Impact of Particle Size on Dry Wear Formulation of AA2024/Titanium Nitride Macro-particle Metal Matrix Composites

A. Chennakesava Reddy

Professor, Department of Mechanical Engineering, JNTU College of Engineering, Hyderabad, India

Abstract: *In the present work, the AA2024 alloy/titanium nitride metal matrix composites were manufactured with particle size of 100µm, 150µm and 200µm titanium nitride. The pin-on-disc wear test was carried out with different combinations of reinforcement, sliding distance, normal load, sliding speed. Based on the experimental results the impact of particle size on the severity of wear was successfully predicted for AA2024/titanium nitride metal matrix composites.*

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

1. INTRODUCTION

Particle reinforced metal matrix composites (PRMMCs) have been the subject of extensive study in the past thirty years due to a need for lightweight structural materials. Al-based composite materials attract more attention because of the low density, high specific strength, good processability, and so on. Large-particle and dispersion-strengthened composites are the two sub-classifcation of particle-reinforced composites. The term “large” is used to indicate that particle–matrix interactions cannot be treated on the atomic or molecular level; rather, continuum mechanics is used. For most of these composites, the particulate phase is harder and stiffer than the matrix. These reinforcing particles tend to restrain movement of the matrix phase in the vicinity of each particle. The degree of reinforcement or improvement of mechanical behavior depends on strong bonding at the matrix–particle interface [1-16]. A significant number of equations relate to wear but were not particularly amenable to analysis, so were left out of later consideration. Two approaches can be taken into account in developing models. One approach is based on empirical data which involves characterization of surfaces, collection of wear and friction data from laboratory tests, analysis and sorting of data. A second approach involves generation of models based on known physical principles, followed by confirmation through data collection [17-26]. Many papers have been written before on this topic but little concrete direction has arisen for developing good wear models. Rhee [27] 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

$$\Delta W = K F^a V^b t^c \quad (1)$$

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

The intention of this research work was to severity of particle size on the dry sliding wear of AA2024/titanium nitride metal matrix composites. The wear tests were conducted on pin-on-disc equipment. The design of experiments was based on Taguchi techniques [28, 29].

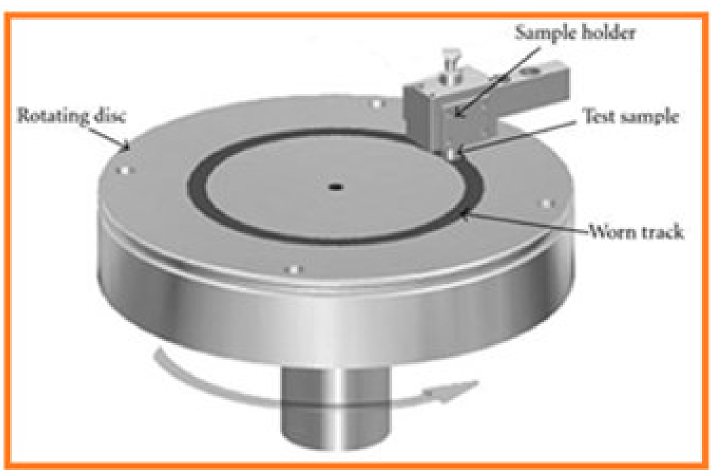

Figure 1: Tests carried out in the present work: (a) Pin-on-disc wear test and (b) Surface roughness test.

2. MATERIALS AND METHODS

AA2024alloy/titanium nitride composites were fabricated by the stir casting process. The volume fraction of titanium nitride in the composites was 30%. The particle size of titanium nitride 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/titanium nitride 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

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

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

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.

Table 3: ANOVA summary of the effective stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	2.73E-02	4.98E-02	7.04E-02	3.09E-04	1	3.09E-04	1.43E+15	86.84
B	4.90E-02	4.46E-02	5.39E-02	1.43E-05	1	1.43E-05	6.61E+13	4.03
C	5.02E-02	5.05E-02	4.68E-02	2.85E-06	1	2.85E-06	1.31E+13	0.80
D	4.20E-02	8.44E-04	1.48E-01	2.97E-05	1	2.97E-05	1.37E+14	8.33
e				8.67E-19	4	2.17E-19	1.00	0.00
T	1.69E-01	1.46E-01	3.19E-01	3.56E-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.

