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Evaluation of Mechanical Behaviour of Tungsten Carbide and Magnesium Reinforced Aluminium Matrix Composites

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Abstract

With industries like automotive and aerospace also being more inclined on the lightweight material and strength that is much substantial, the aluminium-based metal matrix composite has become a major focus of interest. This paper examines the influence of addition of tungsten carbide (WC) and magnesium (Mg) particles on the mechanical characteristics of Al6063 aluminium alloy. The crucible casting technique was made in two composite compositions 2.5 percent and 5 percent WC with a fixed 1 percent Mg(percent weight). The tested fabricated composites were tested on hardness, tensile strength, compressive strength, and impact energy. The findings of this study show that as the WC content is increased, there is a significant increase in hardness and strength with the 5 percent WC 1 percent Mg composite having the best mechanical performance. Nevertheless, the impact performance of the unreinforced Al6063 alloy was better probably because it is more readily ductile and all particles were not agglomerated. This was further substantiated by scanning electron microscopy (SEM) analysis which demonstrated a homogenous distribution of the reinforcement particles and a fine grain structure. On balance, it can be concluded that the created composites have high prospects of use in lightweight structure products that need increased mechanical strength.

Keywords: Aluminium matrix, tungsten carbide, magnesium binder, crucible casting, hardness, tensile strength, compressive strength, impact resistance, surface morphology

INTRODUCTION

The ever-increasing innovations in the automotive and aerospace industries are compelling the need to come up with materials that will have an ideal combination of durability in the long life, high strength, and lightweight design. Some of the most popular material classes that have come to the limelight over the past few years are the metal matrix composite, which is quoted to possess better mechanical and thermal characteristics than the traditional metals and alloys [1–3].

Metal matrix composites are usually generated by blending a ductile metal matrix, i.e., magnesium, aluminium or titanium with high strength ceramic reinforcement in the form of particles, whiskers or fibres [4–5]. These strengthening agents are very effective in improving such vital characteristics as tensile strength, stiffness, compressive strength, wear resistance, thermal stability, and hardness [6–8].

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One of such materials is aluminium matrix composites (AMMCs), especially because aluminium has low density, is easily machinable, and has high resistance to corrosion [9–12]. Addition of ceramic particles into the aluminium alloys such as tungsten carbide (WC) greatly improves their mechanical performance, and thus, they can be effectively utilized in demanding applications like automotive engine part, aerospace structures and high-speed machinery [13–16].

Al6063 is a heat treatable, medium-strength aluminium alloy that finds widespread application in the marine, structural and structural and architectural works. It can be further enhanced with the reinforcement of WC-based particles and the incorporation of magnesium (Mg) that enhances improved wettability and interfacial bonding throughout the fabrication of the composites [17–20]. Nevertheless, even though these reinforcements tend to increase strength and hardness, other properties are likely to be adversely impacted especially ductility and impact toughness among others and thus should be considered carefully.

In this experiment, hybrid aluminium-based matrix composites were prepared through the crucible casting method by reinforcing Al6063 with 2.5 percent and 5 percent WC in the presence of 1 percent Mg (in weight percentage), denoted sample2 and sample3 respectively and sample1 was pure Al6063 and acted as control. Their mechanical behaviour such as hardness, tensile, impact resistance, and compressive strength, of the composites were put to test. Sem was used to study the microstructure and reinforcement particle distribution. The paper gives a fair examination of the trade-offs between strength and toughness and includes a viable trade-off to the application of Al6063-based composites in industries that require the weight-efficiency to be coupled with mechanical.

Methodology

The experiment process began by choosing high-purity Al6063 as the matrix material, tungsten carbide (WC) as the reinforcement, and 1 percent magnesium (Mg) to increase wettability. The materials have been weighed depending on the compositions required and melted in a crucible furnace. WC and Mg were then added to the melted aluminium and stirred continual movement of the melt was carried out to achieve a uniform dissemination of the particles. The molten compound was then cast into pre heated sand molds and left to cool in ambient conditions. solidification The cast specimens were machined to standard size. Mechanical tests such as hardness, tensile, impact, and compression tests were carried out and scanning electron microscopy (SEM) analysis was done to study the microstructural characteristics.

MATERIALS AND METHODS

Development of composites

Al6063 that is commercially available has been chosen as a matrix material due to its favourable combination of corrosion resistance, mechanical properties, and castability. Al6063 is mainly made of magnesium and silicon that forms the main chemical composition and make it strong and wear resistant. Tungsten carbide powder itself was considered the main reinforcement to enhance the total hardness and compressive strength of the composite.

