Wear Performance of Magnesia as Reinforcement of AA2024 Metal Matrix Composites

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Abstract: *In the present work, the AA2024 alloy-magnesia metal matrix composites were fabricated by stir casting practice. The test matrix varied particle* size *of 100µm, 150µm and 200µm. The design of experiments was conducted based on Taguchi's factorial techniques. Dry sliding wear behavior of AA2024 alloy-magnesia composites was studied using a pin-on-disc wear test rig. Good interfacial bonding between the smaller sized magnesia particle and matrix alloy has ensured good wear resistance. The mathematical modeling was validated with experimental results.*

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

1. INTRODUCTION

Composites typically have a fiber or particle phase that is stiffer and stronger than the continuous matrix phase and serve as the principal load carrying members. At the present time, aluminum metal matrix composites have been well recognized and steadily improved because of their advanced engineering properties, such as their improved wear resistance, low density, specific strength and stiffness [1-17]. In recent years aluminum metal matrix composites have been used in the applications of cylinder liners, brake drums, crankshafts. They also possess low wear resistance property, so additional reinforcements must be added. Ceramic materials TiO_2 [18, 19], graphite [20, 21], carbon [22], ZrO_2 [23, 24], TiN [25], B_4C [26], ZrC [27], Si_3N_4 [28] and SiO_2 [29] will provide wear resistance and mechanical strength. These aluminum-based ceramic composites require not only good strength and good wear resistance but also self-lubrication properties. Wear is related to interactions between surfaces and specifically the removal and deformation of material on a surface as a result of mechanical action of the opposite surface. Factors like applied load, sliding speed, sliding distance, reinforcement, manufacturing process are considered to study wear properties [30]. It is essential to identify the major factor which influences the wear behavior. In order to test the wear property, pin-on-disc equipment is used. Taguchi methods are statistical methods developed by Taguchi to improve the quality of manufactured goods, and more recently applied to engineering [31, 32]. Design of experiment is one of the important and powerful statistical techniques to study the effect of multiple variables simultaneously and involves a series of steps which must follow a certain sequence for the experiment to yield an improved understanding of process performance.

The objective of this paper was to model the effect of magnesia particle size on the abrasive wear of AA2024-magnesia composites. For this purpose AA2024-magnesia metal matrix composites were manufactured with particle size varying from 100µm to 200µm. Dry sliding wear of AA2024 alloy-magnesia composites with different particle sizes were studied under different combinations of sliding speed, normal load, sliding distance and particle size based on Taguchi techniques. Most of the reported research focused on the effect of either one or two factors on the dry sliding wear behavior of hybrid composites.

2. MATERIALS AND METHODS

AA2024 alloy-magnesia composites were fabricated by the stir casting process. The volume fraction of magnesia in the composites was 30%. The particle size of magnesia was varied at 100µm, 150 µm and 200 µm. 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-magnesia composite specimens against hardened ground steel (En32) disc (figure 1).

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

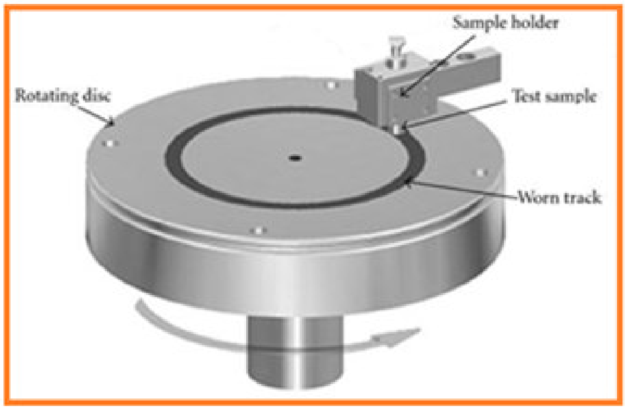

Figure 1: Tests carried out in the present work: (a) Pin-on-disc wear test and (b) Surface roughness test.

In the present work, the wear formulation [23, 25] was attempted based on the following expression:

$$W = K\,(d^{a}F^{b}S^{c}D^{d}) \qquad (1)$$

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 satisfactory as they defend Fisher's test at 90% confidence level. For variation in the wear rate, the percent contribution of magnesia particle size (A), normal load (B), sliding speed (C) and sliding distance (D) are, correspondingly, 79.00%, 6.50%, 2.41% and 12.09%. The R-squared values of particle size, normal load, sliding speed and sliding distance are, respectively, 0.9974, 0.9888, 0.7030 and 0.9956 as stated in figure 3. The tendency of R-squared values is same as that of mean values obtained by Taguchi techniques.

Table 3: ANOVA summary of the effective stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	3.43E-02	5.24E-02	7.09E-02	2.23E-04	1	2.23E-04	5.14E+14	79.00
B	4.73E-02	5.25E-02	5.78E-02	1.83E-05	1	1.83E-05	4.23E+13	6.50
C	5.60E-02	4.97E-02	5.19E-02	6.80E-06	1	6.80E-06	1.57E+13	2.41
D	4.64E-02	8.61E-04	1.58E-01	3.41E-05	1	3.41E-05	7.86E+13	12.09
e				-1.73E-18	4	-4.34E-19	1.00	0.00
T	1.84E-01	1.56E-01	3.38E-01	2.82E-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.

