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Research Article

Enhancement Of Mechanical Properties In Al 7075 Alloys Reinforced With Tic And Graphite Using Stir Casting

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ABSTRACT
This research work focused on the fabrication of Al 7075-based metal matrix composites reinforced with 1 wt.% Titanium Carbide (TiC) and varying amounts of graphite (1 wt.%, 3 wt.%, and 5 wt.%) using the stir casting technique. The produced composites were thoroughly characterized through mechanical testing methods such as tensile and hardness tests, along with microstructural analysis using Scanning Electron Microscopy (SEM). The dispersion of TiC ceramic particles within the ductile Al 7075 aluminium matrix was found to be uniform, with effective bonding at the particle matrix interface. This uniform distribution and strong interfacial bonding contributed to significant improvements in both mechanical and surface properties when compared to the monolithic Al 7075 alloy. The composite with optimal reinforcement content exhibited enhanced tensile properties, achieving an ultimate tensile strength (UTS) of 134.2 MPa, a yield strength of 119.4 MPa, an elongation of 3.2%, and a hardness value of 248 HRC.

Keywords: Al 7075 Alloy, Metal Matrix Composites (MMCs), Titanium Carbide (TiC) Reinforcement, Graphite Particles, Stir Casting Process, Mechanical and Microstructural Characterization

1. Introduction

The increasing demand for advanced lightweight materials with enhanced strength and toughness has driven the development of metal matrix composites (MMCs) [1]. It is well established that hard ceramic particles possess high hardness, a superior Young's modulus, and excellent creep resistance. However, their inherent brittleness significantly limits their application in structural and aerospace components [2]. On the other hand, ductile metallic phases exhibit excellent toughness but generally have lower strength values [3]. To overcome these individual limitations and achieve a combination of both strength and toughness, MMCs have emerged as promising engineering materials. These composites consist of hard ceramic reinforcements uniformly dispersed within a ductile metallic matrix [4]. Among various types of MMCs, aluminium matrix composites (AMCs) are extensively used in the automotive and aerospace industries due to their low density and excellent castability [5]. In addition, AMCs offer a high strength-to-weight ratio, superior stiffness-to-weight ratio, enhanced wear resistance, cost-effectiveness, easy availability, high thermal conductivity, and good thermal stability [6–8]. Numerous studies have investigated Al-based MMCs reinforced with second-phase particles such as Al_2O_3, SiC, B_4C, TiB_2, ZrB_2, and TiO_2 [9–13]. Among these reinforcements, Titanium Carbide (TiC) stands out due to its low density, high strength, excellent wettability with molten aluminium alloys, and minimal chemical reactivity with the matrix [14–16]. Al 7075 aluminium alloy is widely recognized for its ease of fabrication, excellent wear and corrosion resistance, high strength, and heat-treatable nature. It finds applications in a variety of fields including marine structures (ships and submarines), aerospace (aircraft and spacecraft), transportation (trucks and rail vehicles), automobiles, and biomedical devices such as prosthetics. Among the various fabrication techniques for MMCs, stir casting is widely preferred for its simplicity, cost-effectiveness, mass production capability, and process flexibility [17]. Despite extensive research on AMCs, limited studies have focused on reinforcing Al 7075 alloy with TiC ceramic particles. In the present investigation, an effort was made to synthesize and evaluate the mechanical and wear properties of Al 7075/TiC composites using the stir casting technique. The composites were reinforced with 1, 3, & 5 wt.% and 1 wt.% of TiC. The microstructural features were characterized using X-ray diffraction (XRD) and various electron microscopy techniques. The influence of TiC particle content on the mechanical and wear performance of the composites was systematically studied and reported.

