Tribological Behavior of Nano Titanium Carbide Particles Embedded in 8090 AL alloy Metal Matrix Composites

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Abstract: Excellent properties offered by nano titanium carbide particles are exploited as a reinforcement to the 8090 AL alloy matrix. The effects of titanium carbide volume fraction, normal load, sliding distance and sliding speed on the wear performance of stir cast metal matrix composites were studied using a pin-on-disc tribometer. 8090 Al alloy-nano titanium carbide composites show higher wear resistance. High surface area of nano titanium carbide particles embedded in 8090 Al alloy matrix exhibited high adherent titanium carbide tribo-layer at the contact surface. Formed titanium carbide layer reduces the sub-surface deformation of the composite by way of reduced frictional force.

Keywords: Metal matrix composites, wear rate, volume fraction, applied load, sliding distance, sliding speed, titanium carbide.

1. INTRODUCTION

Material property blends and ranges have been, and are yet being, protracted by the development of composite materials as seen from figure 1. This is expressly true for materials that are needed for aerospace, underwater, and transportation applications. Many composite materials are composed of just two phases; one is termed the matrix, which is continuous and surrounds the other phase, often called the reinforcement. For most of these composites, the particulate phase is harder and stiffer than the matrix. These reinforcing particles tend to restrain movement of the matrix phase in the vicinity of each particle [1-4]. In essence, the matrix transfers some of the applied stress to the particles, which bear a fraction of the load. The volume fraction of reinforcement or improvement of mechanical behavior depends on strong bonding at the matrix–particle interface.

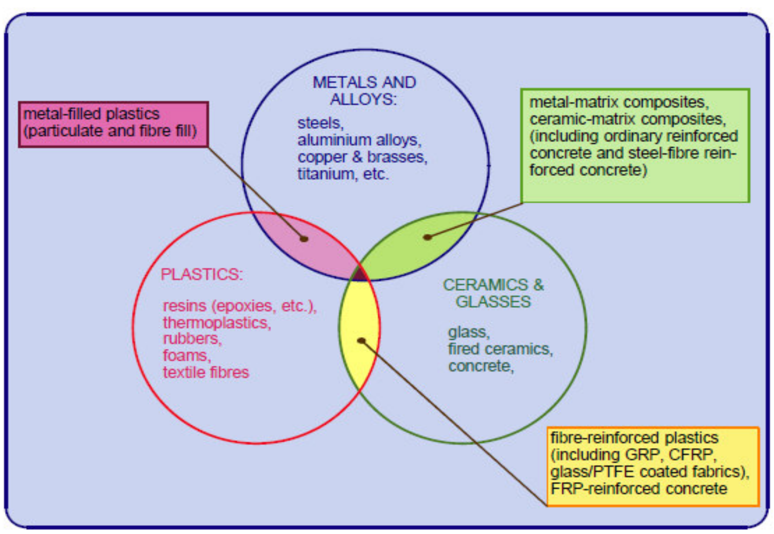

Figure 1: Evolution of composites.

Many investigation have come up on the tribological behavior of composites which were fabricated using a micron to nano size particulates for the realization of wear resistance ability in the matrix materials [5-14].

The present study accents on estimating the wear rate of AA8090/titanium carbide metal matrix composites. The empirically estimated wear rate values have been compared with the experimental values.

2. MATERIALS AND METHODS

Aluminum alloy 8090 was used as matrix material. Titanium carbide (TiC) of 100 nm size was used as a reinforcing material. TiC reinforced AA8090 composites were produced using stir casting technique. The composite specimens were subjected to T-3 heat treatment standards. In order to characterize the dry-sliding wear behavior of the test specimens, wear tests were carried out on a pin-on-disc machine. Circular pins of diameter 8 mm and height 30 mm were used as test specimens. The wear rate was studied as a function of volume fraction of TiC, applied load, sliding speed and sliding distance. Each experiment was repeated twice as per the design experiments as per Taguchi techniques [15]. The levels chosen for the controllable process parameters are summarized in Table 1. The orthogonal array, L9 was preferred to carry out wear tests experimentally (Table 2).