The wear rate was decreased with decrease in particle size of magnesia as shown in figure 3a. This is because of good interfacial bonding between the small size magnesia particle and matrix alloy. Figure 3b indicates an increase in wear rate with increase of normal load. Corresponding to the increased applied load, the wear rate of the composites also increases because of heat generated during the friction in between the contact surfaces. The wear loss of the AA2024 alloy-magnesia composites decreases with increase in the sliding speed. The wear of the AA2024 alloy-magnesia composites increases with the sliding distance as shown in figure 3d. The grooves and detached particles can be seen in the worn surface due to long sliding distances. The wear rate strongly depends on the particle size of magnesia for all the composites. Due to the poor adhesion between the larger magnesia particles and matrix, volume loss is increased.

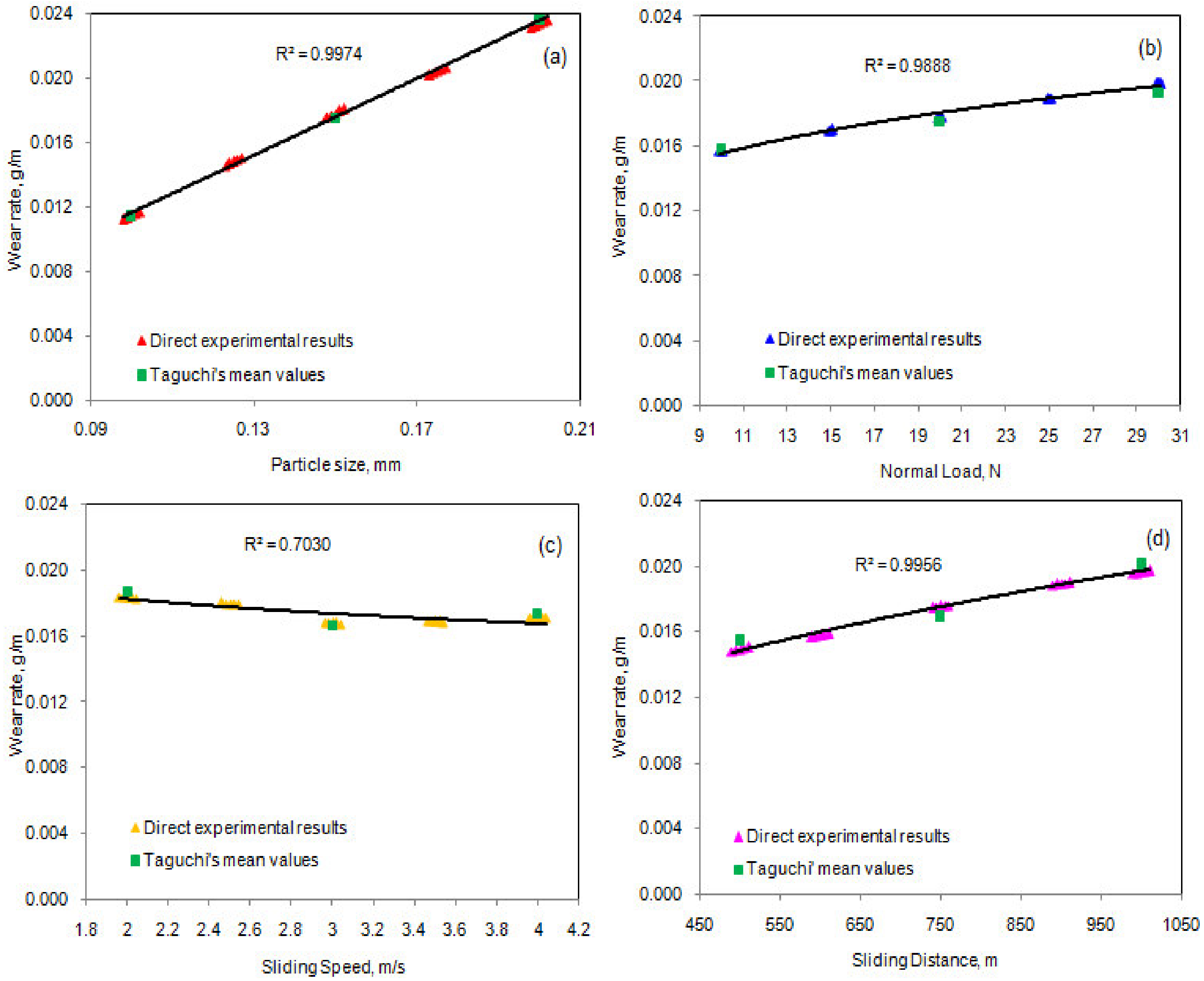

Figure 3: Wear rate as a function of (a) particle size, (b) applied load, (c) sliding speed and (d) sliding distance.