2. Materials and Methods

This study focuses on the fabrication of Al 7075-based composites reinforced with 1 wt.% Titanium Carbide (TiC) and varying graphite contents (1, 3, and 5 wt.%) using the stir casting method, as illustrated in Figure 1. The chemical composition of the base Al 7075 alloy is provided in Table 1, while the parameters used in the stir casting process are outlined in Table 2. In this process, Al 7075 alloy ingots were first placed in a crucible furnace and heated until they reached the fully molten state. Once the alloy was molten, the stirring mechanism was activated. The stir casting setup included a stirring blade made of austenitic stainless steel. Upon formation of a stable vortex in the molten metal, preheated TiC ceramic particles were gradually introduced and uniformly mixed. The stirring was maintained at a constant speed to ensure homogeneous dispersion of the reinforcement particles within the matrix. Before introducing the reinforcement, slag floating on the molten surface was carefully removed. The TiC particles, preheated to enhance wettability, were added in a fixed proportion of 1 wt.% along with graphite in varying proportions (1, 3, and 5 wt.%) to improve mechanical strength while retaining ductility and ensuring good melt fluidity. After uniform mixing, the composite melt was held at high temperature for approximately 10 minutes under vortex conditions to promote even distribution of the reinforcements. Finally, the molten composite was poured into a permanent metallic die with dimensions of 20 mm in diameter and 150 mm in length. The shows a photograph of the bottom-pouring stir casting furnace used in this research. The complete manufacturing steps for both the base Al 7075 alloy and the reinforced Al 7075–TiC composites are also detailed in the experimental workflow.

Figure 1: Al 7075–TiC composite preparation.

Table 1: Al 7075 chemical composition [18].

Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
1.12	0.35	1.4	0.81	2.4	5.8	0.25	0.56	Bal

Table 2: Stir Casting Process [19].

Stirring speed	1100 rpm
Temperature attained	790°C
Time for melting	20-25 minutes
Time for cooling	Normal
Preheating temp for die	500°C
Preheating temp for reinforcements	200 °C
Preheating temp for powder	30 min
Type of cooling	Air cooling.
Weight of Al used	1000 grams
Weight of TiC & Gr	10 gm (for 1wt %)
Dimensions of casting	150 length × 20 dia (in mm)

3. Results and Discussion

The stir-cast Al 7075 composites reinforced with 1 wt.% TiC and varying graphite contents (1, 3, and 5 wt.%) exhibited noticeable improvements in mechanical and microstructural properties compared to the unreinforced alloy. Scanning Electron Microscopy (SEM) revealed a fairly uniform distribution of TiC and graphite particles within the aluminium matrix, contributing to effective load transfer and grain refinement. The presence of graphite acted as a solid lubricant, reducing internal friction and enhancing wear resistance. Tensile testing indicated that the addition of TiC significantly improved both yield strength and ultimate tensile strength, while graphite content helped maintain reasonable ductility. Hardness values also showed a consistent increase with higher reinforcement content, confirming the strengthening effect of the ceramic phase.

- **Microstructure**: Uniform dispersion of TiC and graphite particles was achieved, with minimal porosity and good interfacial bonding observed under SEM.
- **Mechanical Strength**: The composite with 1 wt.% TiC and 1,3&5 wt.% graphite achieved the best balance of tensile strength and ductility.
- **Hardness**: A maximum hardness was recorded for the composite, indicating significant resistance to deformation.

3.1 Microstructure Characterization

The standard metallographic procedure was followed to characterize the fabricated ex-situ metal matrix composite (MMC) samples. Cylindrical specimens of approximately 10 mm in diameter and 10 mm in height were cold-mounted using acrylic resin as shown in Figure 2. The mounted samples were then polished sequentially using silicon carbide (SiC) abrasive papers of varying grit sizes, followed by disc polishing with 9 µm alumina and final lapping with 1 µm diamond suspension to achieve a mirror-like finish [20]. Subsequently, the specimens were chemically etched using Keller's reagent, composed of 95 ml distilled water, 2.5 ml nitric acid (HNO_3), 1.5 ml hydrochloric acid (HCl), and 1.0 ml hydrofluoric acid (HF), to reveal the microstructural features. Scanning Electron Microscopy (SEM) analysis was performed using a Zeiss instrument available at the Osmania University at Chemical Technology Department. Figure 3 presents the SEM images of Al 7075 reinforced with various weight percentages of TiC particles. The micrographs clearly display the primary aluminium matrix (α-Al) and the uniformly distributed TiC reinforcement particles. In the unreinforced monolithic alloy, typical casting defects such as porosity, surface scratches, and asperities were observed. However, in the composite samples, the added TiC particles were well dispersed within the matrix, indicating successful processing. This homogeneous distribution of TiC particles is essential for enhancing the mechanical properties of the composites. Moreover, the SEM images reveal a well-defined interface between the TiC particles and the aluminium matrix, suggesting strong interfacial bonding, which contributes to improved load transfer and mechanical integrity [21]. Such a stable interface is also beneficial for increasing the thermal stability of the composites. In contrast, inadequate bonding could lead to the formation of undesirable intermetallic compounds, which are thermodynamically unstable and detrimental to the overall performance of the material.

