Exploitation of Reinforcement in Revision of Wear Behavior of AA1100/Si_3N_4 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 AA1100/Si_3N_4 metal matrix composites were manufactured at 10% and 30% volume fractions of Si_3N_4. 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 resistance increases with increase of vol.% Si_3N_4 in AA1100 alloy matrix. The three-body abrasion is highly dominated in AA1100/Si_3N_4 composites.*

Keywords: *AA1100, silicon nitride, wear, sliding distance, normal load, sliding speed.*

1. INTRODUCTION

Metal–ceramic composites exhibit superior performance, mechanical stability and failure tolerance such as excellent wear resistance, high fracture toughness and high hardness [1-16]. Especially, aluminum matrix composites reinforced by Si_3N_4 have the potential for use in aerospace applications owing to Si_3N_4 ceramics processing higher Young's modulus, combined with lower density, higher melting point and excellent oxidation resistance. Tribology properties of metal-ceramic composites can generally be enhanced by introducing a secondary phase(s) as three dimensional network structures into the metal matrix materials. There is a glut of papers by experimentalists who have studied the wear behavior of metal composites reinforced by ceramics secondary phases [17-32].

The tribological test are performed in different tribological testers such as pin-on-disk, block-on-ring, abrasive wear tester, etc. Mainly factors like applied load, sliding speed, sliding distance and temperature are varied during tribological testing to study the variation in wear rate and friction coefficient. The researchers have also carried out hardness and microstructure study of the materials to evaluate the hardness improvement and wear behavior of the materials [33-34].

So, in present paper, an attempt has been made to evaluate the dry sliding wear behavior of AA1100/Si_3N_4 composites over a range of loads, sliding distances and sliding speeds. The microstructures of them are discussed. And, the sliding wear mechanisms of them are studied.

2. MATERIALS METHODS

AA1100 alloy/ Si_3N_4 composites were fabricated by the stir casting process and low pressure casting technique with argon gas at 3.0 bar. The particle size of silicon nitride (Si_3N_4) nanoparticles was 100 nm. The composite samples were given H18 solution 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 [25, 26]. Each of the process parameters was deliberated at three levels (Table 1). The orthogonal array, L9 was preferred to carry out wear tests experimentally (Table 2). A pin on disc type friction and wear monitor (ASTM G99) was employed to evaluate the friction and wear behavior of AA1100 alloy/ Si_3N_4 composites against hardened ground steel (En32) disc. Scanning electron microscopy analysis was also carried out to find consequence of wear test AA1100/ Si_3N_4 composite specimens.

Table 1: Control parameters and levels

Factor	Symbol	Level–1	Level–2	Level–3
Reinforcement, Vol.%	A	10	20	30
Load, N	B	20	30	40
Speed, m/s	C	2	3	4
Sliding distance, m	D	500	1000	1500

The elastic modulus of the composites is calculated with the following expressions:

The upper-bound equation is given by

$$\frac{E_c}{E_m} = \left(\frac{1-v_v{}^{2/3}}{1-v_v{}^{2/3}+v_v}\right) + \frac{1+(\delta-1)v_p{}^{2/3}}{1+(\delta-1)\left(v_p{}^{2/3}-v_p\right)} \quad (1)$$

The lower-bound equation is given by

$$\frac{E_c}{E_m} = 1 + \frac{v_p-v_p}{\delta/(\delta-1)-(v_p+v_v)^{1/3}} \quad (2)$$

where, $\delta = E_p/E_m$, v_v and v_p are the volume fractions of voids/porosity and nanoparticles in the composite respectively, and E_m and E_p is elastic moduli of the matrix and the particle respectively.

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 mechanical properties of AA1100/Si_3N_4 composites are shown in figure 1. The tensile strength, elastic stiffness and knoop hardness were increased with volume fraction of Si_3N_4.

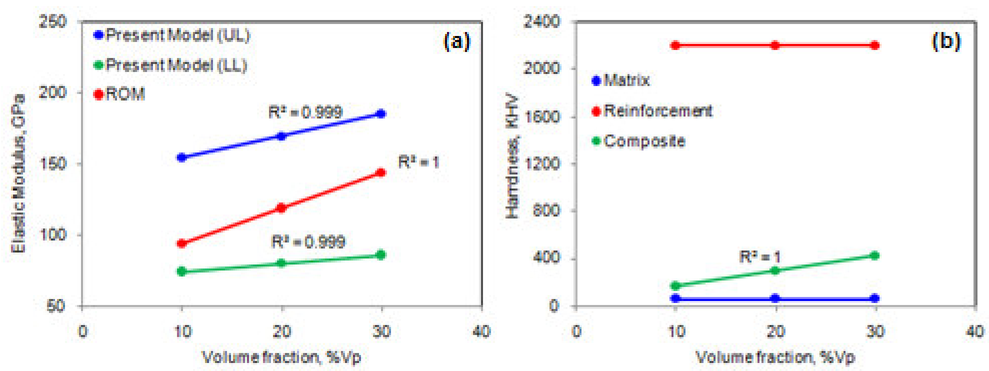

Figure 1: Mechanical Properties of AA1100/Si_3N_4 composites.

