Impact of Particle Size on Dry Wear Formulation of AA2024/Titanium Nitride Macro-particle Metal Matrix Composites

A. Chennakesava Reddy
Professor, Department of Mechanical Engineering, JNTU College of Engineering, Hyderabad, India

Abstract: In the present work, the AA2024 alloy/titanium nitride metal matrix composites were manufactured with particle size of 100µm, 150µm and 200µm titanium nitride. The pin-on-disc wear test was carried out with different combinations of reinforcement, sliding distance, normal load, sliding speed. Based on the experimental results the impact of particle size on the severity of wear was successfully predicted for AA2024/titanium nitride metal matrix composites.

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

1. INTRODUCTION

Particle reinforced metal matrix composites (PRMMCs) have been the subject of extensive study in the past thirty years due to a need for lightweight structural materials. Al-based composite materials attract more attention because of the low density, high specific strength, good processability, and so on. Large-particle and dispersion-strengthened composites are the two sub-classification of particle-reinforced composites. The term “large” is used to indicate that particle–matrix interactions cannot be treated on the atomic or molecular level; rather, continuum mechanics is used. 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. The degree of reinforcement or improvement of mechanical behavior depends on strong bonding at the matrix–particle interface [1-16]. A significant number of equations relate to wear but were not particularly amenable to analysis, so were left out of later consideration. Two approaches can be taken into account in developing models. One approach is based on empirical data which involves characterization of surfaces, collection of wear and friction data from laboratory tests, analysis and sorting of data. A second approach involves generation of models based on known physical principles, followed by confirmation through data collection [17-26]. Many papers have been written before on this topic but little concrete direction has arisen for developing good wear models. Rhee [27] 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

\[ \Delta W = K F^a V^b t^c \]  

where \( \Delta W \) is the weight loss of the friction material and \( K, a, b \) and \( c \) are empirical constants.

The intention of this research work was to severity of particle size on the dry sliding wear of AA2024/titanium nitride metal matrix composites. The wear tests were conducted on pin-on-disc equipment. The design of experiments was based on Taguchi techniques [28, 29].

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

AA2024 alloy/titanium nitride composites were fabricated by the stir casting process. The volume fraction of titanium nitride in the composites was 30%. The particle size of titanium nitride was varied at 100µm, 150µm and 200µm. 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 precised 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/titanium nitride composite specimens against hardened ground steel (En32) disc (figure 1). Knoop microhardness was conducted before and after wear tests.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Symbol</th>
<th>Level–1</th>
<th>Level–2</th>
<th>Level–3</th>
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<tbody>
<tr>
<td>Particle size, µm</td>
<td>A</td>
<td>100</td>
<td>150</td>
<td>200</td>
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<tr>
<td>Load, N</td>
<td>B</td>
<td>10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Speed, m/s</td>
<td>C</td>
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<td>3</td>
<td>4</td>
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<tr>
<td>Sliding distance, m</td>
<td>D</td>
<td>500</td>
<td>750</td>
<td>1000</td>
</tr>
</tbody>
</table>

Table 1: Wear parameters and levels

Table 2: Orthogonal array (L9) and control parameters

<table>
<thead>
<tr>
<th>Treat No.</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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<tbody>
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<td>9</td>
<td>3</td>
<td>3</td>
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</table>

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

\[ W = K (d^a F^b S^c D^d) \]  \hspace{1cm} (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.

Table 3: ANOVA summary of the effective stress

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum 1</th>
<th>Sum 2</th>
<th>Sum 3</th>
<th>SS</th>
<th>v</th>
<th>V</th>
<th>F</th>
<th>P</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>2.73E-02</td>
<td>4.98E-02</td>
<td>7.04E-02</td>
<td>3.09E-04</td>
<td>1</td>
<td>3.09E-04</td>
<td>1.43E+15</td>
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<tr>
<td>B</td>
<td>4.90E-02</td>
<td>4.46E-02</td>
<td>5.39E-02</td>
<td>1.43E-05</td>
<td>1</td>
<td>1.43E-05</td>
<td>6.61E+13</td>
<td>4.03</td>
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<tr>
<td>C</td>
<td>5.02E-02</td>
<td>5.05E-02</td>
<td>4.68E-02</td>
<td>2.85E-06</td>
<td>1</td>
<td>2.85E-06</td>
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<td>D</td>
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<td>8.44E-04</td>
<td>1.48E-01</td>
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<td>-</td>
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<tr>
<td>T</td>
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<td>1.46E-01</td>
<td>3.19E-01</td>
<td>3.56E-04</td>
<td>8</td>
<td></td>
<td>100.00</td>
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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.

3. RESULTS AND DISCUSSION

The analysis of variance (ANOVA) is presented in Table 3. All process parameters are agreeable as they satisfy Fisher’s test at 90% confidence level. The contribution of particle size (A), normal load (B), sliding speed (C) and sliding distance (D) are, in that order, 86.84%, 4.03%, 0.80% and 8.33% of variation in the wear rate. The major significant variable is the particle size.
of titanium nitride. The least significant variable is the sliding speed. The R-squared values of %reinforcement, normal load, sliding speed and sliding distance are, respectively, 0.9991, 0.6320, 0.6106 and 0.9761 as mentioned in figure 3. The sensitivity of R-squared values is same as that of mean values obtained by Taguchi techniques.

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

The wear rate was increased with increase in particle size of titanium nitride as shown in figure 3a. This can be attributed to particle pullout on account of weak bonding between particle and matrix. Figure 3b represents an increase in wear rate with increase of normal load. Due to increased applied load, the deformed AA2024 alloy matrix disengages from the pin’s surface subsequently raise the wear rate. The sliding speed was insignificant on the wear rate (figure 3c). The wear rate increases with sliding distance as shown in figure 3d. Crumbling of the surface layers from the composite pin promotes the loss of material with increasing sliding distance.

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:

$$W = 7.92 \times 10^{-3} (d^{1.319}F^{0.0971}S^{-0.0842}D^{0.4568})$$  \hspace{1cm} (3)

Archard interpreted $K$ factor as a probability of forming wear debris from asperity encounters [30]. Typically for mild wear, $K \approx 10^{-8}$, whereas for severe wear, $K \approx 10^{-2}$. As the value of $K \approx 10^{-3}$, the wear of AA2024/titanium nitride composites is severe because the composite was made of large reinforced particles. The wear rate values computed by the Equation (3) are within the permissible limits of experimental results as seen from figure 4. Hence, the mathematical modeling is adequate to represent the severity of wear of AA2024/titanium nitride metal matrix composites.
4. CONCLUSIONS

The impact of particle size on the severity wear was successfully modeled and validated with experimental results of AA2024/titanium nitride composites. The AA2024/titanium nitride composites have experienced severe wear because of macro size particles reinforced in aluminum alloy matrix.

REFERENCES


