Hardness Contours and Worn Surfaces of AA1100 Alloy/TiO_2 Metal Matrix Composites

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Abstract: *In the present work, the AA1100 alloy/TiO_2 metal matrix composites were manufactured at 10% and 30% volume fractions of TiO_2. 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.% TiO_2 in AA1100 alloy matrix. Combined effect of adhesion and abrasions were predominant in the wear mechanisms of AA1100 alloy/ TiO_2 metal matrix composites.*

Keywords: *Metal matrix composite, AA1100 alloy, titanium oxide, wear, sliding distance, normal load, speed.*

1. INTRODUCTION

Aluminum based metal matrix composites are alternative materials to substitute steel in plentiful fabricated structural parts such as automotive pistons, gears, brake pads, etc., due to their high strength-to-weight and stiffness ratios [1-5 Effect of reinforced particle size and its volume fraction, formation of precipitates, porosity and agglomeration of reinforced particles on mechanical properties were largely covered in many research papers on the composite materials [6-10]. In most of particulate metal matrix composites, the particulate phase is harder and stiffer than the matrix. These reinforcing particulates tend to control movement of the matrix phase in the neighborhood of each particulate [11-17]. In the cast composites, particulate–matrix interactions that lead to strengthening occur on the atomic or molecular level. For wear resistance applications of particulate metal matrix composites, it is very vital to have strong bonding at the matrix–particle interface. Because of poor bonding between matrix and particulate, the detached particle can freely move on the contact zone resulting work hardening and increased material loss [18-21]. Several research papers are available on wear studies of composite materials. A few papers have addressed correlation between worn surfaces and their hardness contours. Archard [22] determined the material loss due to wear as follows:

$$W = Ks\frac{P}{H} \quad (1)$$

where, W is the worn volume, s is the sliding distance, P is the applied load, H is the hardness of the softer material and K is a constant. Quantitative agreement with this model was inadequate. Heat of adsorption on an active surface is different from static test results. Also, the wear rate calculations were based on projected contact area.

The wear characteristics of metal matrix composites depend upon the material morphology such as composition, size, shape and distribution of reinforcements and service conditions such as load, contact surface, contact time and sliding speed [9-11]. The objective of this paper was to correlate the worn surfaces with their hardness contours of AA1100/titanium oxide metal matrix composites. To achieve the goals of the paper, the wear tests were conducted on pin-on-disc equipment. The design of experiments was based on Taguchi techniques [23, 24].

Table 1: Wear 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

2. MATERIALS AND METHODS

The matrix was AA1100 alloy. The reinforcement was titanium oxide (TiO_2) nanoparticles of average size 100nm. AA1100 alloy/TiO_2 composites were fabricated by the stir casting process. The H18 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).

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

A pin-on-disc wear monitor (ASTM G99) was employed to assess the wear behavior of AA1100 alloy/TiO_2 composites against hardened ground steel (En32) disc. Knoop microhardness was conducted before and after wear tests. Optical microscopy analysis was conceded to extract worn surfaces of AA1100/TiO_2 composite specimens.

3. RESULTS

In the present work, the wear rate was as a function of the volume fraction of reinforcement V_f, applied load F, sliding speed N and sliding distance d. The Knoop microhardness was conducted to know the effect of reinforcement on the hardness of the composites before and after wear tests. The microhardness of AA1100 alloy/ TiO_2 composites was increased with increased in TiO_2 content as shown in figure 1.

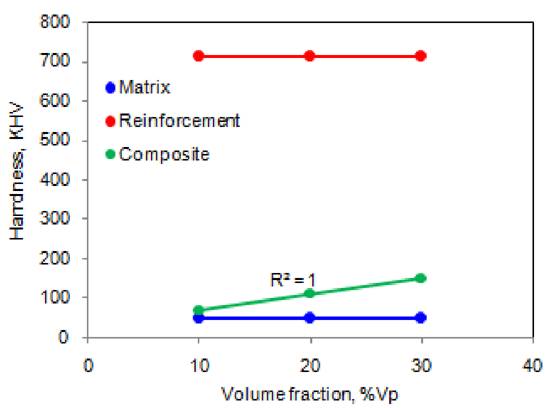

Figure 1: Effect of reinforcement on the hardness of composite.

Table 3: ANOVA summary of the effective stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	37.09	36.01	35.58	0.40	1	0.40	3.55E+12	23.75
B	35.86	36.07	36.75	0.14	1	0.14	1.27E+12	8.49
C	35.90	36.37	36.41	0.05	1	0.05	4.72E+11	3.16
D	34.81	445.54	108.68	1.10	1	1.10	9.65E+12	64.59
e				0.00	4	0.00	1.00	0.00
T	143.66	553.99	217.42	1.70	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.

