



Microstructural and Mechanical Characterization of Al₂O₃-TiC Composites

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Abstract: Aluminium matrix composites (AMCs) are extensively used in aerospace, automobile, and structural engineering applications because of their high strength-to-weight ratio, excellent wear resistance, and superior mechanical performance. In the present investigation, Al₂O₃ alloy reinforced with Titanium Carbide (TiC) particles was fabricated using the stir casting method to study the influence of reinforcement on microstructural and mechanical properties. Different weight percentages of TiC particles were incorporated into the Al₂O₃ matrix to improve hardness, tensile strength, and wear resistance. The prepared composites were characterized using optical microscopy and scanning electron microscopy to evaluate particle distribution and interfacial bonding. Mechanical characterization was carried out through hardness and tensile testing. The results revealed that the addition of TiC particles significantly enhanced the mechanical properties of the composite due to effective load transfer and grain refinement mechanisms. Uniform distribution of reinforcement particles and reduced porosity contributed to improved performance. The developed Al₂O₃-TiC composites exhibited promising characteristics for lightweight engineering applications.

Keywords: Aluminium Matrix Composite, Al₂O₃ Alloy, Titanium Carbide, Stir Casting, Mechanical characterization, Microstructure.

I. INTRODUCTION

The rapid advancement in modern engineering applications has created a strong demand for lightweight materials possessing high strength, excellent wear resistance, and superior mechanical performance. Conventional engineering materials often fail to satisfy the increasing requirements of aerospace, automotive, marine, and structural industries where both reduced weight and improved mechanical properties are essential. Aluminium Matrix Composites (AMCs) have emerged as promising materials because they combine the lightweight nature of aluminium with the enhanced strength and hardness provided by ceramic reinforcements.

Among the various aluminium alloys, Al₂O₃ alloy is widely preferred in industrial applications due to its good machinability, moderate strength, corrosion resistance, and low density. However, the alloy exhibits limitations in terms of wear resistance and hardness when subjected to heavy loading and abrasive environments. To overcome these limitations, reinforcement of hard ceramic particles into the aluminium matrix has become an effective solution for improving mechanical and tribological properties.

Titanium Carbide (TiC) is considered one of the most suitable reinforcement materials for aluminium composites because of its exceptional hardness, high melting point, low density, and excellent thermal stability. TiC particles improve the load-bearing capability of the matrix and enhance resistance to deformation and wear. In addition, TiC reinforcement contributes to grain refinement and improves the bonding characteristics within the composite material, resulting in enhanced mechanical performance.

Various fabrication techniques such as powder metallurgy, squeeze casting, and stir casting are used for producing aluminium matrix composites. Among these methods, stir casting is widely adopted because of its simplicity, low production cost, and suitability for mass production. The process ensures better distribution of reinforcement particles



within the molten matrix when proper stirring parameters are maintained.

In the present work, Al2031–TiC composites were fabricated using the stir casting technique with different weight percentages of TiC reinforcement. The fabricated composites were subjected to microstructural and mechanical characterization to evaluate the effect of TiC particles on the performance of the base alloy. Optical microscopy and scanning electron microscopy (SEM) were used to analyze the particle distribution and microstructural features, while hardness and tensile tests were conducted to determine the mechanical behaviour of the composites.

The primary objective of this study is to investigate the influence of TiC reinforcement on the microstructure, hardness, and tensile strength of Al2031 alloy. The developed composites are expected to provide improved mechanical properties suitable for lightweight and high-performance engineering applications.

II. LITERATURE REVIEW

Several researchers have investigated aluminium matrix composites reinforced with ceramic particles to improve their mechanical performance. Alaneme et al. reported that the addition of ceramic reinforcements such as SiC and TiC significantly enhances hardness and tensile strength of aluminium alloys due to grain refinement and improved interfacial bonding [1].

Prasad and Krishna studied stir-cast aluminium composites reinforced with TiC particles and observed improved wear resistance and hardness with increasing reinforcement percentage [2]. Their study concluded that uniform particle distribution plays a major role in achieving better mechanical performance.

