of Interfacial Tractions for Titanium Boride/AA3003 Alloy Metal Matrix Composites, 1st National Conference on Modern Materials and Manufacturing , Pune, 19-20 December, 1997.
3. A. Chennakesava Reddy, Assessment of Debonding and Particulate Fracture Occurrences in Circular Silicon Nitride Particulate/AA5050 Alloy Metal Matrix Composites , National Conference on Materials and Manufacturing Processes, Hyderabad, India, 27-28 February 1998, pp. 104-109.
4. A. Chennakesava Reddy, Local Stress Differential for Particulate Fracture in AA2024/Titanium Carbide Nanoparticulate Metal Matrix Composites, National Conference on Materials and Manufacturing Processes, Hyderabad, India, 27-28 February 1998, pp. 127-131.
5. A. Chennakesava Reddy, Micromechanical Modelling of Interfacial Debonding in AA1100/Graphite Nanoparticulate Reinforced Metal Matrix Composites, 2nd International Conference on Composite Materials and Characterization, Nagpur, India, 9-10 April 1999, pp. 249-253.
6. A. Chennakesava Reddy, Cohesive Zone Finite Element Analysis to Envisage Interface Debonding in AA7020/Titanium Oxide Nanoparticulate Metal Matrix Composites, 2nd International Conference on Composite Materials and Characterization, Nagpur, India, 9-10 April 1999, pp. 204-209.
7. H. B. Niranjan, A. Chennakesava Reddy, Computational Modeling of Interfacial Debonding in Fused Silica/AA7020 Alloy Particle-Reinforced Metal Matrix Composites, 3rd International Conference on Composite Materials and Characterization, Chennai, India, 11-12 May 2001, pp. 222-227.
8. H. B. Niranjan, A. Chennakesava Reddy, Nanoscale Characterization of Interfacial Debonding and Matrix Damage in Titanium Carbide/AA8090 Alloy Particle-Reinforced Metal Matrix Composites, 3rd International Conference on Composite Materials and Characterization, Chennai, India, 11-12 May 2001, pp. 228-233.
9. S. Sundara Rajan, A. Chennakesava Reddy, Assessment of Temperature Induced Fracture in Boron Nitride/AA1100 Alloy Particle-Reinforced Metal Matrix Composites, 3rd International Conference on Composite Materials and Characterization, Chennai, India, 11-12 May 2001, pp. 234-239.
10. S. Sundara Rajan, A. Chennakesava Reddy, Estimation of Fracture in Zirconia/AA2024 Alloy Particle-Reinforced Composites Subjected to Thermo-Mechanical Loading, 3rd International Conference on Composite Materials and Characterization, Chennai, India, 11-12 May 2001, pp. 240-245.
11. P. M. Jebaraj, A. Chennakesava Reddy, Finite Element Predictions for the Thermoelastic Properties and Interphase Fracture of Titanium Nitride /AA3003 Alloy Particle-Reinforced Composites, 3rd International Conference on Composite Materials and Characterization, Chennai, India, 11-12 May 2001, pp. 246-251.
12. P. M. Jebaraj, A. Chennakesava Reddy, Effect of Thermo-Mechanical Loading on Interphase and Particle Fractures of Titanium Oxide /AA4015 Alloy Particle-Reinforced Composites, 3rd International Conference on Composite Materials and Characterization, Chennai, India, 11-12 May 2001, pp. 252-256.
13. A. Chennakesava Reddy, Effect of CTE and Stiffness Mismatches on Interphase and Particle Fractures of Zirconium Carbide /AA5050 Alloy Particle-Reinforced Composites, 3rd International Conference on Composite Materials and Characterization, Chennai, India, 11-12 May 2001, pp. 257-262.
14. A. Chennakesava Reddy, Behavioral Characteristics of Graphite /AA6061 Alloy Particle-Reinforced Metal Matrix Composites, 3rd International Conference on Composite Materials and Characterization, Chennai, India, 11-12 May 2001, pp. 263-269.
15. A. Chennakesava Reddy, Prediction of CTE of Al/TiB_2 Metal Matrix Composites, 3rd International Conference on Composite Materials and Characterization, Chennai, 11-12 May 2001, pp. 270-275.
16. F. E. Kennedy, A. C. Balbahadur, D. S. Lashmore, Wear, 203-204, 1997, pp. 715-721.

17. A. Chennakesava Reddy, Significance of Testing Parameters on the Wear Behavior of AA1100/B_4C Metal Matrix Composites based on the Taguchi Method, 3rd International Conference on Composite Materials and Characterization, Chennai, 11-12 May 2001, pp. 276-280.
18. A. Chennakesava Reddy, V.M. Shamraj, Reduction of cracks in the cylinder liners choosing right process variables by Taguchi method, Foundry Magazine, 10, 4, 1998, pp. 47-50.
19. A. Chennakesava Reddy, V.S.R. Murti, S. Sundararajan, Control factor design of investment shell mould from coal flyash by Taguchi method, Indian Foundry Journal, 45, 4, 1999, pp. 93-98.