Influence of Matrix Alloy and Si_3N_4 Nanoparticle on Wear Characteristics of Aluminum Alloy Composites

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Abstract: *In the present work, the AA2024/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. The wear resistance increases with increased volume fraction of Si_3N_4 in AA2024 alloy matrix. The scratches were seen on the worn surfaces due to three-body abrasion.*

Keywords: *AA2024, silicon nitride, wear, sliding distance, normal load, sliding speed.*

1. INTRODUCTION

Metal matrix composite achieves mixed property of its base metal and reinforcement. Particle reinforced metal matrix composites (PMMCs) are now emerging as an important class of engineering materials. Most of the experimental and numerical studies [1-15] have been carried out to understand the effect of the morphological variables, such as the particle volume fraction, particle size, shape and orientation on the deformation and damage behavior of the alloy. Dry sliding contacts often contain wear particles and mechanically mixed deformed layers (third bodies) whose behavior needs to be understood and modeled. The abrasive wear and the contact fatigue are the most important from the technological point of view. It was estimated that the total wear of machine elements can be identified in 80-90% as abrasion and in 8% as fatigue wear [16-28]. Contributions of other types of wear are small. Archard [29] formulated the wear equation of the form: the volume of the material removed is directly proportional to the sliding distance, the normal pressure and the dimensionless wear coefficient, and inversely proportional to the hardness of the surface being worn away.

The aim of this project was to assess the influence of matrix alloy and reinforced nanoparticles on the dry sliding wear behavior of AA2024/Si_3N_4 composites over a range of loads, sliding distances and sliding speeds.

2. MATERIALS AND METHODS

AA2024 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 size of silicon nitride (Si_3N_4) nanoparticles was 100nm. The composite samples were given T6 heat treatment before the samples machined to get cylindrical specimens for the wear tests. The design of experiments was carried out as per Taguchi techniques [27, 28]. Each of the process parameters was deliberated at three levels (Table 1). The orthogonal array, L9 was used to conduct wear tests (Table 2). A pin on disc type friction and wear monitor (ASTM G99) was employed to evaluate the friction and wear behavior of AA2024 alloy/ Si_3N_4 composites against hardened ground steel (En32) disc. Knoop hardness test carried out to determine the hardness of the samples before and after wear tests. Scanning electron microscopy analysis was also carried out to find consequence of wear test AA2024/ 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

Elastic modulus was determined using 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 elastic stiffness and knoop hardness were increased with volume fraction of Si_3N_4 as shown in figure 1. This is a general tendency as expected from the composites in the literature and it is well known fact.

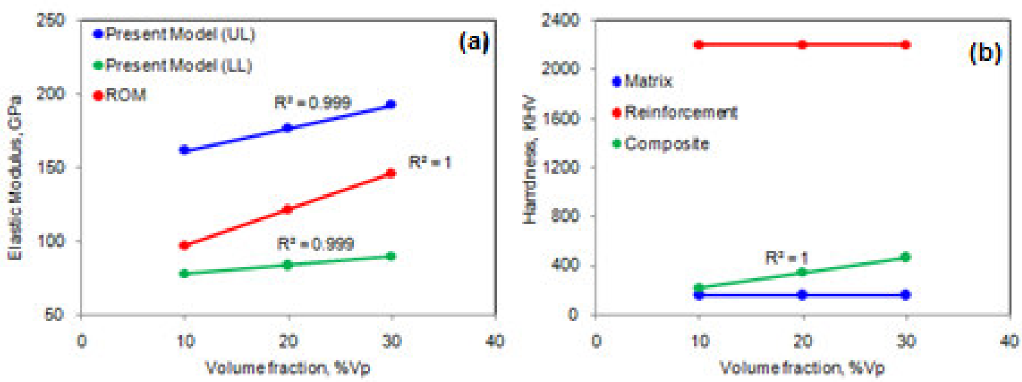

Figure 1: Mechanical Properties of AA2024/Si_3N_4 composites.

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 volume fraction of Si_3N_4 (A), contributes 55.42%. The normal load (B) shares 8.22% of variation in the wear rate. The speed (C) dispenses 7.28% of variation in the wear rate. The sliding distance (D) affords 29.08% of the total variation in the wear rate. The R-squared values of %reinforcement, normal load, sliding speed and sliding distance are, respectively, 0.921, 0.493, 0.306 and 0.865. The trend of mean values obtained by Taguchi techniques is same as that of R-squared values.

Table 3: ANOVA summary of the effective stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	21.82	21.08	20.60	0.25	1.00	0.25	5.91E+12	55.42
B	21.03	21.03	21.44	0.04	1.00	0.04	8.76E+11	8.22

C	21.28	21.31	20.91	0.03	1.00	0.03	7.76E+11	7.28
D	20.73	149.11	63.50	0.13	1.00	0.13	3.10E+12	29.08
e				0.00	4.00	0.00	1.00	0.00
T	84.86	212.53	126.45	0.45	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.

