Application of Factorial Techniques to Validate Wear Model of AA2024-Graphite Microcomposites

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Abstract: *In the present work, the AA2024 alloy-graphite metal matrix composites were manufactured. The test matrix varied particle* size *of 100µm, 150µm and 200µm zirconium oxide. The design of experiments was carried out based on Taguchi's factorial techniques. Dry sliding wear behavior of AA2024 alloy-graphite composites was investigated employing a pin-on-disc wear test rig. Results revealed that the wear rate increased with increasing size of graphite particles. Wear resistance of the composite increased considerably with increasing sliding velocity at constant load. Worn-out surfaces of wear specimens after the test were examined by scanning electron microscopy to study breakage of micro graphite particles. The mathematical modeling was validated with experimental results.*

Keywords: *Metal matrix composite, particle size, AA2024 alloy, graphite, wear, sliding distance, normal load, speed.*

1. INTRODUCTION

Aluminum-based particulate metal matrix composites have fascinated due to their desirable properties. Al composites are used for helicopter parts in aeronautics, rotor vanes in compressors, etc. A low wear resistance of pure aluminum is a serious negative aspect. An addition of a non-metallic second phase such as oxides, carbides, nitrides and borides to aluminum alloys can significantly improve the mechanical properties and wear resistance of the materials. Particle reinforcements are more constructive than the fiber type as they allow a better control of the microstructure and mechanical properties obtained by varying the size and the volume fraction of the reinforcement [1-16]. Solid lubricants are used for applications in which sliding contact occurs to reduce the friction. Solid lubricant provides protection from damage during relative movement between the sliding elements to reduce the friction and wear [17-28]. In many papers, it was reported that graphite particulates form a solid lubricant on a tribosurface. Graphite particle has a brittle structure. The tendency of crack initiation and propagation increases at the graphite-metal interface in the composites. Rhee [29] found that the total wear of a polymer-matrix is a function of the applied load F, speed V and sliding time t according to

$$\Delta W = KF^{a}V^{b}t^{c} \qquad (1)$$

where ΔW is the weight loss of the friction material and *K, a, b* and *c* are empirical constants.

In the current work, dry sliding wear of AA2024 alloy-graphite composites with different particle sizes were studied under different combinations of sliding speed, normal load, sliding distance and particle size based on Taguchi techniques [30, 31]. Scanning electronic microscopy (SEM) was employed to study the microstructure of composites and the morphology of the worn surfaces of the composites.

2. MATERIALS AND METHODS

AA2024 alloy-graphite composites were fabricated by the stir casting process. The volume fraction of graphite in the composites was 20%. The particle size of graphite was varied at 100µm, 150 µm and 200 µm. The T6 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). A pin-on-disc wear monitor (ASTM G99) was employed to assess the wear behavior of AA2024 alloy-graphite composite specimens against hardened ground steel (En32) disc (figure 1).

Table 1: Wear parameters and levels

Factor	Symbol	Level–1	Level–2	Level–3
Particle size, µm	A	100	150	200
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 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

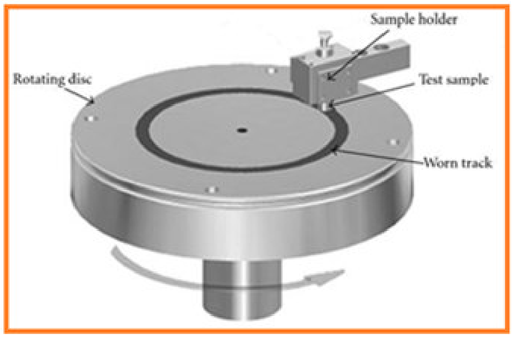

Figure 1: Tests carried out in the present work: (a) Pin-on-disc wear test and (b) Surface roughness test.

In the present work, the wear formulation was attempted based on the following expression:

$$W = K\,(d^a F^b S^c D^d) \qquad (2)$$

where, W is the wear rate in g/m; d is the particle size of reinforcement, mm; F is the normal load, N; S is sliding speed, m/s D is the sliding distance, mm and; K, a, b, c and d are empirical constants.

