Carbide–Oxide Concentration and Stir Process Actions on Functional Behaviour of Aluminium Alloy (Al 7075) Composites: Characteristics Study

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**Abstract:** The aim of this work is to assess the influence that nanoparticle reinforcement made of titanium carbide and alumina on the mechanical behavior of composites made of Al7075 alloy that have been treated by stir casting in conjunction with ultrasonic treatment. While keeping the TiC content constant, five composite versions with different oxide concentrations were created. Mechanical characteristics such as impact toughness, microhardness, elongation, Young's modulus, yield strength and ultimate tensile strength were assessed. Because of the improved interfacial bonding and fine particle dispersion the ideal composite Al7075 with 5 weight % TiC and 3 weight %AlO₃, demonstrated better mechanical performance. These findings point to potential uses in vehicle structural frames that need to be strong, ductile and durable.

# Introduction

Al7075 is a high strength aluminium alloy is renowned for its favorable strength to weight ratio and fatigue resistance, commonly utilized in automotive and aerospace components and its modest hardness and somewhat low wear resistance necessitate property enhancement for structural applications. A proven technique for improving mechanical properties using load transmission, thermal stability and grain refinement involves the reinforcement with ceramic particles such as TiC and AlO₃ [1-4].

Stir casting combined with ultrasonic treatment effectively distributes nanoparticles by reducing agglomeration and improving wettability between the matrix and reinforcement and then the enhanced mechanical and tribological properties of Al7075 based hybrid metal matrix composites supplemented with ceramic nanoparticles have garnered significant attention for structural and wear critical applications. They [5-6] investigated the mechanical properties of Al7075 combined with AlO₃ and TiC discovering that a uniform particle distribution enhanced the material's tensile strength and hardness. Research [7] evaluated the wear and corrosion characteristics of Al7075/TiC composites and found that stir casting produced enhancing wear and corrosion resistance. Al Research [8] incorporated zirconia nanoparticles into 7075 aluminium alloy resulting in improved mechanical strength and ductility due to better load transfer and grain refinement effects.

Research [9-10] did the optimisation of stir squeeze casting parameters for Al7475 hybrid composites supplemented with B₄C, Al₂O₃ and TiB₂ by the Taguchi method and determined that processing parameters influence the resultant mechanical properties. Research [11] incorporated TiC into aluminium matrices through ultrasonic assisted stir casting, observing significant enhancements in hardness and tribological performance. during the uniform distribution. Tile and Thomas [7] concluded that Al7075-based nanocomposites exhibited superior wear resistance under elevated stress levels after examining the effects of reinforcement, load and sliding velocity on wear performance.

Ujah and Von Kallon [8] studied the utilization of nanoparticles, effective casting processes and hybrid reinforcement strategies to enhance characteristics. Sabry and El-Deeb [9] shown substantial enhancements in tribological performance and structural integrity in their study of friction stir welding TiB₂ and AlO₃ into Al6061 and Al6082 alloys indicating compatibility with cross alloy reinforcement. Research [12] investigated the effect of TiC nanoparticles on Al7075-graphene systems revealing that these nanoparticles augment tensile strength via synergistic reinforcement. Raja and Anbumalar [11] utilisedSiC, graphite, and zirconium in Al7075 using ultrasonic-assisted stir casting to produce multi-phase hybrid metal matrix composites, exhibiting significant enhancements in load-bearing capacity and wear resistance.

Research [13-18] expanded the hybrid reinforcement methodology to magnesium nanocomposites incorporating AlO₃ and MoS₂, demonstrating that analogous strategies enhance performance in non-aluminum systems. Research [19-20] enhanced Al7075 along with TiC composites produced in conventional stir casting [21-22] and studied the impact of CNT reinforced metal matrix nanocomposites for high temperature applications by presenting analytical models that characterize their temperature dependent strength and ductility. Research [27] examined the influence of TiC concentration (2–12%) on Al7075 composites. [23-25] also established the optimal reinforcement amounts to enhance strength and hardness. Research [28-30] investigated fracture toughness in Al7075-SiC/AlO₃ hybrid composites, emphasizing the importance of specimen composition and shape by Taguchi design and finite element analysis (FEA). Research [26] conducted analysis of aluminium matrix nano composites reinforced along with nanoparticles and their findings on wear mechanisms, microstructural evolution and mechanical properties.