3.1 Effect of volume fraction, Normal Load, Sliding Speed, Sliding distance on Wear Rate

The analysis of variance (ANOVA) is presented in Table 3. The percent contribution indicates that the parameter, A contributes 48.25%. The parameter, B shares 17.51% of variation in the wear rate. The parameter, C dispenses 12.32% of variation in the wear rate. The parameter, D affords 21.92% of the total variation in the wear rate. The R-squared values of %reinforcement, normal load, sliding speed and sliding distance are, respectively, 0.938, 0.913, 0.738 and 0.920. The trend of mean values obtained by Taguchi techniques is same as that of R-squared values. Analysis of means (AOM) is presented in the form of mean plots as shown in figure 2. The wear rate was decreased with increase in volume fraction of Si_3N_4 in AA1100 alloy matrix (figure 2a). This is owing to high hardness of Si_3N_4 as compared to soft matrix. An increase in wear rate is with increase of normal load applied on the test specimen (figure 2b). This is nothing but scoring wear, a severe form of adhesive wear, occurs due to tearing out of small particles that weld together as a result of overheating due to high contact pressure of the tooth mesh zone, permitting composite to steel disc contact. The wear rate was decreased with increase of speed (figure 2c). At higher sliding speeds, a delamination wear is initiated due to the kinetic friction coefficient. This resulted in a lower wear rate. The wear rate increased with the sliding distance as shown in figure 2d. The severity of wear is decreasing as the contact conforms and so the linear wear per unit sliding distance continuously decreases.

Table 3: ANOVA summary of the effective stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	21.64	20.65	20.19	0.37	1.00	0.37	1.29E+13	48.25
B	20.43	20.74	21.31	0.13	1.00	0.13	4.67E+12	17.51
C	21.10	20.98	20.40	0.09	1.00	0.09	3.29E+12	12.32
D	20.37	143.52	62.48	0.17	1.00	0.17	5.85E+12	21.92
e				0.00	4.00	0.00	1.00	0.00
T	83.54	205.89	124.38	0.76	8.00			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.

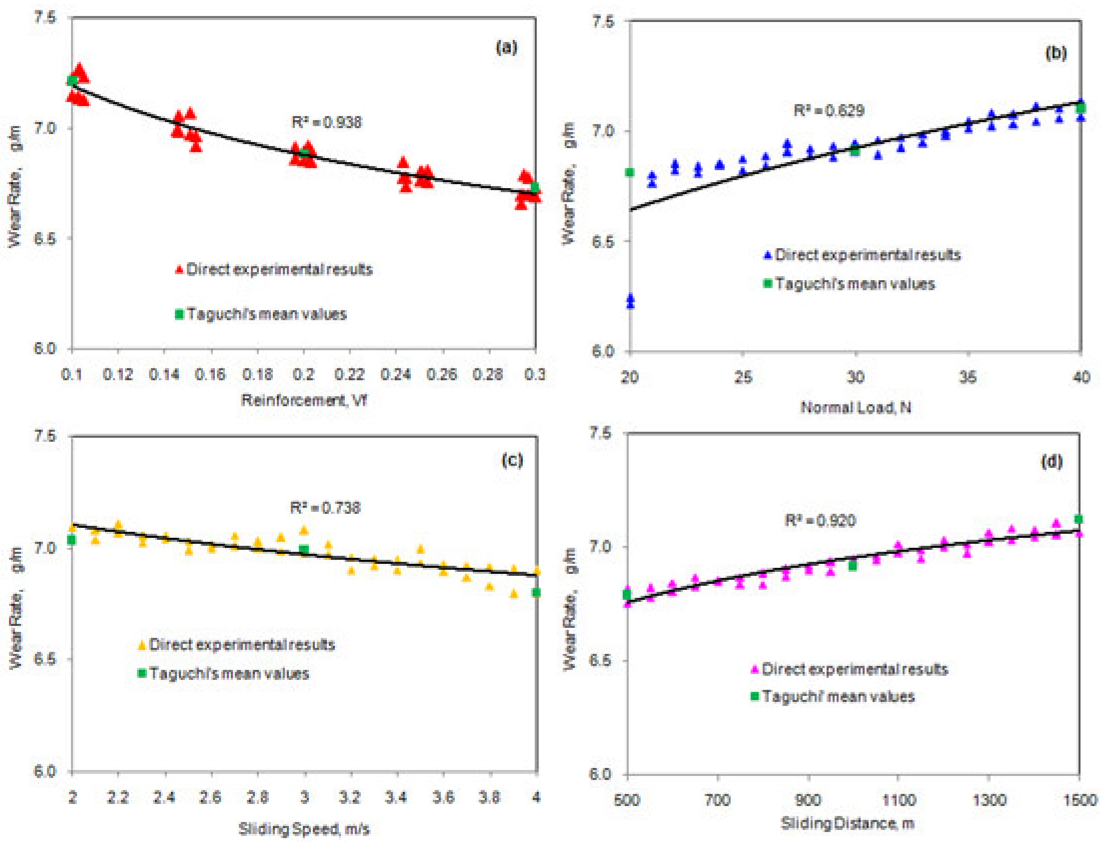

Figure 2: Influence of process parameters on wear rate.