3. RESULTS AND DISCUSSION

The analysis of variance (ANOVA) is presented in Table 3. All process parameters are acceptable as they prove to Fisher's test at 90% confidence level. For variation in the wear rate, the percent contribution of graphite particle size (A), normal load (B), sliding speed (C) and sliding distance (D) are, correspondingly, 96.12%, 2.00%, 0.66% and 1.22%. The dominating variable is the particle size of graphite. The sliding speed, sliding distance and normal are less important because of their least contribution towards variation in the wear rate of composites. The R-squared values of %graphite, normal load, sliding speed and sliding distance are, respectively, 0.9931, 0.9411, 0.6796 and 0.9168 as stated in figure 3. The affinity of R-squared values is on par mean values obtained by Taguchi techniques.

Table 3: ANOVA summary of the effective stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	2.57E-02	5.08E-02	6.46E-02	2.59E-04	1	2.59E-04	1.19E+15	96.12
B	4.40E-02	4.76E-02	4.96E-02	5.40E-06	1	5.40E-06	2.49E+13	2.00
C	4.83E-02	4.77E-02	4.52E-02	1.77E-06	1	1.77E-06	8.18E+12	0.66
D	4.50E-02	7.29E-04	1.41E-01	3.30E-06	1	3.30E-06	1.52E+13	1.22
e				8.67E-19	4	2.17E-19	1.00	0.00
T	1.63E-01	1.47E-01	3.01E-01	2.69E-04	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.

The hardness of AA2024 alloy-graphite composites gradually decreases as graphite content increases. It can be explained by the fact that the graphite has lower hardness than the AA2024 alloy. The wear rate was amplified with increase in particle size of graphite as shown in figure 3a. With the micro particles, the rougher striations are deeper and contain indications of severe ploughing and therefore, abrasive wear effects are predominated. Figure 3b characterizes an increase in wear rate with increase of normal load. Larger particles also have tendency for cracking under increased applied load (figure 4) during wear test. The cracked particles may detach from the pin's surface. The wear loss of the AA2024 alloy-graphite composites tended to decrease when the sliding speed was increased from 2 m/s to 4 m/s. Wear resistance increases when increasing the sliding speed at constant load regardless of size of graphite particles. It can be observed form figure 3d that the wear of the AA2024 alloy-graphite composites material increases as the sliding distance is increased. This is because the instability of the tribolayer which is formed during sliding on the worn surface, at longer sliding distances.