With an emphasis on applications in automotive structural frames where strength, ductility and toughness are crucial this study examines the combined impacts of carbide oxide fillers and sophisticated casting techniques on the functional performance of Al7075 composites.

# Materials and Methods

## Materials

Al7075 alloy is a high strength aluminum alloy based on zinc, magnesium and copper that is extensivelyutilized in structural and aerospace applications due to its exceptional mechanical performance served as the matrix material for this investigation. Because of their high hardness, thermal stability and compatibility with aluminum matrices titanium carbide nanoparticles which have an average particle size of about 50 nm and aluminum oxide nanoparticles which have an average particle size of about 30 nm, were chosen as reinforcements. All of the reinforcement powders were heated to 250°C before mixing in order to progress dispersion and interfacial bonding with the molten alloy during processing and by eliminating surface moisture this preheating step enhances wettability and reduces the development of agglomerates during the composite fabrication process [31-33].

## Composite Formulations

To inspect the impact of TiC and AlO₃ reinforcement on the functional behavior of the Al7075 alloy, five different composite samples were created and the following are the formulations, S1 was made of the unreinforced Al7075 alloy S2 was reinforced with 5 weight % TiC, S3 had 5 weight % TiC and 1 weight % AlO₃, S4 had 5 weight % TiC and 3 weight % AlO₃ and S5 was made with 5 weight % TiC and 5 weight % AlO₃. An evaluation of the synergistic impacts of ceramic hybridization on the mechanical and functional aspects of the composite system was made possible by this gradient in AlO₃ content.

**TABLE 1.** Mechanical Composite Formulations Table

|  |  |
| --- | --- |
| **Sample** | **Description** |
| S1 | Al7075 (Base alloy) |
| S2 | Al7075 + 5 wt% TiC |
| S3 | Al7075 + 5 wt% TiC + 1 wt% Al₂O₃ |
| S4 | Al7075 + 5 wt% TiC + 3 wt% Al₂O₃ |
| S5 | Al7075 + 5 wt% TiC + 5 wt% Al₂O₃ |

This composite design identifies the optimal hybrid formulation that maximizes mechanical performance in Al7075 alloy by examining the individual and combined effects of titanium carbide and alumina oxide nanoparticle reinforcements and to assess the effect of dual ceramic fillers this study gradually raises the AlO₃ content while keeping the TiC loading constant at 5 weight percent. This factorial approach makes it possible to gain a basic understanding of matrix particle interfacial bonding, load transfer efficiency and potential saturation thresholds and all of which are critical for designing lightweight, high-strength aluminum matrix composites that are appropriate for sophisticated structural applications [34-36].

## Fabrication Process

At 750°C the stir casting procedure was performed. For 10 minutes TiC and AlO₃ nanoparticles were introduced while being continuously stirred at 500 rpm. Each melt was then subjected to an ultrasonic treatment (20 kHz, 500W, 5 min) prior to being cast into steel molds that had been warmed. For testing the solidified samples were machined.

