Abrasive Wear of AA3003/ZrC Composites

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Abstract: *In the current work, the AA3003/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 mathematical models were derived. The wear resistance increases with increase of vol.% ZrC in AA3003 alloy matrix. Adhesive and abrasive wears were predominant in AA3003-ZrC metal matrix composites.*

Keywords: *AA3003, zirconium carbide, wear, sliding distance, normal load, sliding speed.*

1. INTRODUCTION

Particle reinforced metal matrix composites have numerous advantages and it was fabricated easily with less cost compared to fiber reinforced metal matrix composites. Particulate reinforced metal matrix composites were raised as the latent materials for the automotive tribological applications predominantly for pistons, brake drum, cylinder liners, connecting rods and cylinder block because of its high wear resistance and less weight. Literatures apparently show that numerous particulates such as silicon carbide (SiC), Al_2O_3 etc., were successfully processed through stir casting technique [1-16].

There were many researches explicating the dry sliding wear behavior of the composites reinforced with SiC, Al_2O_3, B_4C etc., [17-27]. The exposure on zirconium carbide (ZrC) nanoparticles reinforced aluminum composites was not that much in the present scenario. Therefore, the current study addresses the exploration on dry sliding wear behavior of the AA3003/ZrC composites through Taguchi's statistical model [28, 29] and checking the efficiency of the developed model through empirical models.

2. MATERIALS METHODS

The matrix material was AA3003 alloy. The reinforcement material was ZrC nanoparticles of average size 100nm. AA3003 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 H14 heat treatment. The heat-treated samples were machined to get cylindrical specimens of 10 mm diameter and 30 mm length for the wear tests. The design of experiments was carried out as per Taguchi techniques. Each of the process parameters was deliberated at three levels (Table 1). The orthogonal array, L9 was preferred to carry out experiments as given in Table 2. A pin on disc type friction and wear monitor (ASTM G99) was employed to evaluate the friction and wear behavior of AA3003 alloy/ ZrC composites against hardened ground steel (En32) disc.

The microhardness was measured in terms of Knoop hardness number. Scanning electron microscopy analysis was also carried out to find consequence of wear test AA3003/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 estimated assuming the behavior of isotropic materials. 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, vv and vp are the volume fractions of voids/porosity and nanoparticles in the composite respectively and Em and Ep 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 AA3003/ZrC composites are shown in figure 1. The elastic stiffness and knoop hardness were increased with volume fraction of ZrC.

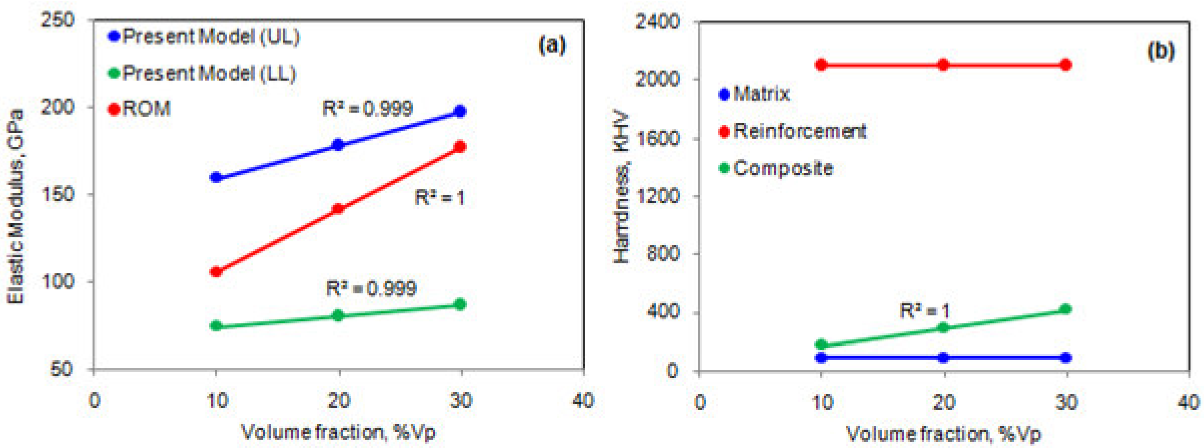

Figure 1: Mechanical Properties of AA3003/ZrC composites.