Table 1: Control parameters and levels

Factor	Symbol	Level–1	Level–2	Level–3
Reinforcement, vf	A	0.1	0.15	0.2
Load, N	B	10	20	30
Speed, m/s	C	2	3	4
Sliding distance, m	D	500	750	1000

. **Table 2:** Orthogonal array (L9) and control parameters

Treat	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

The total wear of a metal matrix composite is modeled mathematically as a function of reinforcement volume fraction, applied load, sliding speed and sliding distance according to

$$W = K{v_f}^a F^b V^c S^d \quad (1)$$

where a, b, c and d are power law coefficients of reinforcement volume fraction (vf), applied load (F), sliding speed (V) and sliding distance (S), respectively. K is the empirical constant.

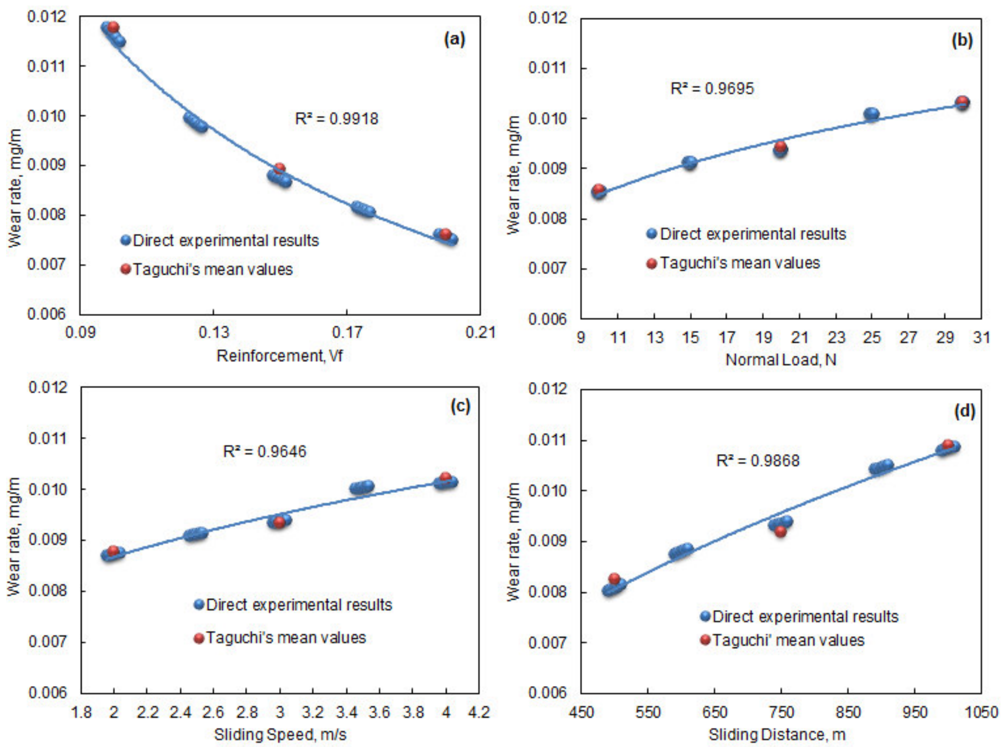

Figure 1: Influence of process parameters on wear rate.

3. RESULTS

The wear rate was reduced with rise in volume fraction of TiC in AA8090 matrix (figure 1a). This is due to high hardness of TiC nanoparticles. An escalation in wear rate is observed with increase of load applied on the test specimen (figure 1b). This effect was due to intensification of plastic deformation. The wear rate was increaseded with the increase of sliding speed (figure 1c). The wear rate increased with the sliding distance as shown in figure 1d. This is due to increase in the deformation and fracture of 8090 Al alloy.

The analysis of variance (ANOVA) is presented in Table 3. The percent contribution indicates that the volume fraction of TiC, gives 59.29%. The normal load adds 10.17% of variation in the wear rate. The sliding speed returns 7.00% of variation in the wear rate. The sliding distance offers 23.54% of variation in the wear rate.

