Three-Body Wear Behavior of AA1100/ZrC Metal Matrix Composites

[1]M. Mastaniah 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- ZrC metal matrix composites were manufactured at 10% and 30% volume fractions of ZrC. 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 rate decreases with increase of vol.% ZrC in AA1100 alloy matrix. Three-body abrasive mechanism was predominant in the wear mechanisms of AA1100-ZrC metal matrix composites.*

Keywords: *AA1100, zirconium carbide, wear, sliding distance, normal load, sliding speed.*

1. INTRODUCTION

Metal matrix composites have added advantages compared to the base material due to the presence of the reinforcements. Aluminum has a good thermal conductivity, less density and a high strength to weight ratio. Upon adding the material, the strength, stiffness, density and thermal/electrical conductivity of the composites improve considerably [1-19]. From the various studies on dry sliding wear of aluminum composites, effects of reinforcement size, volume fractions and morphology on the wear rate can be observed. Similarly, effects of various operation parameters on the dry sliding wear have been discussed in previous studies [20-27].

The objective of the present work was to evaluate the dry sliding wear behavior of AA1100/Zirconium carbide composites over a range of loads, sliding distances and sliding speeds.

2. MATERIALS METHODS

The matrix material was AA1100 alloy. The reinforcement material was zirconium carbide (ZrC) nanoparticles of average size 100nm. AA1100 alloy/ ZrC composites were fabricated by the stir casting process and low pressure casting technique with argon gas at 3.0 bar. The composite samples were given H18 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 [28, 29]. The levels chosen for the controllable process parameters are summarized in Table 1. The orthogonal array (OA), 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/ ZrC composites against hardened ground steel (En32) disc. To determine hardness before and after wear test, the Knoop hardness was conducted. Scanning electron microscopy analysis was also carried out to find consequence of wear test AA1100/ ZrC 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

. Elastic modulus was computed as follows:

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, $\delta = E_p/E_m$, where, 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 elastic stiffness and knoop hardness were increased with volume fraction of ZrC as shown in figure 1.

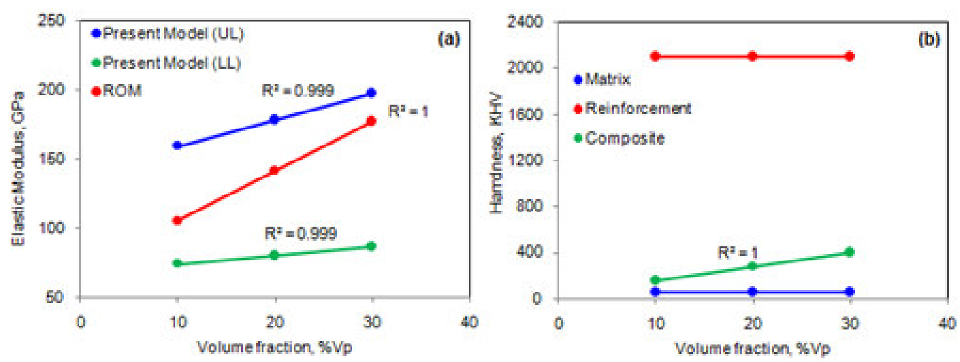

Figure 1: Mechanical Properties of AA1100/ZrC composites.

Table 3: ANOVA summary of the effective stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	21.24	20.30	19.50	0.51	1.00	0.51	8.90E+12	62.02
B	20.03	20.25	20.76	0.09	1.00	0.09	1.64E+12	11.47
C	20.58	20.51	19.95	0.08	1.00	0.08	1.40E+12	9.75
D	19.95	136.69	61.04	0.14	1.00	0.14	2.40E+12	16.76
e				0.00	4.00	0.00	1.00	0.00
T	81.80	197.75	121.25	0.82	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.