3. RESULTS AND DISCUSSION

The analysis of variance (ANOVA) is presented in Table 3. All process parameters are agreeable as they satisfy Fisher's test at 90% confidence level. The contribution of particle size (A), normal load (B), sliding speed (C) and sliding distance (D) are, in that order, 86.84%, 4.03%, 0.80% and 8.33% of variation in the wear rate. The major significant variable is the particle size of titanium nitride. The least significant variable is the sliding speed. The R-squared values of %reinforcement, normal load, sliding speed and sliding distance are, respectively, 0.9991, 0.6320, 0.6106 and 0.9761as mentioned in figure 3. The sensitivity of R-squared values is same as that of mean values obtained by Taguchi techniques.

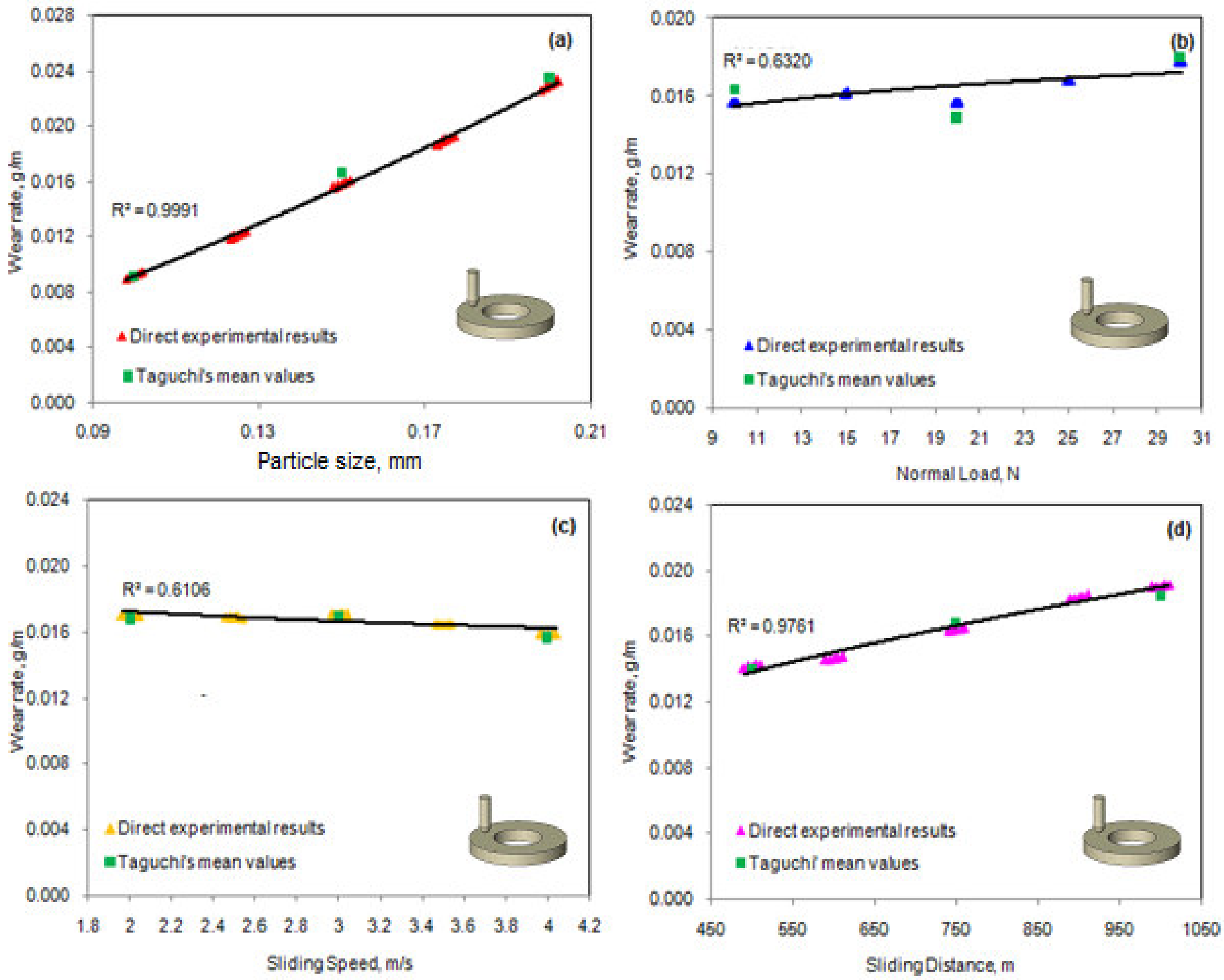

Figure 3: Wear rate as a function of (a) particle size, (b) applied load, (c) sliding speed and (d) sliding distance.