Table 3: ANOVA summary of the wear rate

Source	Sum 1	Sum 2	Sum 3	SS	v	V	P
A	3.53E-02	2.67E-02	2.28E-02	2.73E-05	2	3.53E-02	59.29
B	2.57E-02	2.83E-02	3.10E-02	4.68E-06	2	2.57E-02	10.17
C	2.63E-02	2.80E-02	3.06E-02	3.22E-06	2	2.63E-02	7.00
D	2.47E-02	2.52E-04	8.49E-02	1.08E-05	2	2.47E-02	23.54
e	-	-	-	-	-	-	0.00
T	1.12E-01	8.32E-02	1.69E-01	4.60E-05	8	1.12E-01	100.00

Note: SS is the sum of square, v is the degrees of freedom, V is the variance, P is the percentage of contribution and T is the sum squares due to total variation.

The mathematical relation between wear and contact time is given by

$$W_{rp} = 0.0027 v_f^{-0.6222} \quad (2)$$

$$W_{rf} = 0.0057 F^{0.1739} \quad (3)$$

$$W_{rn} = 0.0074 N^{0.2270} \quad (4)$$

$$W_{rd} = 0.0006 S^{0.4229} \quad (5)$$

where,
W_{rp} is the wear rate due to vol.% of reinforcement (v_f),mg/m
W_{rf} is the wear rate due to normal load (F), mg/m
W_{rn} is the wear rate due to speed (N), mg/m
W_{rd} is the wear rate sliding distance (d), mg/m.

The values of power law coefficients a, b, c and d are, respectively, -0.6222, 0.1739, 0.2270 and 0.4229 from “equations (2) to (5)”. By substituting the representative values of Vf, F, N and S and their corresponding power law coefficients on the right side of “equation (1)” and substituting the experimentally obtained wear rates on the left side of “equation (1)”, the value of K is determined. The over-all wear rate (mg/m) equation for AA3003/TiN composites is given by

$$W = 8.11 \times 10^{-5} \left(v_f^{-0.6222} F^{0.1739} V^{0.2270} S^{0.4229} \right) \quad (6)$$

There is a good fit between the experiment results and empiriical results obtained from “equation (6)” as shown in figure 2.

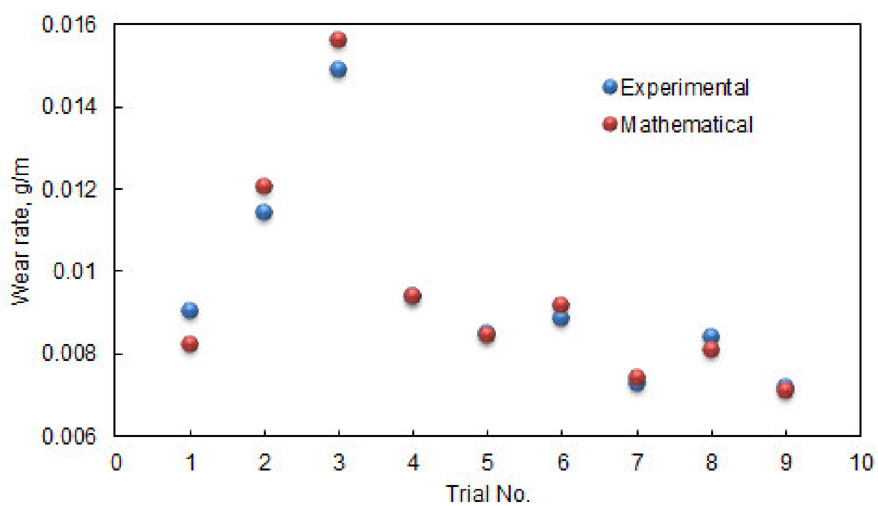

Figure 2: Validation of theoretical results.

4. DISCUSSION

It is imperative to catalogue the magnitude of wear in 8090 Al alloy/TiC composites. The hardness of the composites before and after wear tests are shown in figure 3. It can be realized that the hardness values increase after wear test. The increase in hardness in the worn specimens may be ascribed to the work hardening and plastic deformation. When the load was increased, the plastic deformation would take place in the 8090 Al alloy matrix resulting the conditions of adhesive wear. If the wear is caused by a hard particle (TiC) 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.