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:

$$W = 5.09 \times 10^{-3} \left(d^{1.0222} F^{0.2097} S^{-0.1203} D^{0.4072}\right) \qquad (2)$$

Matrix layer removal, debonding and pull-out of magnesia particles were observed during wear tests on pin-on-disc setup. Archard interpreted K factor as a probability of forming wear debris from asperity encounters [33]. 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 alloy-magnesia composites is moderate because the composite was made of micro-sized reinforced magnesia particles. The wear rate values determined by the Equation (2) are within the acceptable limits of experimental results as seen from figure 4. With this rationale, the mathematical modeling is competent to judge the severity of wear of AA2024-magnesia metal matrix composites.

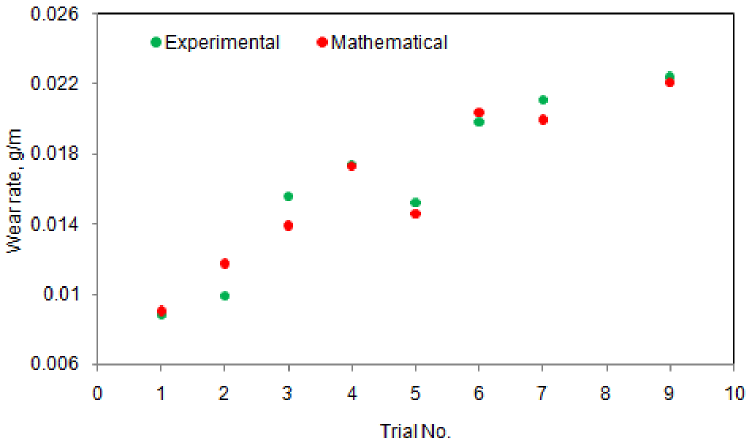

Figure 4: Validation of mathematical modeling with experimental results.

4. CONCLUSIONS

The impact of micro-size particles on the severity of wear was modeled and validated with experimental results of AA2024 alloy-magnesia composites. With smaller sized magnesia particles, the AA2024 alloy-magnesia composites have experienced good wear resistance due to good interfacial bonding between the magnesia particle and matrix alloys.

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. M. S. Ramgir, A. C. Reddy, Effect of Thermal-heating on Nanoparticle Fracture Trend in AA2024/c-BN Particle-Reinforced Metal Matrix Composites, 4th International Conference on Modern Materials and Manufacturing, Chennai, 7-8 December 2012, pp. 305-308.
16. M. S. Ramgir, A. C. Reddy, Effect of Thermo-Tensile Loading on Micromechanical Behavior of AA6061 Alloy-Titanium Carbide Composites, 4th International Conference on Modern Materials and Manufacturing, Chennai, 7-8 December 2012, pp. 309-313.
17. P. Ram Reddy, A. C. Reddy, Microcasting of Mg-Ti alloys and their Wettability in Phosphate Bonded Investment Shell Molds, 4th International Conference on Modern Materials and Manufacturing, Chennai, 7-8 December 2012, pp. 112-115.

18. 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.
19. R. G. Math, A. C. Reddy, Inference of Macro-particles on Wear Rate of AA2024/TiO_2 Metal Matrix Composites, 4th International Conference on Modern Materials and Manufacturing, Chennai, 7-8 December 2012, pp. 329-333.
20. A. Chennakesava Reddy, Application of Factorial Techniques to Validate Wear Model of AA2024-Graphite Microcomposites, 4th International Conference on Modern Materials and Manufacturing, Chennai, 7-8 December 2012, pp. 344-348.
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. 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.
24. V. K. Reddy, A. C. Reddy, Tribological Investigation of Particle Size Effect on Wear Rate of Zirconium Oxide Microcomposites, 4th International Conference on Modern Materials and Manufacturing, Chennai, 7-8 December 2012, pp. 339-343.
25. 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.
26. R. G. Math, A. C. Reddy, Tribological Performance of AA3003/B_4C Metal Matrix Composites, 4th International Conference on Modern Materials and Manufacturing , Chennai, 7-8 December 2012, pp. 314-318.
27. M. Mastanaih, A. C. Reddy, Three-Body Wear Behavior of AA1100/ZrC Metal Matrix Composites, 4th International Conference on Modern Materials and Manufacturing, Chennai, 7-8 December 2012, pp. 319-323.
28. V. K. Reddy, A. C. Reddy, Influence of Matrix Alloy and Si_3N_4 Nanoparticle on Wear Characteristics of Aluminum Alloy Composites, 4th International Conference on Modern Materials and Manufacturing, Chennai, 7-8 December 2012, pp. 324-328.
29. M. Mastanaih, A. C. Reddy, Implication of Macro-sized Silicon Oxide Particles on Wear Rate of AA2024Alloy Metal Matrix Composites, 4th International Conference on Modern Materials and Manufacturing, Chennai, 7-8 December 2012, pp. 334-338.
30. 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.
31. 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.
32. 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.
33. J. F. Archard, W. Hirst, The Wear of Metals under Unlubricated Conditions, Proceedings of the Royal Society. A-236, 1956, pp. 397–410.