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

All process parameters are acceptable as they satisfy Fisher's test at 90% confidence level. The analysis of variance (ANOVA) is presented in Table 3. The percent contribution indicates that the volume fraction of ZrC, contributes 62.02%. The normal load gives 11.47% of variation in the wear rate. The speed devotes 9.75% of variation in the wear rate. The sliding distance tenders 16.76% of the total variation in the wear rate. The R-squared values of %reinforcement, normal load, sliding speed and sliding distance are, respectively, 0.950, 0.883, 0.728 and 0.896. The trend of mean values obtained by Taguchi techniques is same as that of R-squared values. The wear rate was decreased with increase in volume fraction of ZrC in AA1100 alloy matrix (figure 2a). This is due to high hardness of ZrC as compared to soft matrix. The reduction of wear rate was due to increase of composite hardness as seen from figure 1c. An increase in wear rate is with increase of normal load applied on the test specimen (figure 2b). This effect was due to adhesion and increase in plastic deformation at the surface layers. The wear rate was decreased with increase of speed (figure 2c). At higher speeds an oxide layer was formed at the sliding interface. This, in turn, would avoid the direct metallic contacts resulting reduced wear rate. The wear rate increased with the sliding distance as shown in figure 2d.

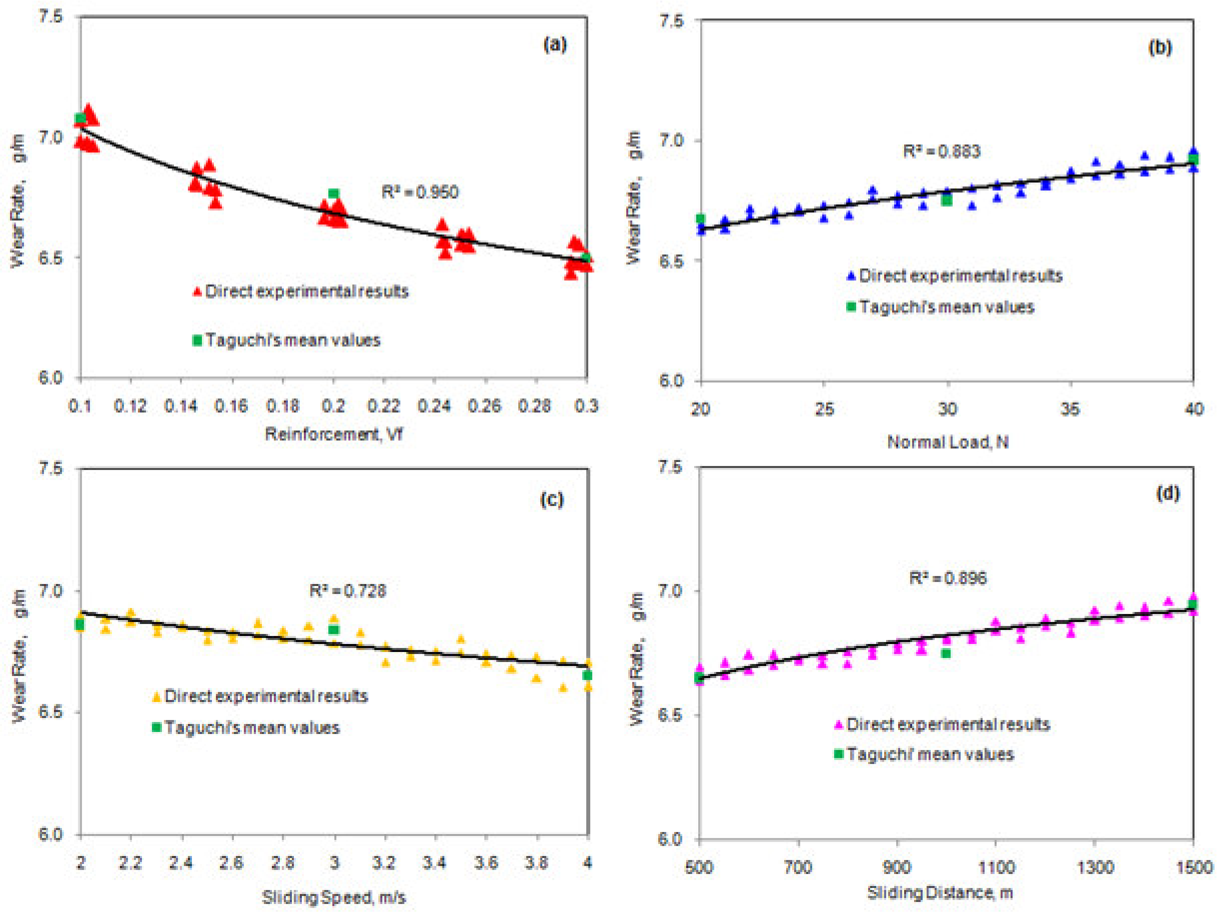

Figure 2: Influence of process parameters on wear rate.