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

In Table 3, the percent contribution indicates that the parameter A contributes variation of 45.44% in the wear rate. The parameter, B dispenses a variation of 23.68% in the wear rate. The parameter, C accords 13.00% of variation in the wear rate. The parameter, D tenders 17.88% of variation in the wear rate. The influence of volume fraction of ZrC on wear rate is shown in figure 1. It can be seen that the wear rate was decreased with increase in volume fraction of ZrC in AA3003 alloy matrix. This is owing to high hardness of ZrC as compared to soft matrix. It is also observed that a general trend of increase in wear rate is with an increase in normal load applied on the test specimen (figure 2b). This was due to the increase in the contact pressure at the interface of the specimen and the steel disc when load was increased. The wear rate was decreased with increase of speed (figure 2c). This was attributed to transfer of materials between specimen and the steel disc due to high interface temperature developed at high velocity. This transfer of material forms a protective layer on the surface which reduces the metal to metal contact thereby reduces the wear rate. The wear rate was proportional to the sliding distance as shown in figure 2d. The protruded hard asperities on the surface of the specimen and the counter surface gets contacted and fractured as the sliding distance increased resulting high wear rate.

Table 3: ANOVA summary of the effective stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	21.31	20.44	19.04	0.87	1	0.87	3.08E+13	45.44
B	19.47	20.20	21.12	0.45	1	0.45	1.60E+13	23.68
C	20.68	20.55	19.56	0.25	1	0.25	8.80E+12	13.00
D	19.91	130.54	60.79	0.34	1	0.34	1.21E+13	17.88
e				0.00	4	0.00	1.00E+00	0.00
T	81.37	191.73	120.51	1.92442	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.