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 specifies that the volume fraction of TiO_2 (A), contributes 23.75%. The normal load (B) allocates 8.49% of variation in the wear rate. The speed (C) allots 3.16% of variation in the wear rate. The sliding distance (D) affords 64.59% of the total variation in the wear rate. The R-squared values of %reinforcement, normal load, sliding speed and sliding distance are, respectively, 0.843, 0.783, 0.684 and 0.990. 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 TiO_2 in AA1100 alloy matrix as shown in figure 2a. As seen from figures 2b-d, an increase in wear rate is with increase of normal load applied on the test specimen, sliding speed and sliding distance.

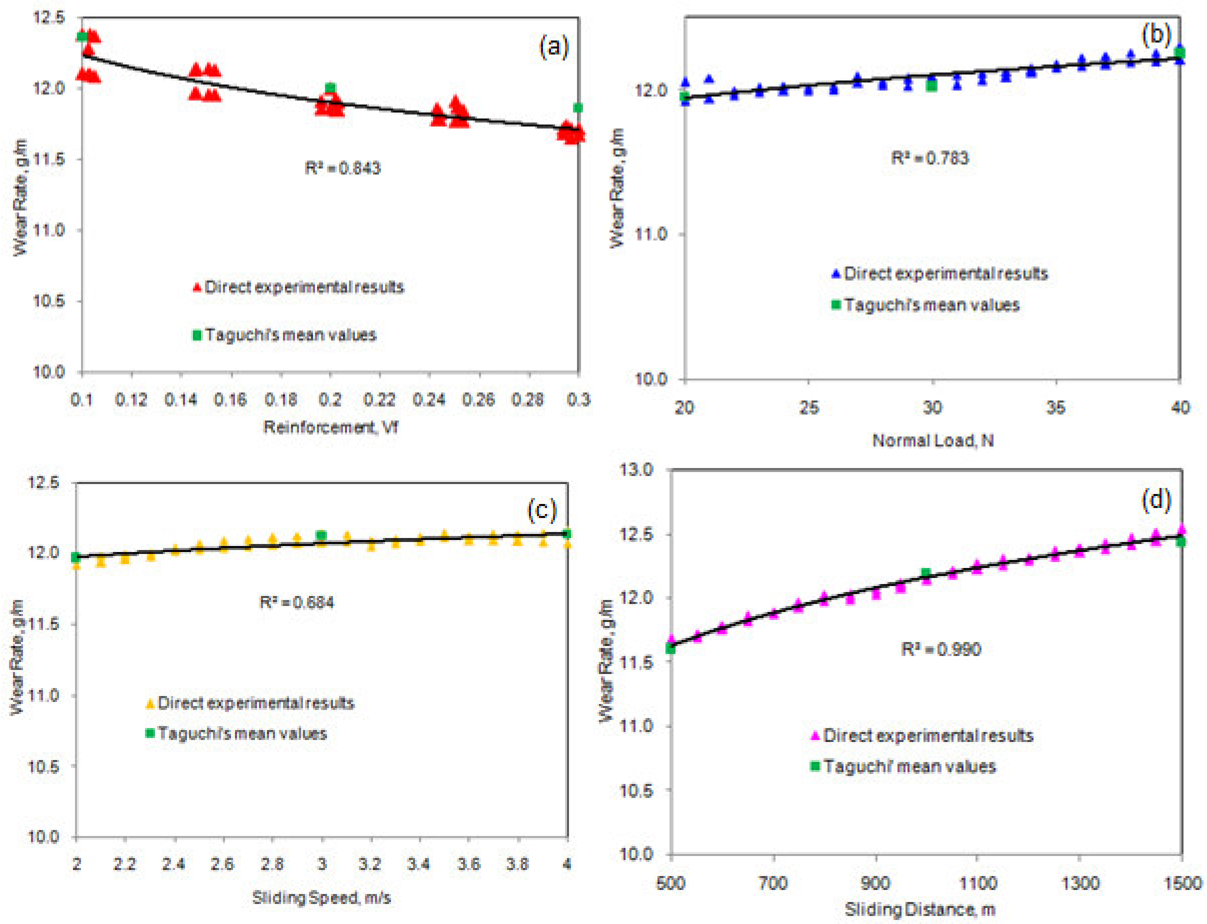

Figure 2: Wear rate as a function of (a) % reinforcement, (b) applied load, (c) sliding speed and (d) sliding distance.

