Implication of Macro-sized Silicon Oxide Particles on Wear Rate of AA2024Alloy Metal Matrix Composites

[1]M. Mastanaiah and A. Chennakesava Reddy[2]

[1]Research Scholar, Department of Mechanical Engineering, JNTU College of Engineering, Hyderabad, India
[2]Professor, Department of Mechanical Engineering, JNTU College of Engineering, Hyderabad, India

Abstract: *In the present work, the AA2024 alloy/silicon oxide metal matrix composites were manufactured. The test matrix varied particle* size *of 100µm, 150µm and 200µm silicon oxide. The composite samples were tested in dry sliding against a steel counterface. Wear rate increased monotonically with increasing particle size at any loading in the range tested.*

Keywords: *Metal matrix composite, particle size, AA2024 alloy, silicon oxide, wear, sliding distance, normal load, speed.*

1. INTRODUCTION

The size parameters characteristic of a composite microstructure can exert a strong influence on its mechanical properties. For instance, strengthening of a metallic matrix by particles; lattice dislocations are forced by the microstructural constraint to distort out or stack up [1-16]. The case of strengthening in particle reinforced metal matrix composites has been extensively researched in the past; however no consensus has been reached regarding wear mechanism. The current work is interested on the size dependence of wear in particle reinforced composites. Defects such as clusters, agglomerates, and segregation of graphite particles play a dominant role in accelerating the fracture process. The variation of friction and wear rate depends on interfacial conditions such as normal load, geometry, relative surface motion, sliding speed, surface roughness of the rubbing surfaces, type of material, system rigidity, temperature, stick slip, relative humidity, lubrication and vibration. Among these factors sliding distance and normal load are the two major factors whose play significant role for the variation of friction and wear rate. High normal pressures and high sliding distances can result in high interface (flash) temperatures that can significantly reduce the strength of most materials [17-28]. In some cases, localized surface melting reduces shear strength and friction drops to a low value determined by viscous forces in the liquid layer. Rhee [29] found that the total wear of a polymer-matrix is a function of the applied load F, speed V and sliding time t according to

$$\Delta W = KF^{a}V^{b}t^{c} \quad (1)$$

where ΔW is the weight loss of the friction material and *K, a, b* and *c* are empirical constants.

This paper elaborates on those results showing the effect of particle size on the tribological behavior, and mathematical modeling of wear rate in terms of particle size, normal load, sliding speed and sliding distance. The wear tests were conducted on pin-on-disc equipment to study the tribological behavior of AA2024/silicon oxide composites. The design of experiments was based on Taguchi techniques [30, 31].

2. MATERIALS AND METHODS

AA2024alloy/silicon oxide composites were fabricated by the stir casting process. The volume fraction of silicon oxide in the composites was 30%. The particle size of silicon oxide was varied at 100µm, 150 µm and 200µm. The T6 heat-treated samples were machined to get cylindrical specimens of 10 mm diameter and 30 mm length for the dry wear tests. The levels chosen for the controllable wear parameters are précised in Table 1. The orthogonal array, L9 was ideal to carry out wear experiments (Table 2). A pin-on-disc wear monitor (ASTM G99) was employed to assess the wear behavior of AA2024 alloy/ silicon oxide composite specimens against hardened ground steel (En32) disc (figure 1). Knoop microhardness was conducted before and after wear tests.

Table 1: Wear parameters and levels

Factor	Symbol	Level–1	Level–2	Level–3
Particle size, µm	A	100	150	200
Load, N	B	10	20	30
Speed, m/s	C	2	3	4
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

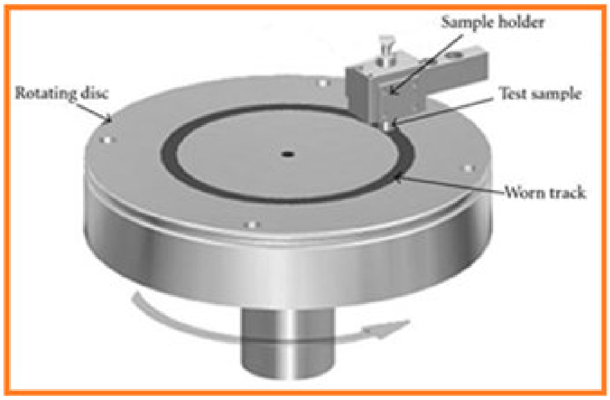

Figure 1: Tests carried out in the present work: (a) Pin-on-disc wear test and (b) Surface roughness test.