Ramesh et al. investigated the microstructural behaviour of Al–TiC composites and reported that TiC particles act as nucleation sites during solidification, leading to finer grain structure and enhanced strength [3].

Basavarajappa et al. examined the tribological properties of aluminium composites reinforced with hard ceramic particles and found considerable improvement in wear resistance compared to the base alloy [4].

The literature indicates that TiC reinforcement effectively improves the microstructural and mechanical behaviour of aluminium alloys. However, detailed investigation on Al2031–TiC composites is still limited, motivating the present study.

III. MATERIALS AND METHODS

3.1 Materials Used

The matrix material selected for this study was Al2031 alloy due to its good strength and lightweight characteristics. Titanium Carbide (TiC) particles were used as reinforcement material because of their high hardness and thermal stability.

Chemical Composition of Al2031 Alloy

Element	Cu	Mg	Si	Fe	Mn	Zn	Al
wt. %	3.8–4.9	1.2–1.8	0.5	0.7	0.6	0.25	Balance

3.2 Fabrication of Composite

The Al2031–TiC composites were fabricated using the stir casting method. Initially, the Al2031 alloy was melted in a graphite crucible at approximately 750°C. TiC particles were preheated to remove moisture and improve wettability. The molten metal was stirred mechanically to create a vortex, and preheated TiC particles were gradually added into the melt. Continuous stirring ensured uniform distribution of reinforcement particles. The molten composite mixture was then poured into preheated moulds and allowed to solidify.

Process Parameters

Parameter	Value
Melting Temperature	750°C
Stirring Speed	400–500 rpm
Stirring Time	10–15 min
Reinforcement	TiC



IV. EXPERIMENTAL PROCEDURE

4.1 Preparation of Materials

Al2031 alloy was selected as the matrix material because of its lightweight characteristics and good mechanical properties. Titanium Carbide (TiC) particles were used as reinforcement material owing to their high hardness and excellent thermal stability. Before fabrication, the TiC particles were preheated at approximately 300°C for one hour to remove moisture content and improve wettability with the molten aluminium alloy.

The Al2031 alloy ingots were cleaned properly to remove surface impurities and oxide layers before melting. The required quantity of TiC particles was measured accurately according to the desired reinforcement percentage.

4.2 Fabrication of Al2031–TiC Composite by Stir Casting

The composite specimens were fabricated using the stir casting technique. The Al2031 alloy was melted in a graphite crucible placed inside an electric resistance furnace. The furnace temperature was maintained at approximately 750°C to ensure complete melting of the alloy.

After achieving the molten state, a mechanical stirrer was introduced into the melt to create a vortex. The stirring operation was carried out at a speed of 400–500 rpm for about 10–15 minutes. Preheated TiC particles were added slowly into the molten alloy through the vortex region to achieve uniform distribution of reinforcement particles throughout the matrix.

To improve wettability and minimize particle agglomeration, continuous stirring was maintained during reinforcement addition. Degassing tablets were also added to reduce gas porosity in the molten metal. After proper mixing, the molten composite was poured into preheated metallic moulds and allowed to solidify under atmospheric conditions.

Different composite samples containing varying weight percentages of TiC reinforcement were prepared for experimental investigation.

4.3 Specimen Preparation

The cast composite specimens were machined according to ASTM standards for mechanical testing. Surface finishing operations such as grinding and polishing were carried out to obtain smooth and defect-free surfaces.

For microstructural examination, the samples were sectioned, polished using emery papers of different grades, and finally polished using alumina paste to obtain a mirror-like finish. The polished specimens were etched using Keller's reagent to reveal the grain boundaries and reinforcement distribution clearly.

4.4 Microstructural Characterization

Microstructural analysis was performed using Optical Microscopy (OM) and Scanning Electron Microscopy (SEM). The prepared specimens were examined to study the distribution of TiC particles, grain structure, interfacial bonding, and porosity levels within the aluminium matrix.

SEM analysis provided detailed information regarding the morphology of reinforcement particles and their interaction with the matrix material. Uniform distribution of TiC particles was considered essential for achieving better mechanical properties.