# Results and Discussion

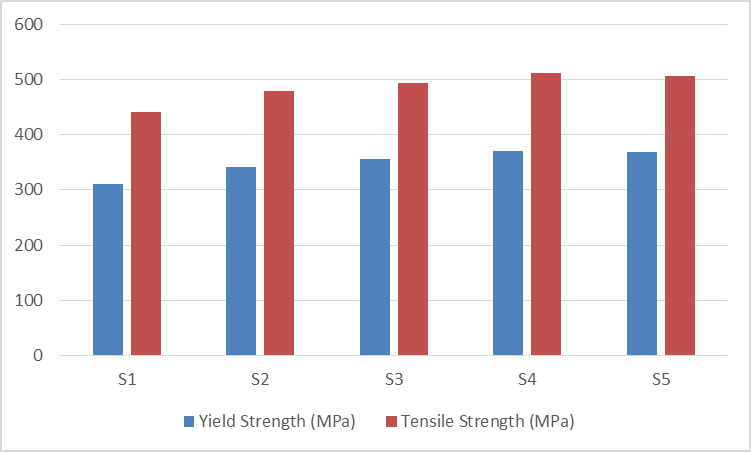
## Tensile properties

The use of ceramic reinforcements meaningfullybetter the tensile behavior of the Al7075 composites. With 10.5% elongation, the base alloy (S1) demonstrated a tensile strength of 442 MPa and a yield strength of 310 MPa. Both yield and tensile strengths dramatically rose to 342 MPa and 480 MPa, respectively, with the addition of 5 weight percent TiC (S2). Grain refinement and Orowan strengthening [37-40], two processes that limit dislocation motion, are responsible for this improvement. Strength and stiffness continued to improve with additional reinforcement with AlO₃ nanoparticles in S3 and S4, with S4 obtaining the highest tensile performance 371 MPa yield strength and 512 MPa tensile strength as well as a Young's modulus of 81 GPa.

**TABLE 2.** Tensile properties

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sample** | **Yield Strength (MPa)** | **Tensile Strength (MPa)** | Elongation (%) | Young’s Modulus (GPa) |
| S1 | 310 | 442 | 10.5 | 72 |
| S2 | 342 | 480 | 9.1 | 76 |
| S3 | 356 | 493 | 8.7 | 78 |
| S4 | 371 | 512 | 8.4 | 81 |
| S5 | 368 | 507 | 7.6 | 80 |

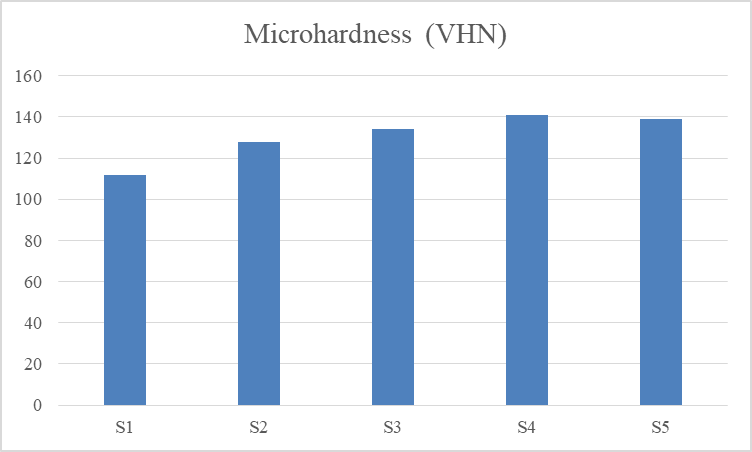
Better interfacial connectivity between the matrix and evenly distributed ceramic phases is the cause of this improvement. However, a minor decrease in strength was noted at 5 weight percent AlO₃ (S5), mostly due to particle agglomeration, which could act as stress concentrators and start microcracks. The effectiveness of adding hybrid nanoparticles was confirmed by the fact that all hybrid samples continued to perform better than the unreinforced matrix.

  
**Figure 1.** Tensile properties

## Microhardness

**TABLE 3.** Microhardness

|  |  |
| --- | --- |
| **Sample** | **Energy Absorption (J)** |
| S1 | 112 |
| S2 | 128 |
| S3 | 134 |
| S4 | 141 |
| S5 | 139 |