The mathematical relation between wear and contact time is given by

$$W_{rp} = 5.933 v_f^{-0.05} \tag{3}$$

$$W_{rf} = 5.57 F^{0.058} \tag{4}$$

$$W_{rn} = 7.131 N^{-0.04} \tag{5}$$

$$W_{rd} = 5.263 d^{0.037} \tag{6}$$

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/ZrC Composites

It is important to identify the consequence of wear in AA1100/ZrC composites. The reason of post-wear evaluation is to focus the changes that are brought in the worn specimens in terms of mechanical properties, microstructure, and worn-surface pattern. The change in hardness of the worn specimens is shown in figure 3. 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 and the frictional temperature. When the load was 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 (ZrC) trapped between the rubbing surfaces, the phenomenon is called three-body abrasive wear. The particle may be either free or partially entrenched into one of the mating materials. The particle removal was higher in the composites having 30% Si_3N_4 than in the composites having 10% ZrC.

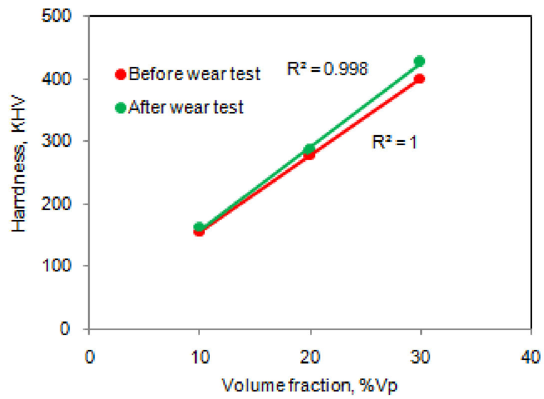

Figure 3: Hardness of AA1100/ZrC composites after wear test.

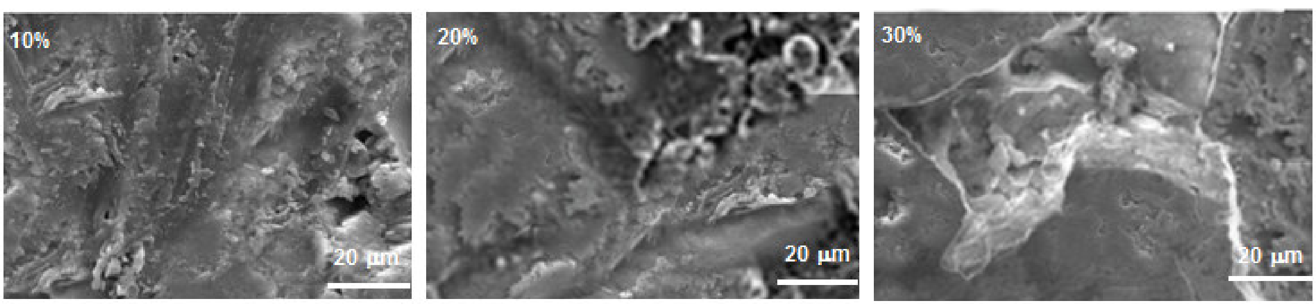

Figure 4: Adhesive and abrasive wear of AA1100/ZrC.

4. CONCLUSION

The study on the wear behavior of AA1100/ZrC composites as the function of vol.% of ZrC, 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.% ZrC nanoparticles in AA1100 alloy matrix. The wear rate increases with increase in normal load and sliding distance. The dominant mechanisms of adhesive wear and three-body abrasive wear.

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