Wear Characteristics of AA5050/TiC Metal Matrix Composites

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Abstract: Aluminum-based metal matrix composites have found application in the manufacture of various automotive engine components such as cylinder blocks, pistons and piston insert rings where adhesive wear (or dry sliding wear) is a predominant process. Materials possessing high wear resistance (under dry sliding conditions) are associated with a stable tribolayer on the wearing surface. For adhesive wear, the influence of applied load, sliding speed, wearing surface hardness, reinforcement fracture toughness and morphology are critical parameters in relation to the wear regime encountered by the material. By using pin on disc apparatus the test was conducted by taking parameters like volume fraction of reinforcement, sliding distance, sliding velocity and loads. For dry sliding, it was found that the magnitude of the plastic strains and the depth of the heavily deformed sub-surface zone increased with both sliding distance and applied load.

Keywords: AA5050, Titanium carbide, wear, sliding distance, normal load, sliding speed.

1. INTRODUCTION

Aluminum metal matrix composites reinforced with discontinuous phases in the forms of whiskers, fibers, and particulates exhibit magnify strength values at higher temperatures, low coefficient of friction and thermal expansion, good wear resistance and stiffness compared to base alloys [1-10]. Several ceramic reinforcements have been identified for Aluminum (Al)-based metal matrix composites [11-19], but recently titanium carbide (TiC) has gained attention over others due to its high hardness, stiffness and wear resistance [20, 21]. TiC particulate reinforced metal matrix composites are very interesting because TiC is thermodynamically stable and enhances the hardness and lightness of the composite.

Adhesive wear is defined as the transfer of material from one surface to another during relative motion by a process of solid-phase welding or as a result of localized bonding between contacting surfaces. Particles that are removed from one surface are either permanently or temporarily attached to the other surface [22-24].

Little information regarding volume fraction related to abrasive or dry sliding wear processes is actually available. The present study is intended to investigate the tribological performance of aluminum matrix composites (AA5050/TiC) sliding against a pin-on-disk tester with the composites as the pins and stainless steel as the disk. The effect of sliding velocity, load, and sliding distance and volume fraction of reinforcement on the wear behavior of the composites is studied. The experiments were executed as per the Taguchi's design of experiments [25].

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

2. MATERIALS METHODS

The matrix material was AA5050 alloy. The reinforcement material was titanium carbide (TiC) nanoparticles of average size 100nm. AA5050/TiC 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 H32 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 AA5050/TiC 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.
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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 TIC, contributes 54.49%. The normal load gives 19.17% of variation in the wear rate. The sliding speed influences 4.48% of variation in the wear rate. The sliding distance supplies 21.86% of variation in the wear rate. The R-squared values of %reinforcement, normal load, sliding speed and sliding distance are, respectively, 0.9702, 0.9534, 0.8615 and 0.9690. 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	4.47E-02	3.50E-02	3.59E-02	1.91E-05	1	1.91E-05	1.18E+14	54.49
B	3.60E-02	3.75E-02	4.21E-02	6.74E-06	1	6.74E-06	4.14E+13	19.17
C	3.75E-02	3.78E-02	4.03E-02	1.58E-06	1	1.58E-06	9.69E+12	4.48
D	3.55E-02	4.79E-04	1.16E-01	7.68E-06	1	7.68E-06	4.72E+13	21.86
e				-6.51E-19	4	-1.63E-19	1.00	0.00
T	1.54E-01	1.11E-01	2.34E-01	3.51E-05	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.

Within an increase in the percentage addition of TiC, the wear rate decreased, suggestive of improved wear resistance (figure 1a). An increase in wear rate is with increase of normal load applied on the test specimen (figure 1b). For above 10N, the wear rates for both materials were similar in this regime with surface morphologies characterized by severe plastic deformation. The wear rate increases with the increase of sliding speed (figure 1c). At these low sliding velocities, the reinforcement did not appear to influence the wear rate and the wear rate for the composites and matrix alloy was similar. At higher sliding speeds, a transition in the wear process occurred which was associated with a breakdown of the tribolayer, with wear being controlled by sub-surface cracking-assisted adhesive transfer and by abrasion. The wear rate increased with the sliding distance as shown in figure 1d. As the sliding distance increases the wear rate increases and as the % of reinforcement increases wear rate decreases because TiC nanoparticles are crushed and form work harden layer between pin and the counter face thus reduces the wear rate of composites.

The mathematical relation between wear and contact time is given by

$$W_{rp} = 0.00686\, v_f^{-0.3230} \tag{1}$$

$$W_{rf} = 0.0085\, F^{0.1396} \tag{2}$$

$$W_{rn} = 0.0115\, N^{0.1084} \tag{3}$$

$$W_{rd} = 0.0022\, d^{0.2730} \tag{4}$$

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.

