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Characterization of Al6061-Based Hybrid MMCs reinforced with TiC and Graphene

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ABSTRACT

This study investigates the mechanical properties of Al6061-based hybrid metal matrix composites (MMCs) reinforced with a fixed graphene content of 0.5 wt% and varying titanium carbide (TiC) content at 1 wt%, 2 wt%, and 3 wt%. The composites were fabricated using the stir casting process, which ensures uniform dispersion of reinforcements within the aluminum matrix. The mechanical properties, including hardness, tensile strength, and ductility, were systematically evaluated following ASTM standards to assess the impact of TiC reinforcement at different weight fractions. The results indicate that the addition of TiC significantly enhances the hardness and tensile strength of the composites due to the formation of a refined grain structure and improved load transfer efficiency. However, ductility exhibits an inverse relationship with TiC content, as higher reinforcement levels contribute to increased brittleness.

Keywords : Al6061-based hybrid MMCs, Graphene reinforcement, Titanium carbide (TiC), Mechanical properties, Stir casting

I. INTRODUCTION

Introduction

Aluminum matrix composites (MMCs) based on aluminum have gained ample attention because of their improved mechanical, thermal, and tribological properties, suitable for high-performance applications in defense, aerospace, and automotive industries. Among several aluminum alloys, Al6061 is particularly noted for its enhanced strength-to-weight ratio, superior corrosion resistance, and enhanced wear performance, suggesting its potential candidacy for structural application involving lightweight materials with high strength. Nevertheless, despite these characteristics, pure Al6061 experiences inferior hardness, wear resistance, and ductility, limiting its wider application under harsh environments. To mitigate this, reinforcement of Al6061 with ceramic particulates and nanomaterials has been made possible as an alternative. Hybrid reinforcement with titanium carbide (TiC) and graphene possesses synergistic effects on mechanical improvements. TiC is well-known for its greater hardness, better thermal stability, and good wetting with aluminum, contributing towards enhanced hardness and wear resistance. Conversely, graphene, with improved aspect ratio, superior mechanical performance, and improved thermal conductivity, contributes towards better tensile strength and load-bearing capability in the composite. A uniform graphene composition of

0.5 wt% allows uniform strengthening, and the varying reinforcement content of 1 wt%, 2 wt%, and 3 wt% of TiC provides the leeway to optimize reinforcement levels in order to obtain maximum hardness, tensile strength, and ductility[1-4].

From the literature, it is evident that TiC and graphene reinforcements significantly influence the enhancement of the mechanical properties. However, the majority of the research work is on single-reinforcement systems, and very few research works have been carried out on the synergistic effect of TiC and graphene in hybrid MMCs. Further, there are few published articles on the influence of varying the content of TiC with a constant content of graphene, particularly in Al6061-based MMCs. This research gap is intended to be filled by this research, where the mechanical behavior of Al6061-TiC-Graphene hybrid composites with constant content of graphene as 0.5 wt% and varying content of TiC as 1 wt%, 2 wt%, and 3 wt% is studied. The primary objectives of this research are to evaluate the hardness of Al6061-based hybrid MMCs with these levels of reinforcement, study the enhancement of tensile strength gained by hybrid reinforcement, investigate the variation in ductility through the addition of different content of TiC, and optimize the process parameters for stir casting to achieve effective reinforcement dispersion[5-9]. Through these objectives, this research intends to provide valuable information on the optimum composition and production parameters required to enhance the mechanical properties of Al6061-based MMCs for advanced structural and engineering applications.

Experimental Details

Al6061 is the base metal of choice because it is strong, resistant to corrosion, and appropriate for structural applications that require high performance. In this work, graphene and titanium carbide (TiC) are used as reinforcement materials; both of them help to enhance the mechanical characteristics of the composite. Incorporated at a fixed content of 0.5 wt%, graphene is high-purity graphene nanoplatelets with an average thickness of 30–50 nm and a lateral size of roughly 10 μm, so guaranteeing enhanced tensile strength, thermal conductivity, and load distribution within the composite. With micro-sized TiC powder having an average particle size of 10-20 μm to ensure uniform dispersion within the Al6061 matrix, titanium carbide is added at varied weight fractions of 1 wt%, 2 wt%, and 3 wt%. This increases hardness and wear resistance.