**Figure 2.**Microhardness

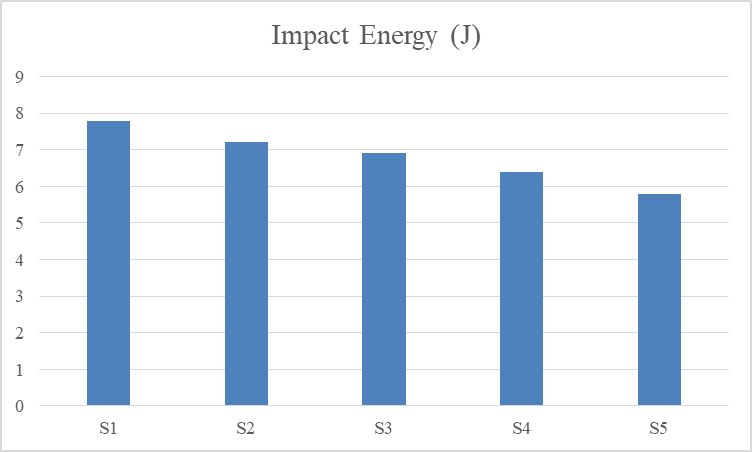
As the amount of ceramic reinforcement in the composites grew, so did their microhardness levels. The microhardness of the basic alloy (S1) was 112 VHN. The hardness increased to 128 VHN after adding 5 weight % TiC (S2). This characteristic was improved by adding more AlO₃ along with S3 and S4 reaching 134 and 141 VHN respectively. S4 had the maximum microhardness demonstrating the combined hardening effect of TiC and AlO₃ through uniform dispersion and ability to support loads [41-45]. A slight decrease to 139 VHN in S5 indicates a declining return once more because of potential particle clustering which may have an impact on the homogeneity of the reinforcing distribution.

## Impact Toughness

In contrast to strength and hardness, impact toughness tests showed an inverse trend. With the highest impact energy of 7.8 J the unreinforced matrix (S1) demonstrated its intrinsic ductility.The impact energy diminishes as the ceramic concentration increases, with S2 measuring 7.2 J and S4 decreasing to 6.4 J. The conventional tradeoff between strength and toughness in particle-reinforced composites was exemplified by the minimum value of 5.8 J observed for S5. The primary factors backing to the reduction in impact energy are the maximum brittleness induced by the rigid ceramic phases and the restricted plastic deformation within the matrix [46-49].

**TABLE 4.** Impact Toughness

|  |  |
| --- | --- |
| **Sample** | **Tensile Strength (MPa)** |
| S1 | 7.8 |
| S2 | 7.2 |
| S3 | 6.9 |
| S4 | 6.4 |
| S5 | 5.8 |



**Figure 3.** Impact Toughness

In spite of the decrease sample S4 showed the best balance obtaining the highest mechanical strength and microhardness while retaining acceptable levels of toughness, confirming its appropriateness for structural applications needing both rigidity and moderate energy absorption [51-53].

# Application in Automotive Interior Trims

For automotive frame components to withstand dynamic loads and extreme temperatures, a well-balanced combination of high strength, structural stiffness and impact resistance is necessary. A viable option in this respect is the Al7075 hybrid composite reinforced with 5 weight % TiC and 3 weight %AlO₃. In comparison to the unreinforced alloy this structure exhibits a 26% increase in microhardness and an approximate 20% increase in tensile strength suggesting better load bearing and wear resistant properties. It is appropriate for crash-load situations because it maintains sufficient impact toughness even with the addition of stiff ceramic reinforcements. For automobile subframe members, cross rails and chassis brackets—where both mechanical integrity and crashworthiness [50] are crucial—these synergistic property enhancements make the composite the perfect lightweight, high-performance option.

# Conclusion

The mechanical enactment of the composite has considerably enhanced since TiC and AlO₃ nanoparticles were added to the Al7075 matrix by stir casting and ultrasonic treatment. With a tensile strength of 512 MPa microhardness of 141 VHN and impact energy of 6.4 J the ideal composition of the formulations under investigation—which contained 5 weight percent TiC and 3 weight percent Al₂O₃ displayed a balance between strength, hardness and toughness. These improvements can be ascribed to the hybrid processing route's improved grain structures, robust interfacial bonding and uniform dispersion of nanoparticles. The results indicate the viability of hybrid Al7075 nanocomposites as high strength, lightweight materials for automotive structural components where weight reduction and mechanical integrity are important.

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