Figure 2: Microstructure sample and instrument for characterization.

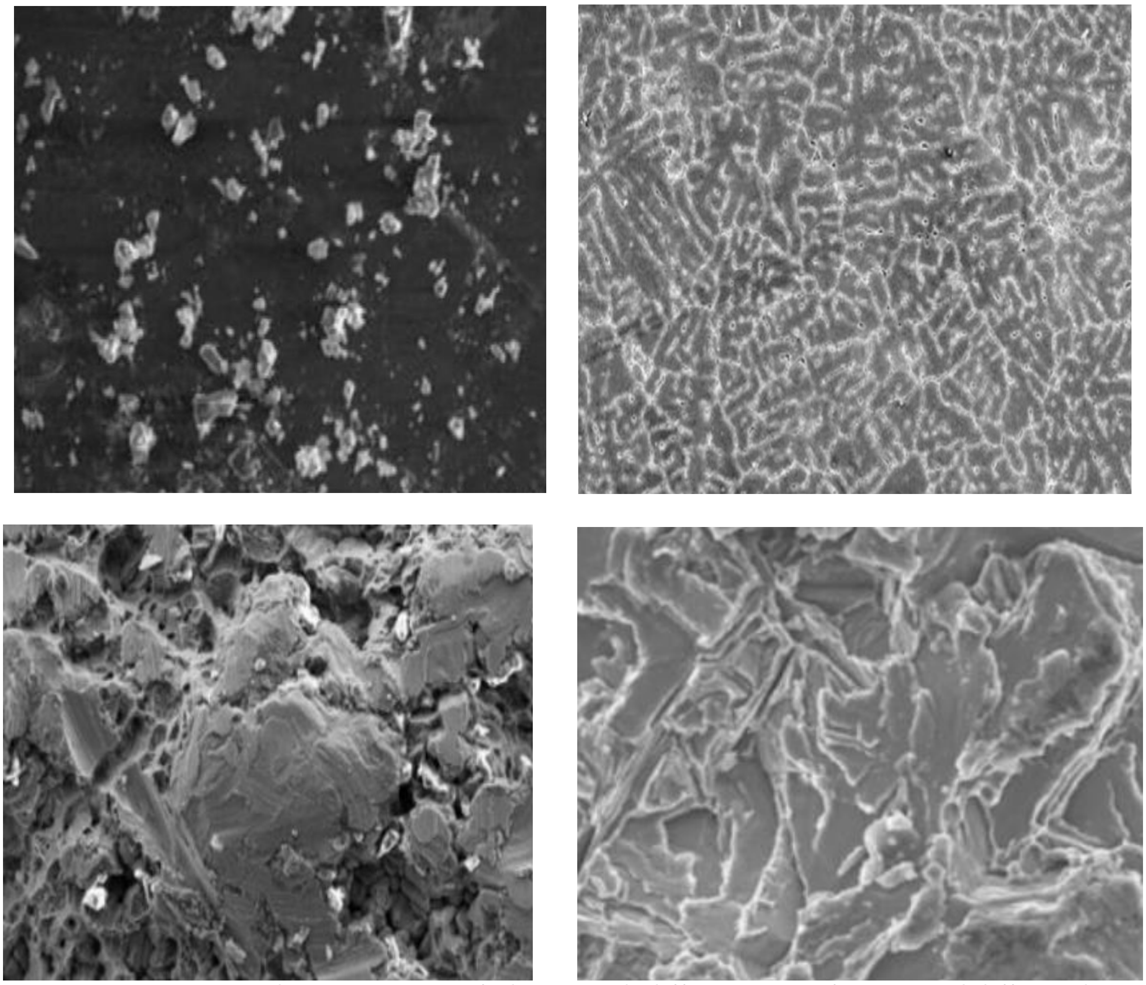

Figure 3: Microstructure characterization of Al 7075 with different magnification and different locations.

3.2 Tensile Properties

The tensile properties of the Al 7075-based composites reinforced with 1 wt.% TiC and varying graphite content (1, 3, and 5 wt.%) were evaluated to assess the influence of reinforcements on mechanical performance. The results showed a noticeable improvement in both ultimate tensile strength (UTS) and yield strength (YS) compared to the unreinforced Al 7075 alloy as shown in Figure 4. The enhancement in strength is attributed to the uniform dispersion of hard TiC particles within the soft aluminium matrix, which acted as effective barriers to dislocation movement. Additionally, the presence of graphite contributed to maintaining a reasonable level of ductility, preventing a drastic drop in elongation. Among all compositions, the composite with 1 wt.