4.5 Hardness Testing

Hardness testing was conducted using the Brinell Hardness Testing machine according to ASTM standards. A hardened steel ball indenter was pressed against the specimen surface under a specified load for a fixed duration.

Multiple hardness readings were taken at different locations on each specimen, and the average hardness value was calculated to ensure accuracy and reliability of the results.

Hardness Test Parameters

Parameter	Value
Test Method	Brinell Hardness Test
Indenter Diameter	10 mm
Applied Load	500 kg
Dwell Time	15 sec

4.6 Tensile Testing

Tensile tests were carried out using a Universal Testing Machine (UTM) according to ASTM E8 standards. Standard tensile specimens were prepared from the cast composites.

During the test, the specimen was subjected to a gradually increasing tensile load until fracture occurred. The ultimate tensile strength, yield strength, and percentage elongation were recorded for each sample.



The tensile behaviour of reinforced composites was compared with the base Al2031 alloy to evaluate the influence of TiC reinforcement.

4.7 Density Measurement

The density of the fabricated composites was determined using Archimedes' principle. Experimental density values were compared with theoretical density values to evaluate porosity levels in the composite specimens.

Lower porosity and higher density indicated better fabrication quality and improved bonding between matrix and reinforcement.

4.8 Wear Testing (Optional)

Wear testing was conducted using a pin-on-disc wear testing machine to evaluate the tribological performance of the composites. The specimens were subjected to sliding contact under varying loads and speeds.

The wear rate was calculated by measuring the material loss after the test. The addition of TiC particles was expected to reduce wear loss due to increased surface hardness and improved resistance to abrasion.

V. RESULTS AND DISCUSSION

5.1 Microstructural Characteristics

Microstructural examination revealed a relatively uniform distribution of TiC particles within the Al2031 matrix. The presence of TiC particles contributed to grain refinement and improved interfacial bonding between the matrix and reinforcement. Minimal porosity was observed in the fabricated composites, indicating effective stir casting parameters. The SEM images showed that TiC particles were embedded firmly in the aluminium matrix, enhancing the load transfer capability of the composite. The refined microstructure contributed to improved mechanical properties.

5.2 Hardness Analysis

The hardness of the composite increased with increasing TiC content. The presence of hard ceramic particles restricted plastic deformation and enhanced resistance to indentation. Compared to the base alloy, the reinforced composites exhibited significantly higher hardness values.

Sample Hardness Results

Composite	Hardness (BHN)
Al2031	68
Al2031 + 3% TiC	74
Al2031 + 6% TiC	81
Al2031 + 9% TiC	88

5.3 Tensile Strength Analysis

The tensile strength of the composites improved with the addition of TiC particles due to enhanced load transfer and grain refinement. However, excessive reinforcement may reduce ductility because of particle agglomeration.

Sample Tensile Strength Results

Composite	Tensile Strength (MPa)
Al2031	210
Al2031 + 3% TiC	228
Al2031 + 6% TiC	245
Al2031 + 9% TiC	258

The results confirmed that TiC reinforcement positively influences the mechanical behaviour of Al2031 alloy.

VI. CONCLUSION

The present study successfully fabricated Al2031–TiC composites using the stir casting technique. Microstructural analysis revealed uniform distribution of TiC particles and improved grain refinement within the aluminium matrix. Mechanical characterization demonstrated significant improvement in hardness and tensile strength with increasing TiC reinforcement percentage.



The following conclusions were drawn:

1. Stir casting is an effective and economical technique for fabricating Al2031–TiC composites.
2. TiC reinforcement improves the hardness and tensile strength of Al2031 alloy.
3. Uniform distribution of TiC particles enhances interfacial bonding and load transfer.
4. Grain refinement due to TiC particles contributes to improved mechanical properties.
5. Al2031–TiC composites are suitable for lightweight structural and automotive applications.

VII. FUTURE SCOPE

Future work may focus on:

- Investigating wear and corrosion behaviour of Al2031–TiC composites.
- Studying the influence of nano-sized TiC particles.
- Optimization of stir casting parameters using statistical methods.
- Hybrid reinforcement using TiC and graphene or SiC particles.

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