The wear rate was increased with increase in particle size of titanium nitride as shown in figure 3a. This can be attributed to particle pullout on account of weak bonding between particle and matrix. Figure 3b represents an increase in wear rate with increase of normal load. Due to increased applied load, the deformed AA2024 alloy matrix disengages from the pin's surface subsequently raise the wear rate. The sliding speed was insignificant on the wear rate (figure 3c). The wear rate increases with sliding distance as shown in figure 3d. Crumbling of the surface layers from the composite pin promotes 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:

$$W = 7.92 \times 10^{-3} \left(d^{1.319} F^{0.0971} S^{-0.0842} D^{0.4568}\right) \quad (3)$$

Archard interpreted *K* factor as a probability of forming wear debris from asperity encounters [30]. Typically for mild wear, $K \approx 10^{-8}$, whereas for severe wear, $K \approx 10^{-2}$. As the value of $K \approx 10^{-3}$, the wear of AA2024/titanium nitride composites is severe because the composite was made of large reinforced particles. The wear rate values computed by the Equation (3) are within the permissible limits of experimental results as seen from figure 4. Hence, the mathematical modeling is adequate to represent the severity of wear of AA2024/titanium nitride metal matrix composites.

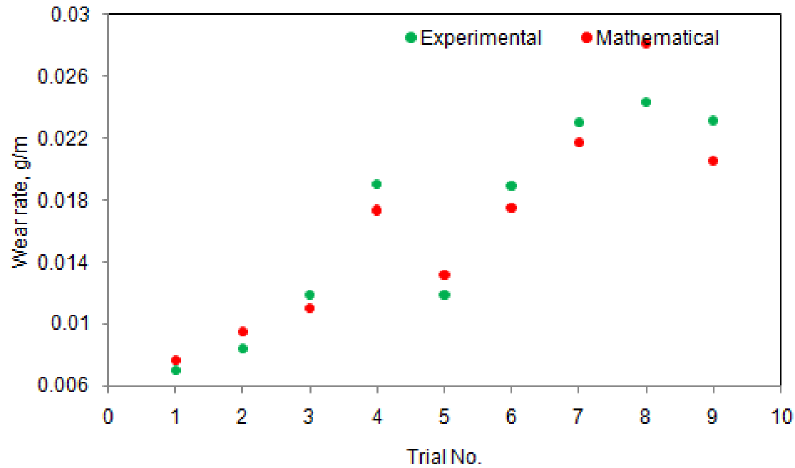

Figure 4: Validation of mathematical modeling with experimental results.

4. CONCLUSIONS

The impact of particle size on the severity wear was successfully modeled and validated with experimental results of AA2024/titanium nitride composites. The AA2024/titanium nitride 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. Y. S. A. Kumar, A. C. Reddy, Interfacial Criterion for Debonding of Titanium Boride/AA4015 Metal Matrix Composites, 2nd International Conference on Modern Materials and Manufacturing, Pune, 10-11 December 2010, pp. 265-268
15. Y. S. A. Kumar, A. C. Reddy, Fabrication and Properties of AA7020-TiN Composites under Combined Loading of Temperature and Tension, 2nd International Conference on Modern Materials and Manufacturing, Pune, 10-11 December 2010, pp. 276-280
16. A. C. Reddy, Fracture behavior of brittle matrix and alumina trihydrate particulate composites, Indian Journal of Engineering & Materials Sciences, 9, 2002, pp.365-368.
17. R. G. Math, A. C. Reddy, Sliding Wear of AA7020/MgO Composites against En32 Steel Disc, 2nd International Conference on Modern Materials and Manufacturing, Pune, 10-11 December 2010, pp. 281-286

18. G. V. R. Kumar, A. C. Reddy, Tribological Analogy of Cast AA2024/TiB_2 Composites, 2nd International Conference on Modern Materials and Manufacturing , Pune, 10-11 December 2010, 287-291
19. 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.
20. 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.
21. 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.
22. 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.
23. R. G. Math, A. C. Reddy, Hardness Patterns on Worn Surfaces of AA7020 Alloy/SiO_2 Particulate Metal Matrix Composites, 2nd International Conference on Modern Materials and Manufacturing , Pune, 10-11 December 2010, pp. 297-301.
24. G. V. R. Kumar, A. C. Reddy, Surface Profiles of Dry Worn Surfaces of AA2024 Alloy/TiC Metal Matrix Composites, 2nd International Conference on Modern Materials and Manufacturing , Pune, 10-11 December 2010, pp. 302-306
25. 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.
26. 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.
27. S. K. Rhee, Wear equation for polymers sliding against metal surfaces, Wear, 16, 1970, pp. 431-445.
28. 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.
29. 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.
30. J. F. Archard, W. Hirst, The Wear of Metals under Unlubricated Conditions, Proceedings of the Royal Society. A-236, 1956, pp. 397–410.