% TiC and 3 wt.% graphite exhibited the best balance between strength and ductility, recording a UTS of 134.2 MPa, YS of 119.4 MPa, and elongation of 3.2% [22,23] as shown in Figure 5. This performance improvement indicates strong interfacial bonding between the reinforcement and matrix, which facilitates efficient load transfer. Furthermore, the absence of significant interfacial defects or clustering of particles helped in minimizing premature failure and crack initiation during tensile loading. Overall, the results confirm that the addition of TiC and graphite reinforcements significantly enhances the tensile performance of Al 7075 alloys without compromising their workability.

Figure 4: Casted samples, machined as per slandered and after tensile test backed samples.

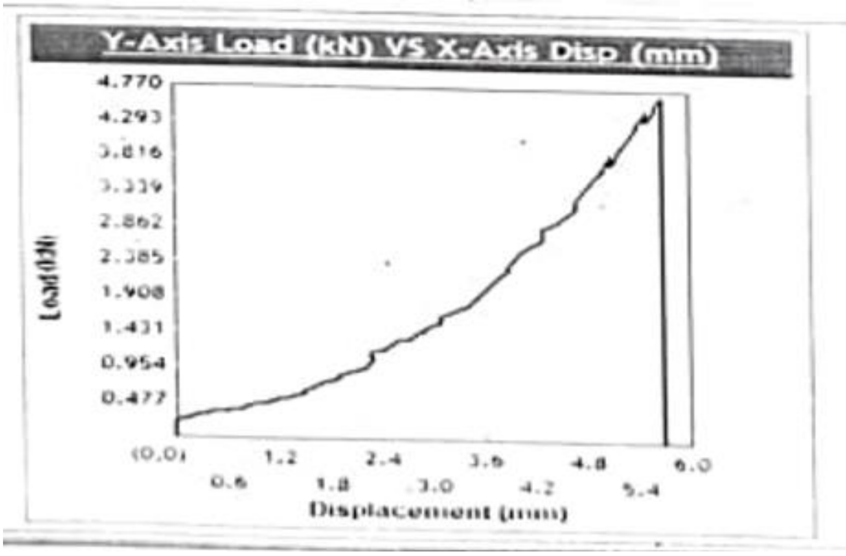

Figure 5: Tensile test computer generated plots.