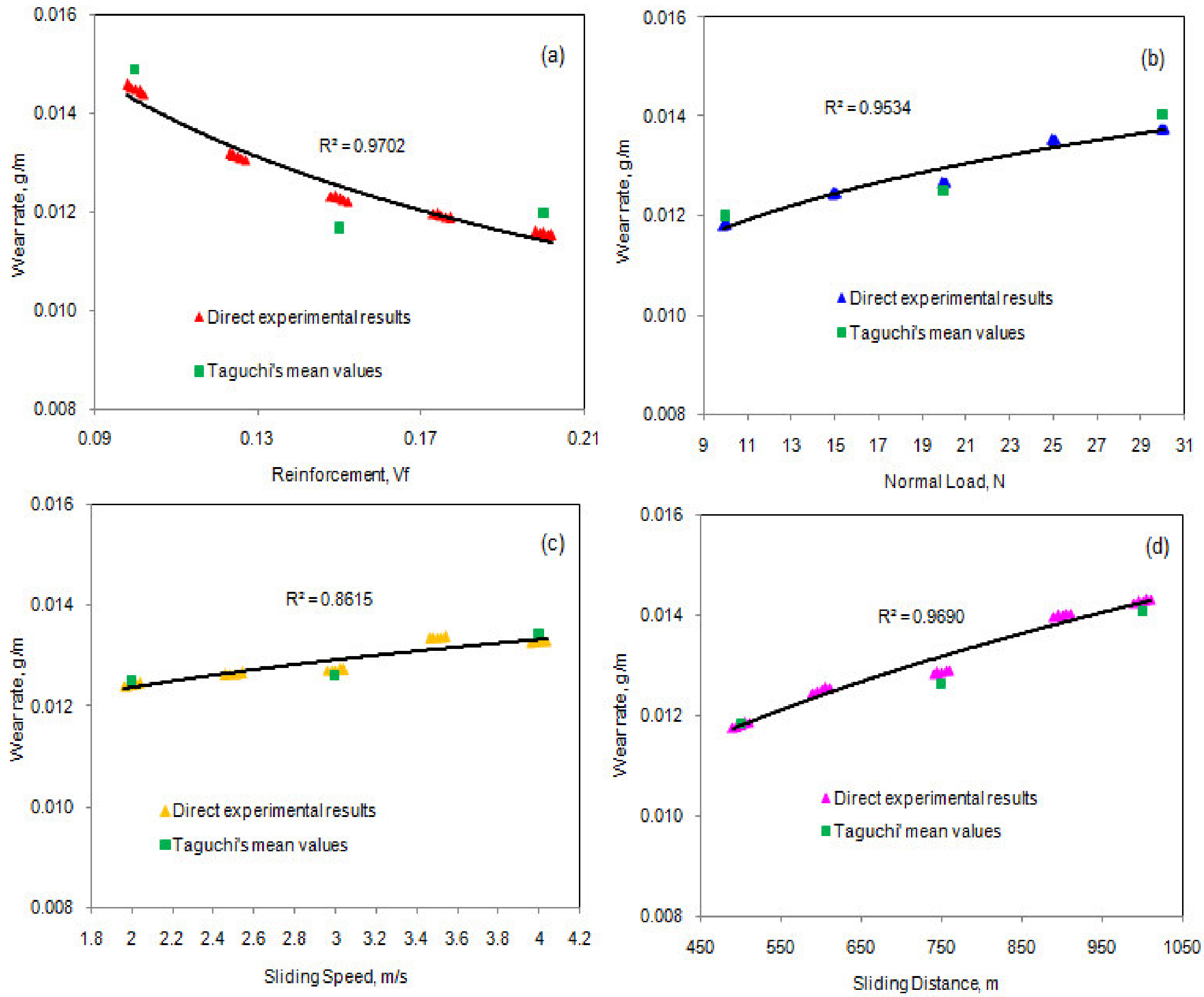

Figure 1: Influence of process parameters on wear rate.

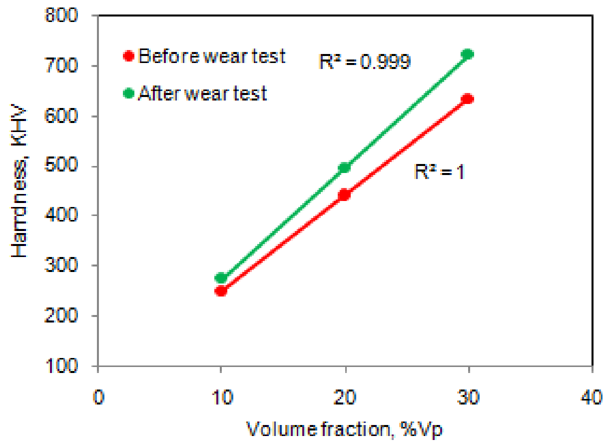

Figure 2: Hardness of AA5050/TiC composites after wear test.

