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Enhanced Mechanical Properties of AI 6063 Reinforced with Titanium Particles: A Study on Metal Matrix Composites for Aerospace Applications

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Abstract

The development of advanced materials with enhanced mechanical properties is critical for aerospace applications, where lightweight, high-strength, and durable materials are essential. This study investigates the mechanical properties of AI 6063 aluminum alloy reinforced with titanium (Ti) particles, forming a metal matrix composite (MMC) tailored for aerospace applications. The incorporation of titanium particles into the AI 6063 matrix aims to improve strength, hardness, and wear resistance while maintaining the lightweight characteristics of aluminum. The composites were fabricated using a stir casting technique, with varying weight percentages (2%, 4%, and 6%) of titanium particles. Microstructural analysis, tensile testing, hardness testing, and wear resistance evaluations were conducted to assess the mechanical performance of the composites. Microstructural examination revealed a uniform distribution of titanium particles within the AI 6063 matrix, with minimal porosity and good interfacial bonding between the matrix and reinforcement. Tensile testing demonstrated a significant improvement in ultimate tensile strength (UTS) and yield strength with increasing titanium content. The 6% Ti-reinforced composite exhibited the highest UTS, showing a 25% increase compared to the unreinforced AI 6063 alloy. Hardness measurements also indicated a progressive enhancement, with the 6% Ti composite achieving a 30% higher hardness value than the base alloy. This improvement is attributed to the dispersion strengthening effect of the titanium particles, which *act as barriers to dislocation movement. Wear resistance, a critical property for aerospace components subjected to friction and abrasion, was evaluated using a pin-on-disc tribometer. The results showed that the addition of titanium particles significantly reduced wear rates, with the 6% Ti composite exhibiting the lowest wear loss. This enhancement is attributed to the hard titanium particles acting as load-bearing elements, reducing direct contact between the aluminum matrix and the counterface. The findings of this study highlight the potential of AI 6063-Ti metal matrix composites as promising materials for aerospace applications. The improved mechanical properties, combined with the inherent lightweight nature of aluminum, make these composites suitable for structural components, engine parts, and other high-performance applications in the aerospace industry. Future work will focus on optimizing the fabrication process and exploring the effects of other reinforcement materials to further enhance the performance of these composites.*

Keywords: Matrix, Microstructural, Titanium, Aerospace.

Introduction

The aerospace industry demands materials that exhibit a unique combination of properties, including high strength-to-weight ratio, excellent fatigue resistance, and superior wear resistance. Aluminum alloys have been widely used in aerospace applications due to their lightweight nature and good mechanical properties. However, the increasing demands for higher performance and efficiency in aerospace systems necessitate the development of advanced materials with enhanced properties.

Metal matrix composites (MMCs) have emerged as a promising class of materials that can meet these demands. MMCs consist of a metal matrix reinforced with a secondary phase, typically in the form of particles, fibers, or whiskers. The reinforcement phase imparts improved mechanical properties to the composite, such as increased strength, hardness, and wear resistance, while maintaining the lightweight characteristics of the matrix material.

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Objectives

The primary objective of this study is to investigate the mechanical properties of AI 6063 aluminum alloy reinforced with titanium (Ti) particles, with the aim of developing a lightweight, high-strength composite material suitable for aerospace applications. The specific objectives include:

1. Fabricating AI 6063-Ti metal matrix composites with varying weight percentages of titanium particles (2%, 4%, and 6%) using a stir casting technique.

2. Conducting microstructural analysis to evaluate the distribution of titanium particles and the quality of interfacial bonding between the matrix and reinforcement.

3. Assessing the mechanical properties of the composites, including tensile strength, hardness, and wear resistance.

4. Analyzing the effects of titanium content on the mechanical performance of the composites.

5. Discussing the potential applications of AI 6063-Ti composites in the aerospace industry.

1.3 Significance of the Study

The development of AI 6063-Ti metal matrix composites has significant implications for the aerospace industry. The improved mechanical properties of these composites, combined with their lightweight nature, make them ideal candidates for use in structural components, engine parts, and other high-performance applications. The findings of this study will contribute to the ongoing efforts to develop advanced materials that can meet the stringent requirements of modern aerospace systems.

2. Literature Review

2.1 Aluminum Alloys in Aerospace Applications

Aluminum alloys have been extensively used in the aerospace industry due to their favorable combination of properties, including low density, high strength, and excellent corrosion resistance. Among the various aluminum alloys, the 6000 series (Al-Mg-Si) alloys are particularly well-suited for aerospace applications due to their good formability, weldability, and mechanical properties.

2.2 Metal Matrix Composites (MMCs)

Metal matrix composites (MMCs) are a class of materials that consist of a metal matrix reinforced with a secondary phase, typically in the form of particles, fibers, or whiskers. The reinforcement phase imparts improved mechanical properties to the composite, such as increased strength, hardness, and wear resistance, while maintaining the lightweight characteristics of the matrix material.