The stir casting method is used to create the composite; several steps guarantee consistent reinforcement distribution and enhanced mechanical performance. To get a totally liquid state, the Al6061 alloy is first melted in a graphite crucible at 750°C. Both TiC and graphene reinforcements are preheated to 300°C to remove moisture and stop clustering, so improving the wettability and guaranteeing even dispersion. Mechanical stirring at a controlled speed of 500 rpm for ten minutes helps to homogeneous mix the reinforcements once the aluminum is completely molten. This constant stirring action guarantees consistent dispersion of TiC and graphene over the aluminum matrix and helps in breaking up agglomerates. The molten composite is poured into preheated molds following careful mixing to prevent thermal shock and enable slow solidification under ambient conditions, so ensuring low porosity and enhanced interfacial bonding between the matrix and reinforcements.

To assess their performance, the created composite specimens are rigorously mechanical tested and characterised. Following ASTM E92 guidelines, the Vickers Hardness Test measures hardness by means of a 0.5 kgf load applied for 10 seconds on a polished specimen surface and recording of the indentation diameter to derive the stiffness value. Using a Universal Testing Machine (UTM) in line with ASTM E8 criteria, samples are machined into standard dog-bone forms and subjected to uniaxial tension with a strain rate of 1 mm/min until fracture; the ultimate tensile strength is then recorded. Measuring the elongation at fracture percentage under ASTM standards helps one to assess ductility and gain understanding of the composite's plastic deformation capacity before failure[5-8].

Results and discussions

Hardness

The Vickers hardness of Al6061 and its composites reinforced with 0.5 weight percent graphene and varied TiC content (1 weight percent, 2 weight percent, and 3 weight percent) are shown in Figure 1. The trend amply shows how much harder a reinforcement adds makes. Whereas the composite with 3 weight percent TiC shows the highest hardness value, the pure Al6061 alloy shows the lowest hardness. The composite including 1 weight percent TiC shows an increase of roughly 10.77% compared to the base alloy; the 2 weight percent and 3 weight percent TiC composites show an increase of roughly 18.46% and 26.15%, respectively. TiC and graphene's dispersion strengthening action helps to explain the improvement in hardness since it limits grain development and increases dislocation resistance. Being a hard ceramic reinforcement, TiC also greatly increases the composite's load-bearing capacity and indentation resistance. On the other hand, too high TiC content might cause agglomeration, which would somewhat impede more hardness improvement. Together with their great hardness and thermal stability, TiC's and graphene's homogeneous dispersion helps to explain why composite hardness has improved overall[10-12].

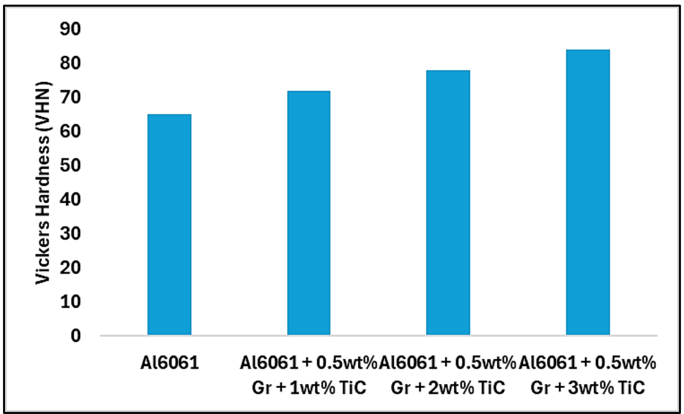

Fig.1 variation of hardness of alloy and its composites

Ultimate Tensile Strength

With a rising TiC content, the fig. 2 shows the tensile strength of Al6061 and its hybrid composites in a positive trend. Tensile strength is lowest in the pure Al6061 alloy; the composite including 3 weight percent TiC shows the best value. The 1 weight percent TiC composite shows a 20% improvement over the base alloy; the two weight percent TiC composites show increases of 36% and 45%, respectively. Enhanced grain refinement and improved interfacial bonding resulting from the synergistic action of graphene and TiC help to strengthen the load-bearing capability of the composite. While TiC particles prevent dislocation movement, so enhancing total tensile strength, the high aspect ratio of graphene helps in stress transfer. The rise in TiC content introduces extra hard ceramic phases that improve fracture toughness and deformation resistance, so strengthening the composite. But because of particle clustering, which can result in stress concentration points, more brittleness may start to offset additional increases in tensile strength at higher TiC concentrations[8-14].