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. The reinforcement particles act as load bearing elements. Achievement of a lower wear rate for the AA5050/TiC metal matrix composites, would involve the utilization of materials exhibiting high hardness and adequate fracture toughness.

4. CONCLUSION

For adhesive wear, the influence of applied load, sliding speed, wearing surface hardness, reinforcement volume fraction and sliding distance are critical parameters in relation to the wear regime encountered by the material. The material could be transferred back and forth several times during sliding and eventually produce wear debris particles. It was suggested that the formation of these wear particles could be a direct result of their work-hardening ability. With increasing deformation the reinforcement particles at the wearing surface fragmented.

REFERENCES

1. 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.
2. 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.
3. 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.
4. 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.
5. 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.
6. A. Chennakesava Reddy, Micromechanical and fracture behaviors of Ellipsoidal Graphite Reinforced AA2024 Alloy Matrix Composites, 2nd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 10-11 March 2000, pp. 96-103.
7. A. Chennakesava Reddy, Constitutive Behavior of AA5050/MgO Metal Matrix Composites with Interface Debonding: the Finite Element Method for Uniaxial Tension, 2nd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 10-11 March 2000, pp. 121-127.

8. B. Kotiveera Chari, A. Chennakesava Reddy, Interphase Cracking in Titanium Nitride/2024 Alloy Particle-Reinforced Metal-Matrix Composites, 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 22-25 February 2002, pp. 162-167.
9. V. V. Satyanarayana, A. Chennakesava Reddy, Computation of Interphase Separation and Particle Fracture of Titanium Oxide/3003 Particle Reinforced Composites: The Role of Thermo-Mechanical Loading, 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 22-25 February 2002, pp. 168-173.
10. V. V. Satyanarayana, A. Chennakesava Reddy, Micromechanical Modeling of Reinforcement Fracture in Zirconium Carbide/4015 Particle-Reinforced Metal-Matrix Composites , 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 22-25 February 2002, pp. 174-178.
11. A. Chennakesava Reddy, Two dimensional (2D) RVE-Based Modeling of Interphase Separation and Particle Fracture in Graphite/5050 Particle Reinforced Composites, 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 22-25 February 2002, pp. 179-183.
12. A. Chennakesava Reddy, Simulation of MgO/AA6061 Particulate-Reinforced Composites Taking Account of CTE Mismatch Effects and Interphase Separation, 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 22-25 February 2002, pp. 184-187.
13. Ch. Rajanna, A. Chennakesava Reddy, Effects of Interphase and Interface Characteristics on the Tensile Behavior of Boron Nitride/7020 Particle Reinforced Composites Subjected to Thermo-Mechanical Loading, 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 22-25 February 2002, pp. 188-191.
14. Ch. Rajanna, A. Chennakesava Reddy, Modeling of Interphases in SiO_2/AA8090 alloy Particle -Reinforced Composites under Thermo-Mechanical Loading Using Finite Element Method, 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 22-25 February 2002, pp. 192-195.
15. A. Chennakesava Reddy, Wear Resistant Titanium Boride Metal Matrix Composites, 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, 22-25 February 2002, pp. 201-205.
16. A. Chennakesava Reddy, Thermal Expansion Studies on Aluminum Matrix Composites with Different Reinforcement Volume Fractions of Si_3N_4 Nanoparticles, 4th International Conference on Composite Materials and Characterization, Hyderabad, 7-8 March 2003, pp. 221-225.
17. 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.
18. A. Chennakesava Reddy, Evaluation of Thermal Expansion of Al/B_4C Metal Matrix Composites, 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, 22-25 February 2002, pp. 196-200.
19. 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.
20. B. Kotiveera Chari, A. Chennakesava Reddy, Finite Element Modeling and Experimental Validation of Interphase Debonding and Particle Fracture in Titanium Carbide/AA1100 Alloy, 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 22-25 February 2002, pp. 156-161.
21. 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.
22. A. Chennakesava Reddy, Wear Resistant Titanium Boride Metal Matrix Composites, 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, 22-25 February 2002, pp. 201-205.
23. A. Chennakesava Reddy, On the Wear of AA4015 – Fused Silica Metal Matrix Composites, 4th International Conference on Composite Materials and Characterization, Hyderabad, 7-8 March 2003, pp. 226-230.
24. 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.