3.3 Hardness

The mechanical behavior of the fabricated Al 7075/TiC composites was evaluated in terms of Rockwell hardness and bending stress, as illustrated in Figure 6. Hardness measurements were performed using a Rockwell hardness tester under a load of 150 kgf with a dwell time of 20 seconds as shown in Figure 6. The average hardness of the unreinforced Al 7075 monolithic alloy was found to be approximately 120 HRC. In contrast, the composites reinforced with 1 wt.% TiC and varying graphite content (1, 3, and 5 wt.%) exhibited significantly enhanced hardness values, reaching up to 260 HRC [24]. This represents an increase of nearly 40% compared to the monolithic alloy. The substantial improvement in hardness can be attributed to several synergistic factors. The presence of hard TiC ceramic particles acted as strong obstacles to dislocation motion, resulting in increased dislocation density. Additionally, the incorporation of reinforcements promoted grain refinement during solidification, thereby increasing the grain boundary area which also contributed to hardening. Furthermore, the effective metallurgical bonding between the α-Al matrix and TiC particles enhanced the load-bearing capacity of the composite, thereby improving resistance to plastic deformation. These microstructural enhancements collectively led to the observed increase in hardness across the reinforced composite samples.

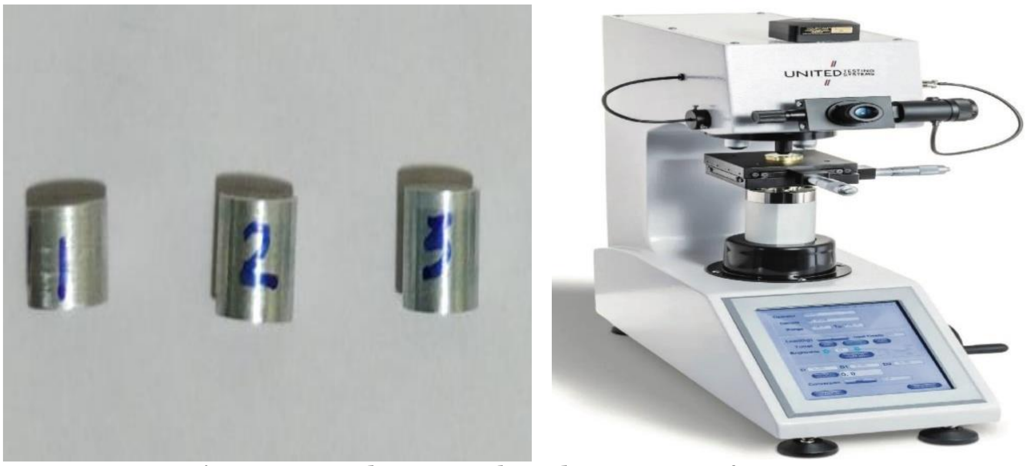

Figure 6: Hardness sample and instruments for testing.

4. Conclusion

The influence of TiC reinforcement particles on the mechanical and microstructural behavior of Al 7075 alloy was systematically investigated and reported. Based on the experimental findings, the following conclusions can be drawn:

- **Successful Fabrication**: TiC particles were successfully incorporated into the Al 7075 matrix using the stir casting technique. The resulting composites exhibited a uniform distribution of TiC reinforcement throughout the aluminium matrix, indicating effective mixing and solidification.
- **Mechanical Property Enhancement**: The composite reinforced with 1 wt.% TiC and varying graphite contents (1%, 3%, and 5%) demonstrated significant improvements in mechanical performance. The best combination achieved an ultimate tensile strength of 134.2 MPa, yield strength of 119.4 MPa**,** elongation of 3.2%**,** and Rockwell hardness of 260 HRC**.**
- **Improved Tensile Strength**: The addition of TiC and graphite reinforcements led to a notable increase up to 60% in tensile strength compared to the unreinforced Al 7075 alloy. This enhancement is attributed to grain refinement, homogeneous dispersion, and strong interfacial bonding between the matrix and reinforcement particles.
- **Microstructure Characterization**: Microstructural analysis revealed the absence of voids, cracks, or delamination at the matrix–reinforcement interface. This defect-free bonding facilitated efficient load transfer from the ductile aluminium matrix to the rigid TiC particles, thereby contributing to the observed improvement in tensile strength.

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Conflicts of interest/Competing interests
The authors declare no conflicts of interest/competing interests

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