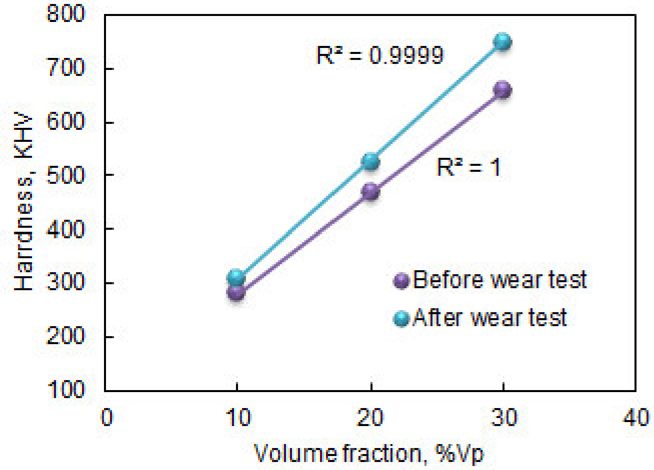

Figure 3: Hardness of AA8090/SiC composites after wear test.

The 87th percentile is used as a benchmark for the probability analysis. The probability plots were created for each treatment by fitting with normal distributions and also estimated the 87th percentile for each population as shown in Fig.9. The estimated 87th percentiles for each population are:
0.005581 for the volume fraction of SiC,
0.005182 for the sliding speed,
0.005288 for the applied load and
0.005482 for sliding distance.

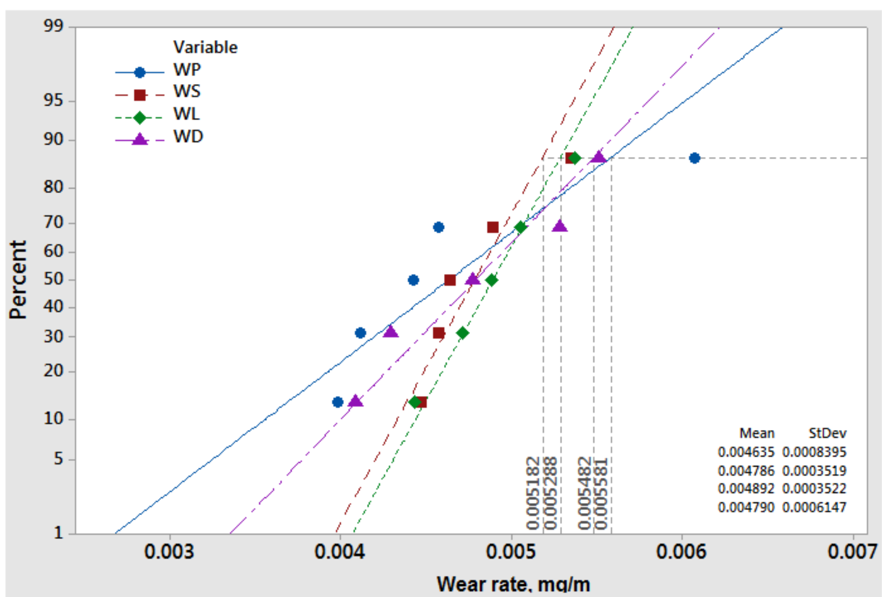

Figure 4: Weight loss functions: (a) reinforcement, (b) applied load, (c) sliding speed and (d) sliding distance.

The estimated 87th percentiles indicate the worth of the factors A, B, C and D on the wear rate. This order is also same as that acquired from ANOVA. To withstand the wear rate of 0.005581 mg/m, the volume fraction of TiC should be 20%. The wear rate is within this limit for all the levels of applied load and sliding speed in the present work.

5. CONCLUSION

The analysis on the wear behavior of 8090 Al alloy/TiC composites as the function of vol.% of TiC, normal load, sliding speed and sliding distance using Taguchi's design of experiments was conceded successfully. The wear resistance increases with increase of vol.% TiC nanoparticles in 8090 Al alloy matrix. The optimum wear rate of 0.005581mg/m can be achieved with the volume fraction of TiC should be 20%.

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