In the present work, the wear formulation was attempted based on the following expression:

$$W = K\ (d^a F^b S^c D^d) \quad (2)$$

where, *W* is the wear rate in g/m; *d* is the particle size of reinforcement, mm; *F* is the normal load, N; *S* is sliding speed, m/s *D* is the sliding distance, mm and; *K, a, b, c* and *d* are empirical constants.

3. RESULTS AND DISCUSSION

The analysis of variance (ANOVA) is presented in Table 3. All process parameters are satisfying as they convince Fisher's test at 90% confidence level. For variation in the wear rate, the membership of particle size (A), normal load (B), sliding speed (C) and sliding distance (D) are, correspondingly, 85.07%, 5.82%, 2.15% and 6.95%. The worth mentioning variable is the particle size of silicon oxide. The ignorable variable is the sliding speed. The R-squared values of %reinforcement, normal load, sliding speed and sliding distance are, respectively, 0.9936, 0.9372, 0.7312 and 0.9810 as stated in figure 3. The concern of R-squared values is same as that of mean values arrive at by Taguchi techniques.

Table 3: ANOVA summary of the effective stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	3.04E-02	5.72E-02	7.49E-02	3.34E-04	1	3.34E-04	7.71E+14	85.07
B	4.80E-02	5.50E-02	5.96E-02	2.28E-05	1	2.28E-05	5.27E+13	5.82
C	5.79E-02	5.08E-02	5.39E-02	8.46E-06	1	8.46E-06	1.95E+13	2.15
D	4.87E-02	9.24E-04	1.63E-01	2.73E-05	1	2.73E-05	6.30E+13	6.95
e				1.73E-18	4	4.34E-19	1.00	0.00
T	1.85E-01	1.64E-01	3.51E-01	3.93E-04	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.