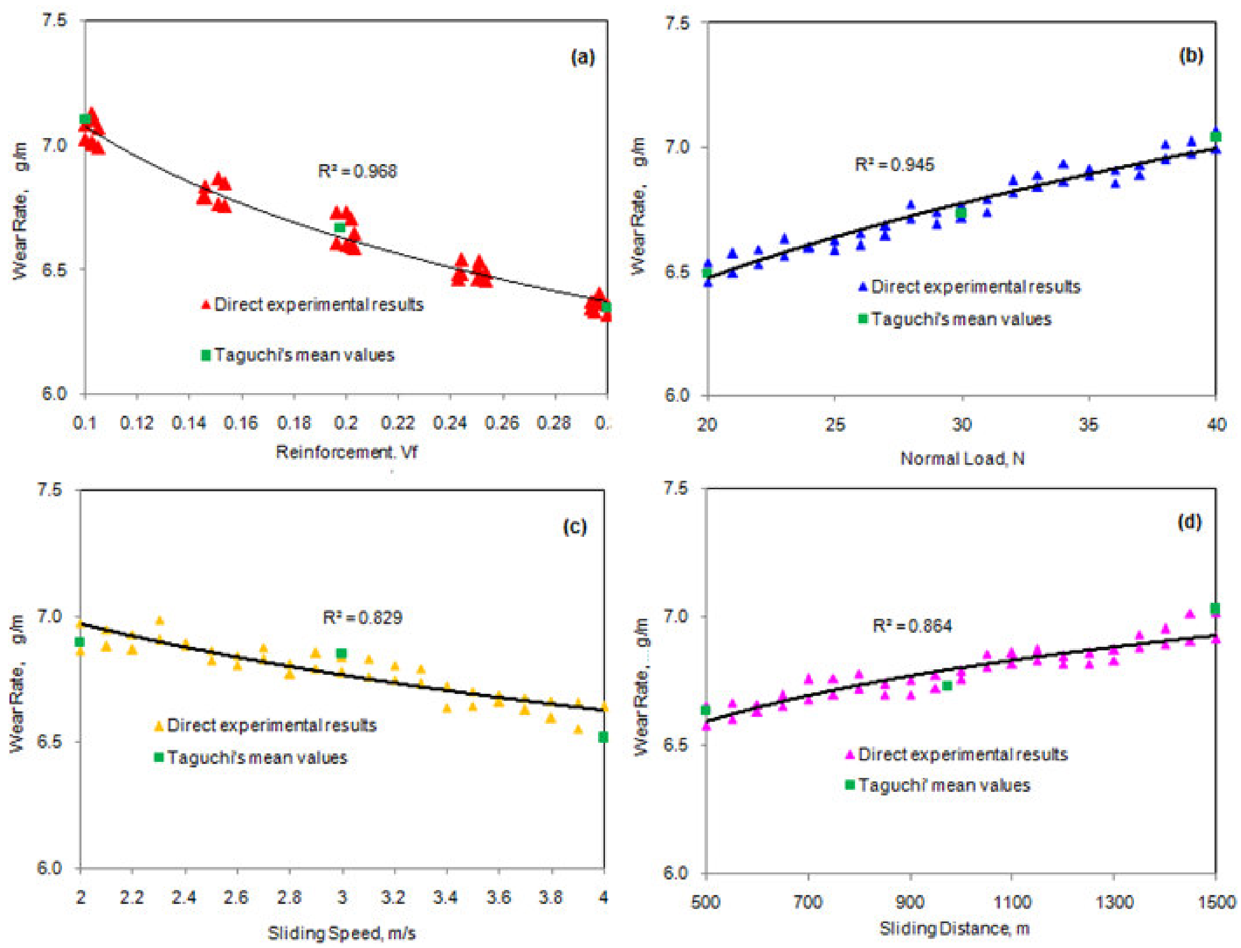

Figure 2: Influence of process parameters on wear rate.

The mathematical relation between wear and contact time is given by

$$W_{rp} = 5.678 v_f^{-0.09}$$

$$W_{rf} = 4.621 F^{0.112}$$

$$W_{rn} = 7.334 N^{-0.07}$$

$$W_{rd} = 4.997 d^{0.044}$$

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.

The R-squared values are in the range of 0.829 to 0.968. These values indicate the parameter influence on wear rate and the best fit of the trend.

3.2 Consequence of Wear in AA3003/ZrC Composites

It is necessary to know the consequence of wear in AA3003/ZrC 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 ageing due to the frictional temperature. In the composites having 10 volume fraction of ZrC, a large amount of debris and fracture of AA3003 alloy matrix were observed due to its softness (figure 4a). In the composites having 20 or 30 vol.% of ZrC, removal of particles from the matrix material and scratches due to rubbing action of detached particles were observed (figure 4b-c).

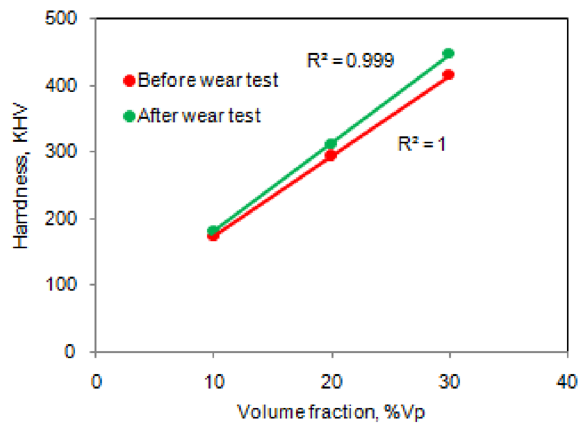

Figure 3: Harness of AA3003/ZrC composites after wear test.

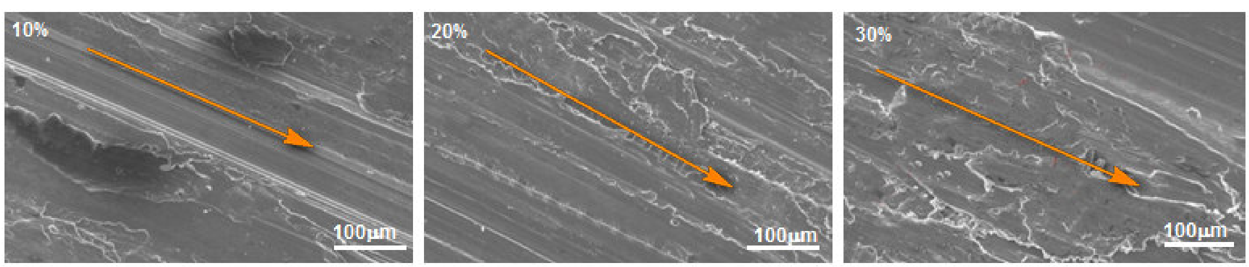

Figure 4: Wear behavior of AA3003/ZrC composites.

4. CONCLUSION

The wear behavior of the composites as the function of volume fraction % of reinforcement, 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 in AA3003 alloy matrix. The consequences of wear were work hardening, matrix fracture and particle removal.

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