The mathematical relation between wear and contact time is given by

$$W_{rp} = 6.209 v_f^{-0.06} \quad (3)$$

$$W_{rf} = 5.530 F^{0.067} \quad (4)$$

$$W_{rn} = 7.329 N^{-0.04} \quad (5)$$

$$W_{rd} = 5.254d^{0.04} \quad (6)$$

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.

3.2 Consequence of Wear in AA1100/Si_3N_4 Composites

It is essential to know the consequence of wear in AA1100/ Si_3N_4 composites. The hardness values increase after wear test as shown in figure 3. The increase in hardness in the worn specimens may be attributed to the work hardening and the frictional temperature. When the applied force increased, the plastic deformation would take place in the AA1100 alloy matrix which could adhere to the steel disc and consequently, resulting the conditions of adhesive wear as shown in figure 4. If the wear is caused by a hard particle (Si_3N_4) trapped between the rubbing surfaces it is called three body wear. The three-body abrasion which involves Si_3N_4 hard particles, either trapped between two sliding surfaces and abrading one or both surfaces. The particle removal was higher in the composites having 30% Si_3N_4 than in the composites having 10% Si_3N_4.

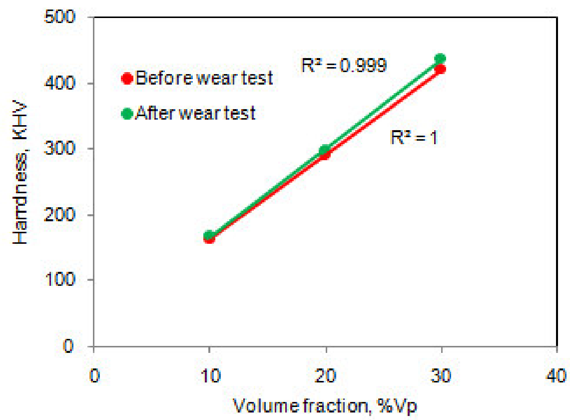

Figure 3: Hardness of AA1100/ Si_3N_4 composites after wear test.

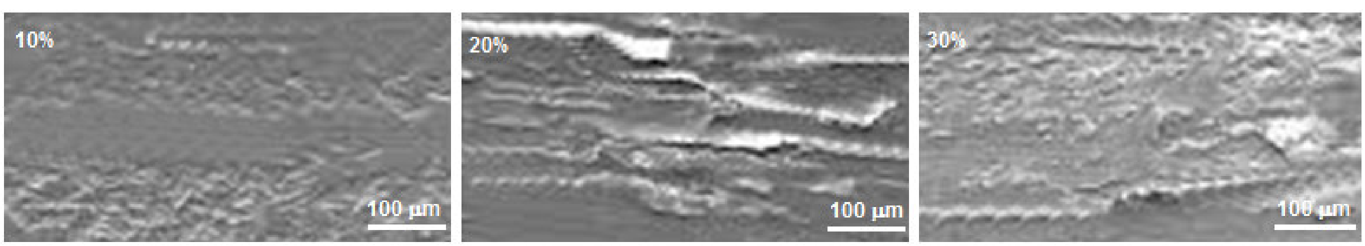

Figure 4: Adhesive and abrasive wear of AA1100/Si_3N_4.

4. CONCLUSION

The study on the wear behavior of AA1100/Si_3N_4 composites as the function of vol.% of Si_3N_4, 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.% Si_3N_4 nanoparticles in AA1100 alloy matrix. The three-body abrasion is highly dominated in AA1100/Si_3N_4 composites.

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. 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.
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. 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.
20. 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.
21. 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.
22. 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.
23. 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.
24. 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.
25. V. K. Reddy, A. C. Reddy, Influence of Matrix Alloy and Si3N4 Nanoparticle on Wear Characteristics of Aluminum Alloy Composites, 4th International Conference on Modern Materials and Manufacturing, Chennai, 7-8 December 2012, pp. 324-328.
26. 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.
27. R. G. Math, A. C. Reddy, Inference of Macro-particles on Wear Rate of AA2024/TiO2 Metal Matrix Composites, 4th International Conference on Modern Materials and Manufacturing, Chennai, 7-8 December 2012, pp. 329-333.
28. 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.
29. 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.
30. 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.
31. A. M. Hassan, A. Alrashdan, M. T. Hayajneh, A. T. Mayyas, Wear behavior of Al-Mg-Cu-based composites containing SiC particles, Tribology International, 42, 2009, pp. 1230‑1238.
32. R. Ipek, Adhesive wear behaviour of B_4C and SiC reinforced 4147 Al matrix composites (Al/B_4C-Al/SiC), Journal of Materials Processing Technology, 162‑163, 2005, pp. 71‑75.
33. 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.
34. 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.