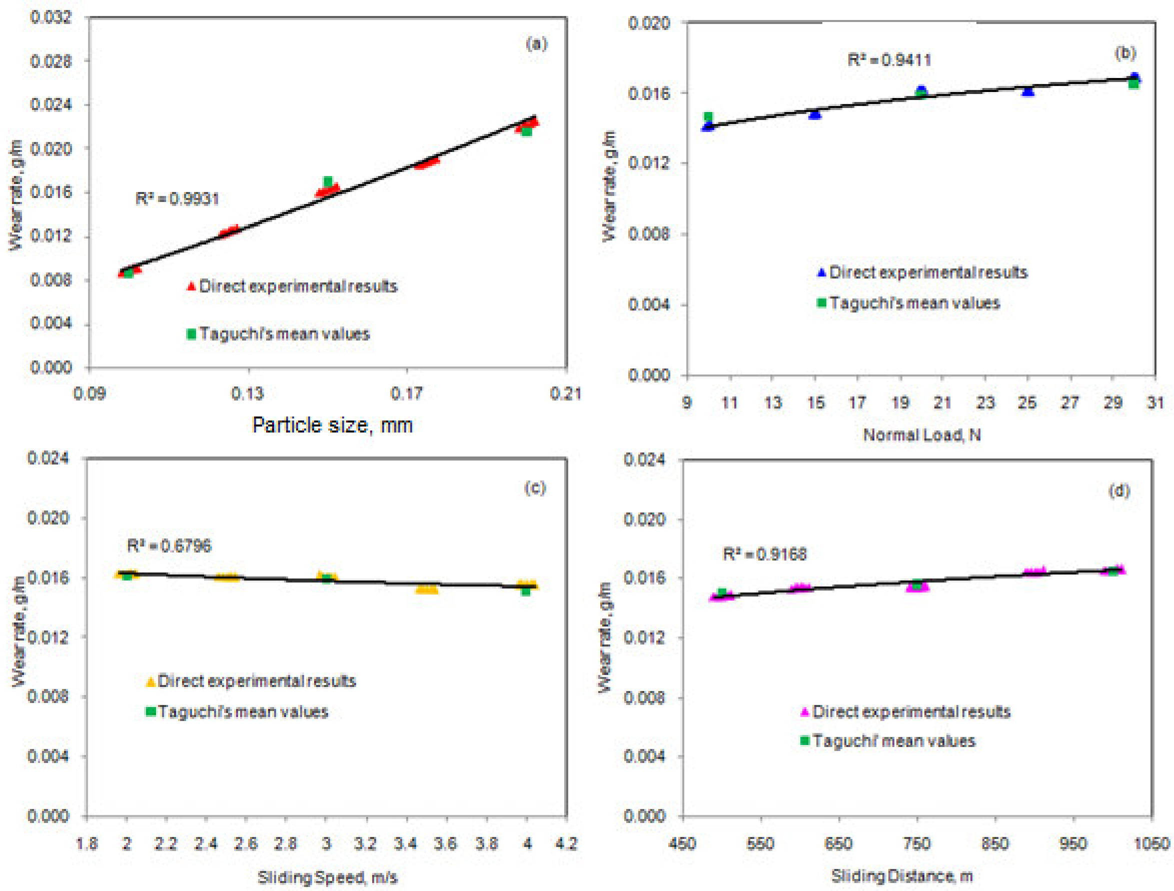

Figure 3: Wear rate as a function of (a) particle size, (b) applied load, (c) sliding speed and (d) sliding distance.

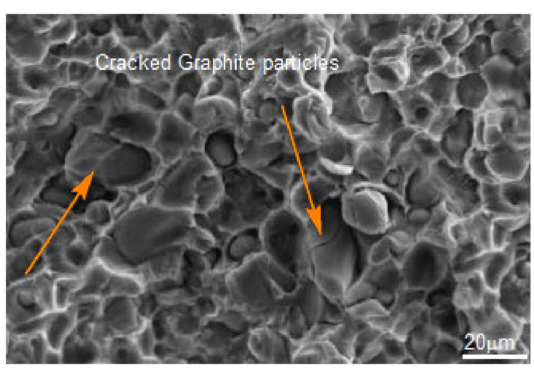

Figure 4: SEM image illustrating cracked 200 μm particles in AA2024-graphite composite.

The mathematical relation between wear and volume fraction of reinforcement, applied load, sliding speed and sliding distance were obtained by curve fitting in terms of power laws as follows:

$$W = 3.83 \times 10^{-2}\ (d^{1.3107} F^{0.1804} S^{-0.0828} D^{0.1821}) \quad (3)$$

Archard interpreted *K* factor as a probability of forming wear debris from asperity encounters [32]. Typically for mild wear, $K \approx 10^{-8}$, whereas for severe wear, $K \approx 10^{-2}$. As the value of $K \approx 10^{-2}$, the wear of AA2024 alloy-graphite composites is severe because the composite was made of micro-sized reinforced particles. The wear rate values determined by the Equation (3) are within the acceptable limits of experimental results as seen from figure 5. For this rationale, the mathematical modeling is rich enough to describe the severity of wear of AA2024-graphite metal matrix composites.

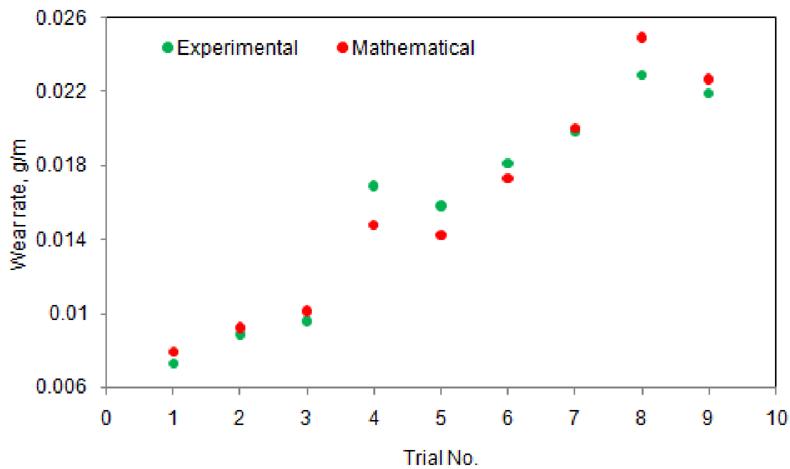

Figure 5: Validation of mathematical modeling with experimental results.

4. CONCLUSIONS

The effect of micro-size particles on the severity of wear was inventively modeled and validated with experimental results of AA2024 alloy-graphite composites. The AA2024 alloy-graphite composites have experienced severe wear due to macro particle damage during wear tests.

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