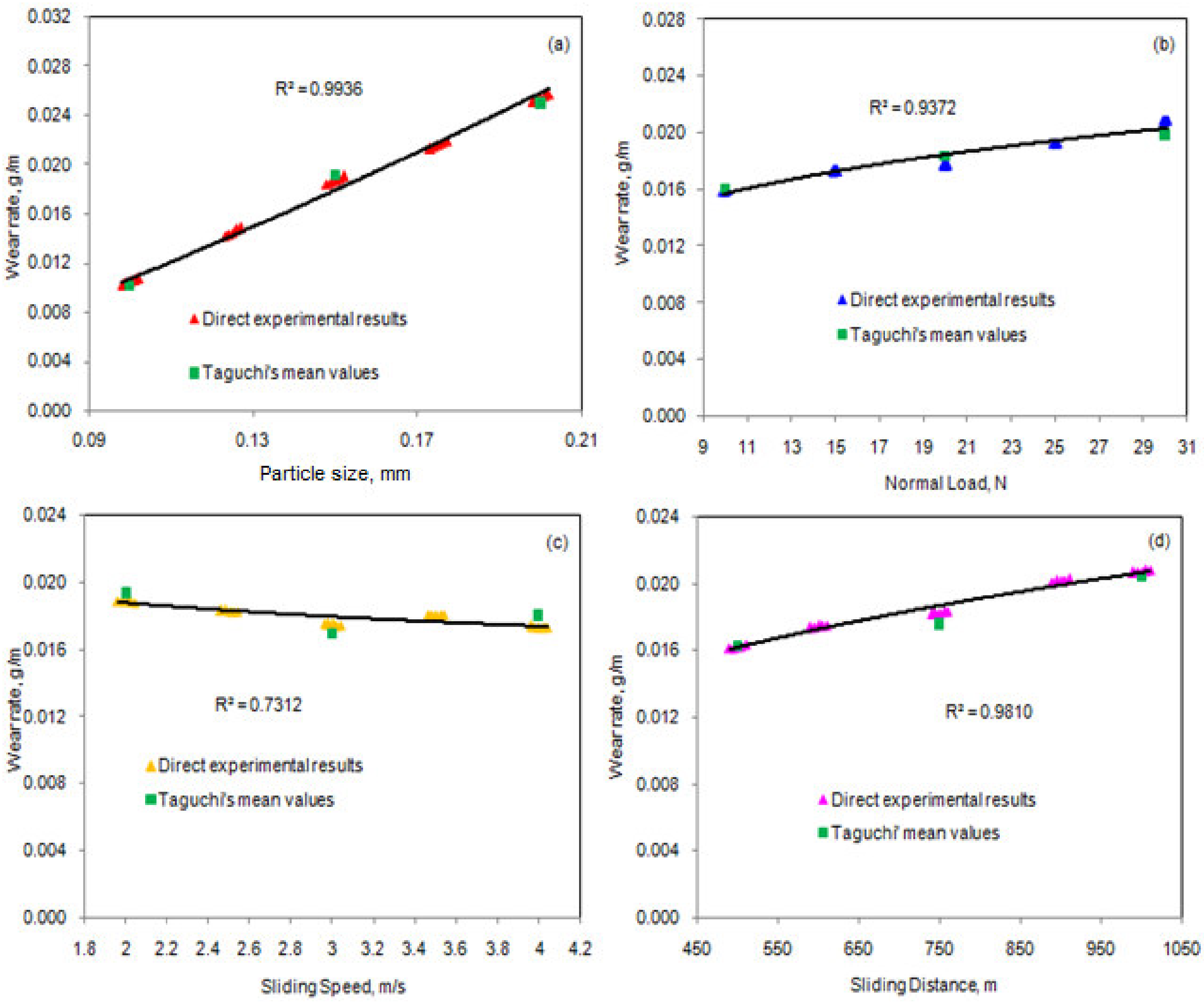

Figure 3: Wear rate as a function of (a) particle size, (b) applied load, (c) sliding speed and (d) sliding distance.

The wear rate was amplified with increase in particle size of silicon oxide as shown in figure 3a. For the larger particles, contact area between the matrix and the reinforcement is less and so is the interface between these phases. This decreased interface region would result in deprived stiffening and diminished strength of the composite ensuing in enhanced wear of the material. Also, when the particulates get dislocated during the process of wear, they get entrapped between the mating surfaces, causing three body type abrasion. Figure 3b characterizes an increase in wear rate with increase of normal load. The sliding speed had no influence on the wear rate (figure 3c). The wear rate increases with sliding distance as shown in figure 3d. Collapse of the surface layers from the composite pin supports the loss of material with increasing sliding distance.

The mathematical relation between wear and volume fraction of reinforcement, applied load, sliding speed and sliding distance were obtained by curve fitting in terms of power laws as follows:

$$W = 1.11 \times 10^{-2} \left(d^{1.2748} F^{0.2332} S^{-0.105} D^{0.351}\right) \quad (3)$$

Archard interpreted K factor as a probability of forming wear debris from asperity encounters [32]. Typically for mild wear, $K \approx 10^{-8}$, whereas for severe wear, $K \approx 10^{-2}$. As the value of $K \approx 10^{-2}$, the wear of AA2024/silicon oxide composites is severe because the composite was made of micro-sized reinforced particles. The wear rate values determined by the Equation (3) are within the tolerable limits of experimental results as seen from figure 4. For this reason, the mathematical modeling is ample to characterize the severity of wear of AA2024/silicon oxide metal matrix composites.