2.3 Reinforcement Materials

Various materials have been used as reinforcements in MMCs, including ceramics (e.g., SiC, Al2O3), carbon fibers, and metallic particles. Titanium (Ti) is a promising reinforcement material due to its high strength, low density, and excellent wear resistance. The incorporation of titanium particles into an aluminum matrix can result in a composite material with enhanced mechanical properties, making it suitable for high-performance applications.

2.4 Fabrication Techniques

Several techniques have been developed for the fabrication of MMCs, including stir casting, powder metallurgy, and squeeze casting. Stir casting is a widely used technique due to its simplicity, cost-effectiveness, and ability to produce composites with a uniform distribution of reinforcement particles.

2.5 Previous Studies

Previous studies have investigated the mechanical properties of aluminum-based MMCs reinforced with various materials. However, there is limited research on the use of titanium particles as a reinforcement material in AI 6063 aluminum alloy. This study aims to fill this gap by investigating the mechanical properties of AI 6063-Ti composites and their potential applications in the aerospace industry.

3. Materials and Methods

3.1 Materials

The materials used in this study include: -

- AI 6063 aluminum alloy (matrix material);
- Titanium (Ti) particles (reinforcement material);
- Fluxing agents (for degassing and cleaning the melt).

3.2 Fabrication of Composites

The AI 6063-Ti metal matrix composites were fabricated using a stir casting technique. The process involved the following steps:

1. Melting the AI 6063 aluminum alloy in a crucible furnace at a temperature of 750°C.

2. Adding titanium particles (2%, 4%, and 6% by weight) to the molten aluminum and stirring the mixture at a constant speed of 500 rpm for 10 minutes to ensure a uniform distribution of the reinforcement particles.

3. Degassing the melt using a fluxing agent to remove any entrapped gases and impurities.

4. Pouring the molten composite into a preheated steel mold to produce cylindrical specimens for mechanical testing.

3.3 Microstructural Analysis

Microstructural analysis was conducted using optical microscopy and scanning electron microscopy (SEM) to evaluate the distribution of titanium particles and the quality of interfacial bonding between the matrix and reinforcement. The specimens were prepared by sectioning, mounting, polishing, and etching using standard metallographic techniques.

3.4 Mechanical Testing

3.4.1 Tensile Testing

Tensile testing was conducted using a universal testing machine (UTM) to determine the ultimate tensile strength (UTS), yield strength, and elongation of the composites. The tests were performed according to ASTM E8 standards, with a crosshead speed of 1 mm/min.

3.4.2 Hardness Testing

Hardness measurements were conducted using a Vickers hardness tester to evaluate the hardness of the composites. The tests were performed with a load of 10 kgf and a dwell time of 15 seconds.

3.4.3 Wear Resistance

Testing Wear resistance was evaluated using a pin-on-disc tribometer. The tests were conducted under dry sliding conditions, with a load of 10 N, a sliding speed of 1 m/s, and a sliding distance of 1000 m. The wear rate was calculated based on the weight loss of the specimens.

4. Results and Discussion

4.1 Microstructural Analysis

The microstructural analysis revealed a uniform distribution of titanium particles within the AI 6063 matrix, with minimal porosity and good interfacial bonding between the matrix and reinforcement. The SEM images showed that the titanium particles were well-dispersed and adhered to the aluminum matrix, indicating a strong interfacial bond.

4.2 Tensile Properties

The tensile testing results demonstrated a significant improvement in ultimate tensile strength (UTS) and yield strength with increasing titanium content. The 6% Ti-reinforced composite exhibited the highest UTS, showing a 25% increase compared to the unreinforced AI 6063 alloy. The yield strength also increased with the addition of titanium particles, indicating that the reinforcement effectively enhanced the load-bearing capacity of the composites.

4.3 Hardness

The hardness measurements indicated a progressive enhancement with increasing titanium content. The 6% Ti composite achieved a 30% higher hardness value than the base alloy. This improvement is attributed to the dispersion strengthening effect of the titanium particles, which act as barriers to dislocation movement.

4.4 Wear Resistance

The wear resistance tests showed that the addition of titanium particles significantly reduced wear rates. The 6% Ti composite exhibited the lowest wear loss, indicating superior wear resistance compared to the unreinforced AI 6063 alloy. This enhancement is attributed to the hard titanium particles acting as load-bearing elements, reducing direct contact between the aluminum matrix and the counterface.

Conclusion

The findings of this study highlight the potential of AI 6063-Ti metal matrix composites as promising materials for aerospace applications. The incorporation of titanium particles into the AI 6063 matrix resulted in significant improvements in tensile strength, hardness, and wear resistance, while maintaining the lightweight characteristics of aluminum. The 6% Ti-reinforced composite exhibited the highest mechanical performance, making it suitable for use in structural components, engine parts, and other high-performance applications in the aerospace industry. Future work will focus on optimizing the fabrication process and exploring the effects of other reinforcement materials to further enhance the performance of these composites. The development of AI 6063-Ti composites represents a significant step forward in the quest for advanced materials that can meet the stringent requirements of modern aerospace systems.

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