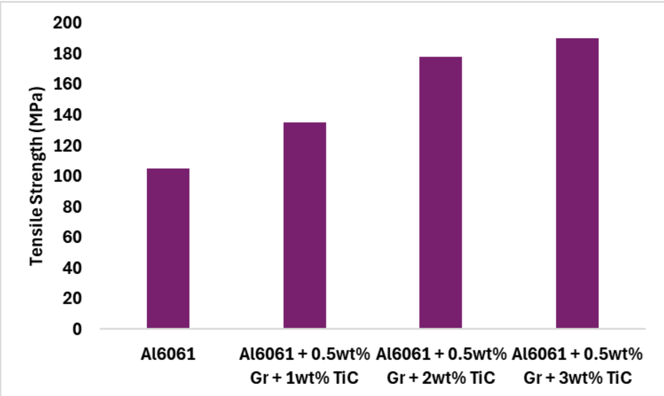

Fig.2 Variation of tensile strength of Al6061 alloy and its composites

Ductility

The ductility of Al6061 and its hybrid composites is shown in fig. 3; the ductility gradually decreases as TiC content rises. Although the composite with 3 weight percent TiC records the lowest ductility value, the base alloy shows the best ductility. The 1 weight percent TiC composite shows a 20% elongation decrease when compared to pure Al6061; the two weight percent TiC composites show reductions of 32% and 50%, respectively. The observed trend is expected since higher stiffness and lower plastic deformation capacity resulting from the change in ceramic reinforcement content help to explain TiC particles provide extra interfaces and stress concentration zones that help early crack initiation and reduce ductility by means of which they Moreover, the presence of hard reinforcements reduces the matrix's capacity for plastic flow, so producing a more brittle material. But the trade-off in ductility for the increases in hardness and tensile strength makes these composites appropriate for uses when high strength and wear resistance take front stage over elongation [12-15].

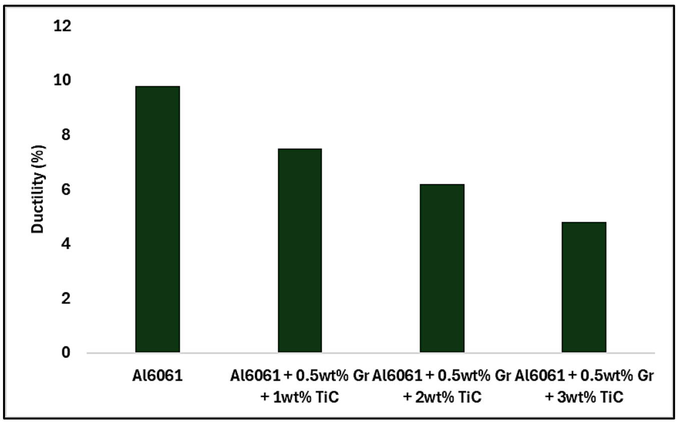

Fig.3 Variation of Ductility of alloy and its composites

Conclusions:

- With a maximum increase of 26.15% at 3 wt% TiC resulting from grain refinement and ceramic reinforcement effects, the addition of TiC and graphene greatly increases the hardness of Al6061 composites.
- The Al6061 + 0.5 wt% Gr + 3 wt% TiC composite shows effective load-bearing capacity by up to 45% by which tensile strength increases.
- With a maximum reduction of 50% at 3 wt% TiC, ductility shows a progressive drop with increasing TiC content, so indicating more material brittleness.
- The composite is fit for high-strength structural uses since the combination of graphene and TiC offers a balanced enhancement in mechanical characteristics.
- As it maintains a reasonable degree of ductility and achieves notable strength and hardness improvements, the ideal reinforcement level seems to be 2 weight percent TiC.

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