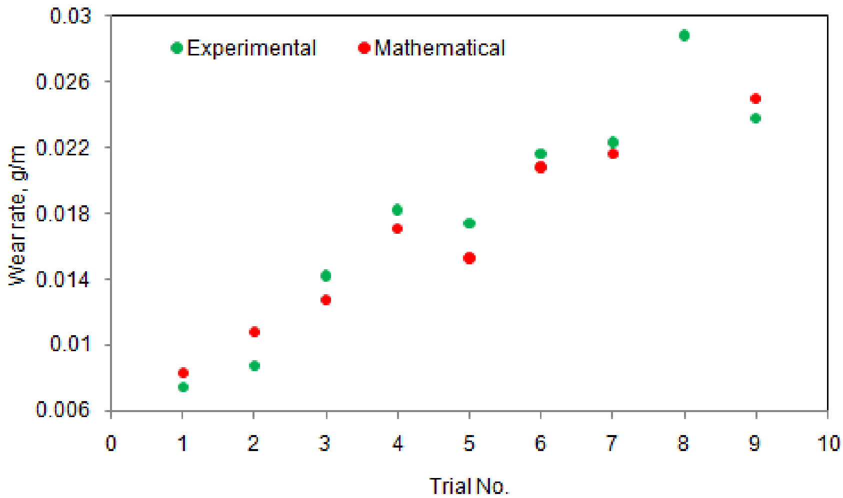

Figure 4: Validation of mathematical modeling with experimental results.

4. CONCLUSIONS

The inference micro-size particles on the severity wear was efficiently modeled and established with experimental results of AA2024/silicon oxide composites. The AA2024/silicon oxide composites have experienced severe wear because of macro size particles reinforced in aluminum alloy matrix.

REFERENCES

1. A. C. Reddy, Mechanical properties and fracture behavior of 6061/SiCp Metal Matrix Composites Fabricated by Low Pressure Die Casting Process, Journal of Manufacturing Technology Research, 1, 2009, pp.273-286.
2. A. C. Reddy, Tensile properties and fracture behavior of 6063/SiC_P metal matrix composites fabricated by investment casting process, International Journal of Mechanical Engineering and Materials Sciences, 3, 2010, pp.73-78.
3. A. C. Reddy and B. Kotiveerachari, Effect of aging condition on structure and the properties of Al-alloy / SiC composite, International Journal of Engineering and Technology, 2, 2010, pp.462-465.
4. A. C. Reddy and B. Kotiveerachari, Influence of microstructural changes caused by ageing on wear behaviour of Al6061/SiC composites, Journal of Metallurgy & Materials Science, 53, 2011, pp. 31-39.
5. A. C. Reddy, Tensile fracture behavior of 7072/SiCp metal matrix composites fabricated by gravity die casting process, Materials Technology: Advanced Performance Materials, 26, 2011, pp. 257-262.
6. A. C. Reddy, Influence of strain rate and temperature on superplastic behavior of sinter forged Al6061/SiC metal matrix composites, International Journal of Engineering Research & Technology, 4, 2011, pp.189-198.
7. A. C. Reddy , Evaluation of mechanical behavior of Al-alloy/SiC metal matrix composites with respect to their constituents using Taguchi techniques, i-manager's Journal of Mechanical Engineering, 1, 2011, pp.31-41.
8. A. C. Reddy and Essa Zitoun, Matrix al-alloys for alumina particle reinforced metal matrix composites, Indian Foundry Journal, 55, 2009, pp.12-16.
9. A. C. Reddy and Essa Zitoun, Tensile behavior of 6063/Al_2O_3 particulate metal matrix composites fabricated by investment casting process, International Journal of Applied Engineering Research, 1, 2010, pp.542-552.
10. A. C. Reddy and Essa Zitoun, Tensile properties and fracture behavior of 6061/Al_2O_3 metal matrix composites fabricated by low pressure die casting process, International Journal of Materials Sciences, 6, 2011, pp.147-157.
11. A. C. Reddy, Strengthening mechanisms and fracture behavior of 7072Al/Al_2O_3 metal matrix composites, International Journal of Engineering Science and Technology, 3, 2011, pp.6090-6100.
12. A. C. Reddy, S. Sundararajan, Influences of ageing, inclusions and voids on the ductile fracture mechanism of commercial Al-alloys, Journal of Bulletin of Material Sciences, 28, 2005, pp. 75-79.
13. A. C. Reddy, Evaluation of mechanical behavior of Al-alloy/Al_2O_3 metal matrix composites with respect to their constituents using Taguchi, International Journal of Emerging Technologies and Applications in Engineering Technology and Sciences, 4, 2011, pp. 26-30.
14. A. C. Reddy, Fracture behavior of brittle matrix and alumina trihydrate particulate composites, Indian Journal of Engineering & Materials Sciences, 9, 2002, pp.365-368.
15. A. S. Goud, A. C. Reddy, Evaluation of Nanoparticle Fracture in MgO Reinforced Aluminum matrix composites, 3rd International Conference on Modern Materials and Manufacturing, New Delhi, 9-10 December 2011, pp. 320-324.
16. A. S. Goud, A. C. Reddy, Interface Failure Analysis of TiB_2 Reinforced Aluminum Alloy Matrix Composites, 3rd International Conference on Modern Materials and Manufacturing, New Delhi, 9-10 December 2011, pp. 325-328.