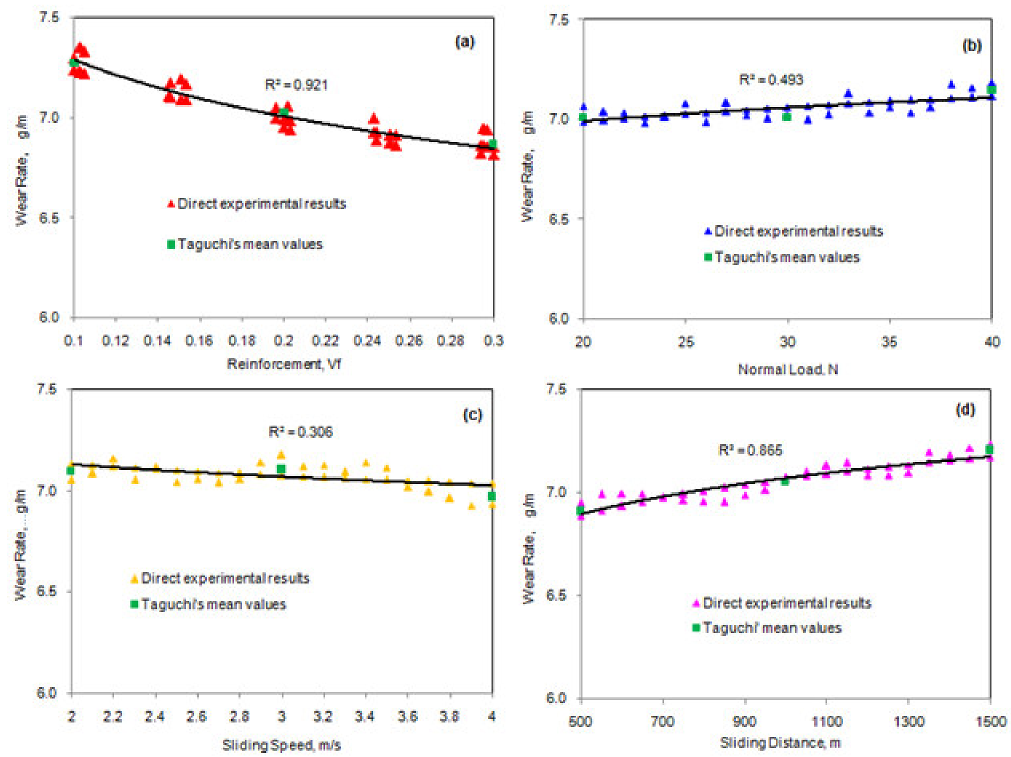

Figure 2: Influence of process parameters on wear rate.

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 AA2024 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 scoring wear with enhanced contact between and disc and increased coefficient of friction. The wear rate was decreased with increase of speed (figure 2c). This is delamination wear attributed to the kinetic friction coefficient. The wear rate increased with the sliding distance as shown in figure 2d. The mathematical relation between wear and contact time is given by

$$W_{rp} = 6.393 {v_f}^{-0.05} \tag{3}$$

$$W_{rf} = 6.516 F^{0.023} \tag{4}$$

$$W_{rn} = 7.277 N^{-0.02} \tag{5}$$

$$W_{rd} = 5.527 d^{0.035} \tag{6}$$

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 AA2024/Si_3N_4 Composites

It is essential to know the consequence of wear in AA2024/ Si_3N_4 composites. The hardness values increase after wear test as shown in figure 3. When the applied force increased, the plastic deformation would take place in the AA2024 alloy matrix which could adhere to the steel disc and consequently, resulting the conditions of adhesive wear as shown in figure 4. The three body wear was also occurred due to hard Si_3N_4 particle trapped between the rubbing surfaces.

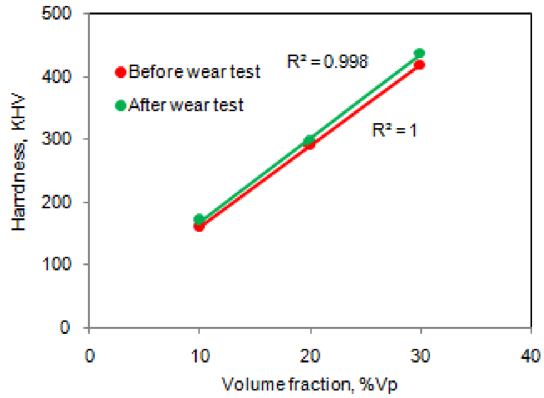

Figure 3: Hardness of AA2024/ Si_3N_4 composites after wear test.

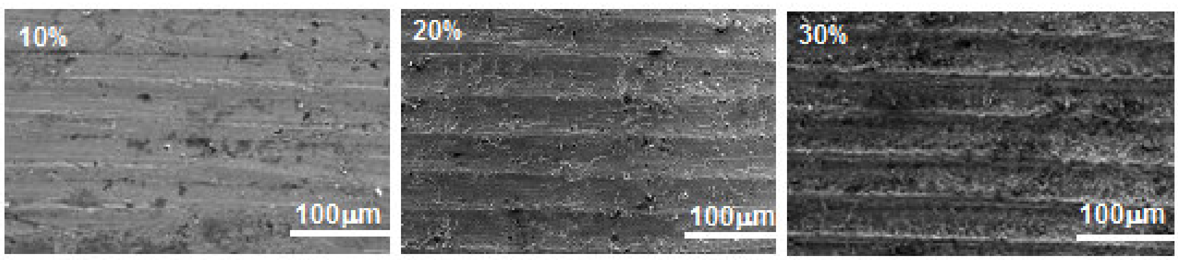

Figure 4: Adhesive and abrasive wear of AA2024/Si_3N_4.

4. CONCLUSION

The study on the wear behavior of AA2024/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 effectively. The wear resistance increases with increased volume fraction of Si_3N_4 nanoparticles in AA2024 alloy matrix. The three-body abrasion is highly subjugated in the AA2024/Si_3N_4 nanoparticulate metal matrix composites.

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