4. DISCUSSION

Composites produced by high volume fraction of TiO_2, wear out slower than those produced by low volume fraction. TiO_2 particles minimize the plastic deformation on the wearing surface resulting reduced wear rate. When the reinforcement, TiO_2 nanoparticles, increased from 10% to 30 vol.%, a decrease in wear rate was detected. This might be owing to the increase of composite hardness with increase of TiO_2 in AA1100 alloy matrix (figure 3). The increase in the load causes rise in friction and contact between pin and disc. This promotes the formation of an AA1100 alloy-rich layer on the disc's surface. This effect results in adhesion and increases the matrix deformation at the surface layers, leading to loss of the metal. At higher speeds an oxide-like transferred layer formed at the sliding interface and reduced direct metallic contacts. This resulted in a lower wear rate. For long sliding distances, the shear stress exceed the shear strength of the particle/matrix interface resulting particle debonding contributing to an increase in the rate of wear. This might be due to the delamination and chipping out of the TiO_2 particles from the matrix. At the same time due to the inclusion of trapped wear particles and roughening the substrate, the friction force increases due to the increase of ploughing effect. When the applied increased the plastic deformation would take place in the AA1100 alloy matrix which could adhere to the steel disc and consequently, resulting the conditions shown in figure 4.

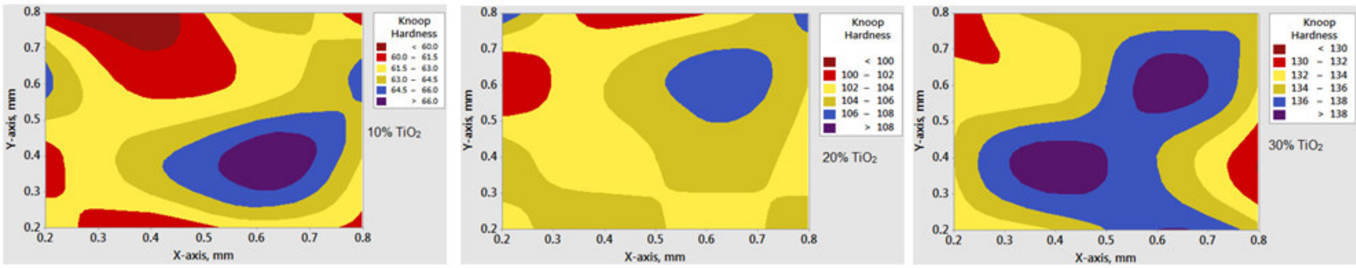

Figure 3: Hardness contours of AA1100/ TiO_2 composites after wear test.

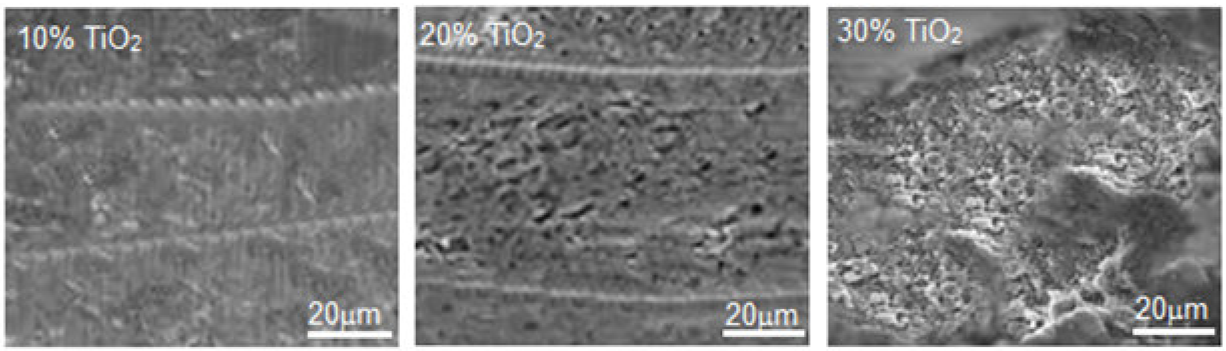

Figure 4: Adhesive wear.

4. CONCLUSIONS

The study on the wear behavior of AA1100/ TiO_2 composites as the function of vol.% of TiO_2, normal load, sliding speed and sliding distance using Taguchi's design of experiments was carried out successfully. The wear rate decreases with increase of vol.% TiO_2 nanoparticles in AA1100 alloy matrix due to increased hardness of the composites.

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