17. A. C. Reddy, Wear and Mechanical Behavior of Bottom-Up Poured AA4015/Graphite Particle-Reinforced Metal Matrix Composites, 6th National Conference on Materials and Manufacturing Processes, Hyderabad, 8-9 August 2008, pp. 120-126.
18. A. C. Reddy, S. Madahava Reddy, Evaluation of dry sliding wear characteristics and consequences of cast Al-Si-Mg-Fe alloys, ICFAI Journal of Mechanical Engineering, 3, 2010, pp.1-13.
19. A. C. Reddy, Sliding Wear and Micromechanical Behavior of AA1100/Titanium Oxide Metal Matrix Composites Cast by Bottom-Up Pouring, 7th International Conference on Composite Materials and Characterization, Bangalore, 11-12 December 2009, 205-210.
20. A. C. Reddy, Hardness Contours and Worn Surfaces of AA1100 Alloy/TiO_2 Metal Matrix Composites, 2nd International Conference on Modern Materials and Manufacturing, Pune, 10-11 December 2010, pp. 292-296.
21. A. C. Reddy, Correlation of Surface Profiles and Worn Surfaces of AA6061/Graphite Metal Matrix Composites, 2nd International Conference on Modern Materials and Manufacturing , Pune, 10-11 December 2010, pp. 307-311.
22. A. C. Reddy, M. Vidya Sagar, Two-dimensional theoretical modeling of anisotropic wear in carbon/epoxy FRP composites: comparison with experimental data, International Journal of Theoretical and Applied Mechanics, 6. 2010, pp. 47-57.
23. M. S. Ramgir, A. C. Reddy, Control of B_4C Reinforced Particulates on Dry Wear Resistance of AA2024/B4C Composites, 3rd International Conference on Modern Materials and Manufacturing, New Delhi, 9-10 December 2011, pp. 336-340.
24. V. K. Reddy, A. C. Reddy, Mathematical Models for Dry Wear of H18 Heat Treated AA1100/TiB2 Composites, 3rd International Conference on Modern Materials and Manufacturing, New Delhi, 9-10 December 2011, pp. 341-346.
25. M. Mastanaiah, A. C. Reddy, Abrasive Wear of AA3003/ZrC Composites, 3rd International Conference on Modern Materials and Manufacturing, New Delhi, 9-10 December 2011, pp. 347-351.
26. R. G. Math, A. C. Reddy, Unlubricated Sliding of AA4015/TiB2 Metal Matrix Composites, 3rd International Conference on Modern Materials and Manufacturing, New Delhi, 9-10 December 2011, pp. 352-356.
27. A. C. Reddy, Experimental Validation of Dry Wear Formulation of AA7020/Zirconia Nanoparticle Metal Matrix Composites, 3rd International Conference on Modern Materials and Manufacturing, New Delhi, 9-10 December 2011, pp. 357-361.
28. A. C. Reddy, Impact of Particle Size on Dry Wear Formulation of AA2024/Titanium Nitride Macro-particle Metal Matrix Composites, 3rd International Conference on Modern Materials and Manufacturing , New Delhi, 9-10 December 2011, pp. 362-366.
29. S. K. Rhee, Wear equation for polymers sliding against metal surfaces, Wear, 16, 1970, pp. 431-445.
30. A. C. Reddy, V.M. Shamraj, Reduction of cracks in the cylinder liners choosing right process variables by Taguchi method, Foundry Magazine, 10, 1998, pp. 47-50.
31. A. C. Reddy, V.S.R. Murti, S. Sundararajan, Control factor design of investment shell mould from coal flyash by Taguchi method, Indian Foundry Journal, 45, 1999, pp. 93-98.
32. J. F. Archard, W. Hirst, The Wear of Metals under Unlubricated Conditions, Proceedings of the Royal Society. A-236, 1956, pp. 397–410.