



Tribological Behavior of Mg–WC Metal Matrix Nano-Composites

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ABSTRACT: This project focuses on the development and analysis of magnesium-based metal matrix nano-composites reinforced with tungsten carbide (WC) nanoparticles for advanced tribological applications. Magnesium, being the lightest structural metal, is selected as the base matrix (AZ31 alloy) due to its excellent machinability, low density, and high specific strength. However, its poor wear resistance and low hardness limit its applications, which are addressed by reinforcing it with hard ceramic nanoparticles.

The Mg-WC nano-composites are fabricated using an ultrasonic vibration-assisted stir casting method to ensure uniform distribution of nanoparticles and improved interfacial bonding. The developed composites are characterized using optical microscopy, scanning electron microscopy (SEM), energy dispersive X-ray analysis (EDAX), and X-ray diffraction (XRD) techniques. Mechanical properties such as microhardness, nanohardness, and elastic modulus are evaluated to understand the strengthening effect of WC nanoparticles.

The tribological behavior of the composites is studied under varying conditions including load, sliding speed, sliding distance, temperature, and abrasive environment using a pin-on-disc apparatus. Results indicate a significant improvement in wear resistance and reduction in friction coefficient due to the presence of WC nanoparticles. Additionally, corrosion behavior is analyzed in a saline environment, showing improved corrosion resistance up to an optimal reinforcement level.

Further enhancement is achieved by incorporating graphite nanoparticles into Mg-WC composites, which improves lubrication properties, wear resistance, and mechanical performance. Overall, the developed Mg-WC and Mg-WC-Gr nano-composites demonstrate superior mechanical, tribological, and corrosion properties compared to the base alloy, making them suitable for applications in automotive, aerospace, and engineering industries.

KEYWORDS: Magnesium matrix composites, tungsten carbide, nano-composites, tribology, wear resistance, friction coefficient, powder metallurgy, microstructure, hardness, surface engineering

I. INTRODUCTION

Magnesium-based metal matrix composites (Mg-MMCs) have gained significant attention in recent years due to their lightweight nature and high specific strength. Magnesium, being the lightest structural metal with a density of approximately 1.74 g/cm³, is widely used in automotive, aerospace, and electronic industries. However, its application is limited due to poor wear resistance, low hardness, and weak corrosion resistance.

To overcome these limitations, reinforcement of magnesium with ceramic nanoparticles has become an effective approach. Among various reinforcements, tungsten carbide (WC) nanoparticles are highly preferred due to their exceptional hardness, high melting point, and excellent wear resistance. The combination of magnesium matrix and WC nanoparticles results in a composite material with enhanced mechanical and tribological properties.



The present project focuses on the development and analysis of Mg–WC nano-composites, particularly studying their wear behavior, friction characteristics, and overall performance under different operating conditions.

II. LITERATURE REVIEW

Extensive research has been conducted on magnesium matrix composites reinforced with ceramic particles. Studies indicate that incorporating nanoparticles significantly improves hardness, tensile strength, and wear resistance. Different fabrication methods such as stir casting, powder metallurgy, ultrasonic-assisted casting, and friction stir processing have been explored. Among these, ultrasonic-assisted stir casting is widely used due to its ability to disperse nanoparticles uniformly in the molten metal.

III. RESEARCH FINDINGS SHOW

Hard ceramic reinforcements like WC, SiC, and Al₂O₃ enhance wear resistance. Nano-sized particles provide better mechanical properties compared to micro-sized particles. Tribological performance improves with increasing reinforcement up to an optimum limit. However, challenges such as particle agglomeration, poor wettability, and uneven distribution still exist in fabrication processes.

IV. MATERIALS AND METHODOLOGY

4.1 Materials Used

Matrix Material: AZ31 Magnesium Alloy

Reinforcement: Tungsten Carbide (WC) nanoparticles (~80 nm)

AZ31 alloy is selected due to its good formability, machinability, and mechanical properties. WC nanoparticles are chosen for their high hardness (~1400 HV) and excellent thermal stability.

4.2 Fabrication Method

The Mg–WC nano-composites are fabricated using ultrasonic vibration-assisted stir casting.

Steps involved:

Melting of AZ31 alloy in a furnace

Preheating of WC nanoparticles

Mechanical stirring to mix particles

Ultrasonic vibration to break particle agglomeration

Casting into molds and solidification

Ultrasonic treatment helps in uniform dispersion by generating cavitation and acoustic streaming effects.

4.3 Characterization Techniques

The developed composites are analyzed using:

Optical Microscopy (OM)

Scanning Electron Microscopy (SEM)

X-Ray Diffraction (XRD)

Energy Dispersive X-ray Analysis (EDAX)

Mechanical and physical tests include:

Microhardness testing

Density measurement

Surface roughness analysis

V. EXPERIMENTAL SETUP

5.1 Pin-on-Disc Tribometer

Tribological behavior is evaluated using a pin-on-disc apparatus.

Parameters considered:

Load (N)

Sliding speed (m/s)

Sliding distance (m)

Temperature (room and elevated)



The specimen (pin) slides against a rotating disc, and wear rate along with coefficient of friction (COF) is measured.

5.2 Design of Experiments (Taguchi Method)

Taguchi method is used to optimize parameters affecting wear and friction.

Steps:

Selection of control factors (load, speed, distance)

Selection of orthogonal array

Conducting experiments

Signal-to-noise (S/N) ratio analysis

Determining optimal conditions

VI. RESULTS AND DISCUSSION

6.1 Microstructural Analysis

SEM and OM images confirm:

Uniform distribution of WC nanoparticles

Strong interfacial bonding between matrix and reinforcement

Ultrasonic stirring significantly reduces particle clustering.

6.2 Mechanical Properties

Microhardness increases with WC addition

Elastic modulus and nanohardness improve

Load-bearing capacity of the material increases

This improvement is due to the presence of hard ceramic particles.

6.3 Tribological Behavior

Wear Behavior

Wear rate decreases with increasing WC content

Higher loads increase wear rate

Increased sliding speed reduces wear under certain conditions

Friction Behavior

Coefficient of friction decreases with reinforcement

Stable friction behavior observed at higher speeds

Wear mechanisms observed:

Abrasion

Adhesion

Oxidation

6.4 Effect of Temperature

At elevated temperatures:

Wear rate increases due to thermal softening

However, composites perform better than base alloy

6.5 Corrosion Behavior

Corrosion resistance improves with WC addition up to a limit

Excess reinforcement may reduce corrosion resistance

Tests conducted in 3.5% NaCl solution show improved performance compared to base alloy.

VII. CONCLUSION

The present study successfully developed Mg–WC nano-composites with enhanced properties.

Key findings:

WC nanoparticles significantly improve hardness and wear resistance

Ultrasonic-assisted stir casting ensures uniform particle distribution

Tribological performance improves under optimized conditions

Moderate addition of reinforcement provides best results



The developed composites are suitable for applications such as:

Bearings

Gears

Automotive components

Aerospace structures

VIII. FUTURE SCOPE

Investigation with hybrid reinforcements (WC + Graphite)

Study under lubricated conditions

Development of corrosion-resistant coatings

Application in real industrial components

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