In order to enhance the mixture of the matrix and primary reinforcement, 1 percent of magnesium was only added. Mg lowers surface tension of molten aluminium which will enhance wetting and uniform dispersion of particles of tungsten. Basically this Mg acts as binder and improves the bonding between Al6063 matrix and tungsten carbide reinforcement.

The crucible casting technique was used to make the composite materials. Three batches were made namely: control which contained 100 percent of Al6063 (sample1), a composite which contained Al6063 combined with 2.5 percent WC and 1 percent Mg (sample2), and another one which contained Al6063 mixed with 5 percent WC and 1 percent Mg (sample3). Melting of the Al6063 alloy was performed in a coal-fired furnace with the help of a graphite. Tungsten carbide (WC) and magnesium

(Mg) pre-weighed amounts were subsequently added to the melted aluminium and constant stirring carried out so that the reinforcements could be mixed as uniformly as possible. The molten composites were then transferred into preheated sand molds with cylindrical and rectangular shape holes and left to cool and harden at room temperature. Once the casts were solid, the samples were machined to put them to a standard size that could be used in mechanical testing.

Mechanical Testing Methods

A sequence of mechanical tests was undertaken in the evaluation of the prepared specimens to establish their performance behaviour. The measurement of surface resistance was done by conducting rockwell hardness testing on the B-scale. Tensile test was done under ASTM E8 using Universal Testing Machine (UTM) to determine yield strength, ultimate tensile strength and elongation. The Izod impact test of the notched samples based on the ASTM D256 was used to establish the impact strength. Besides, standard compression test procedures were used to assess compressive strength on the UTM.

Microstructural Analysis (SEM)

Each polished sample of each composition was scanned using the Electron Microscopy (SEM) to examine the distribution of tungsten particles and find microstructural characteristics like porosity, agglomeration, and bonding quality of particles and matrix.

RESULTS AND DISCUSSION

This paper reports and discusses the mechanical laboratory tests of the metal matrix composite based on Al6063 reinforced with various amounts of tungsten carbide (WC) and with a fixed amount of magnesium (Mg) 1%. The reinforced composite samples (sample2 and sample3) are compared with unreinforced Al6063 (Sample1) in order to identify the changes in hardness, tensile strength, compressive strength and impact of the composite.

Hardness

The hardness test using the Rockwell B-scale demonstrated a clear method of hardness increasing with the increase in the WC content with a pure Al6063 (sample1) recording the lowest hardness value of HRB 39, sample2 and sample3 having a higher value of HRB 47 and HRB 53 respectively as shown in figure 1. This has been improved by the hardness of WC particles which is inherently high and therefore increases resistance to surface deformation by limiting plasticity of the aluminium matrix, and in the process improves its surface wear property.

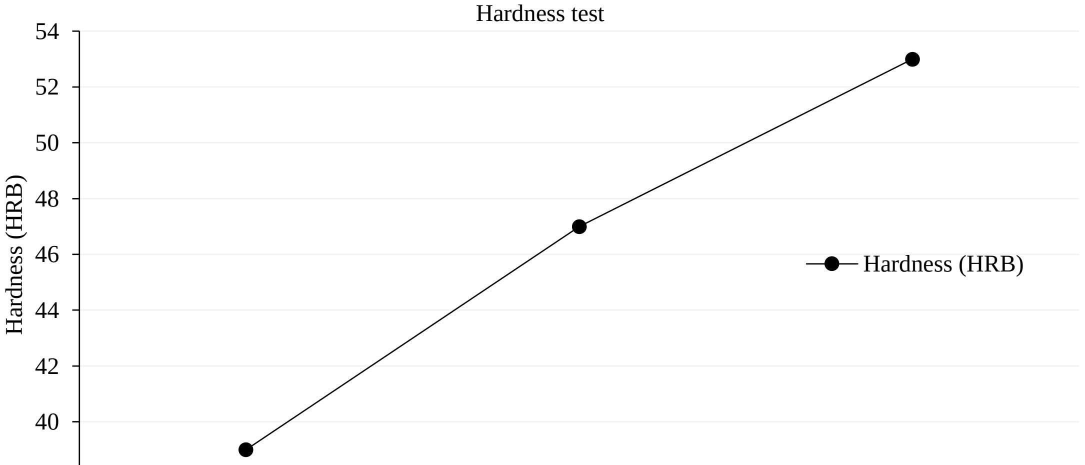

Figure 1. Hardness test.

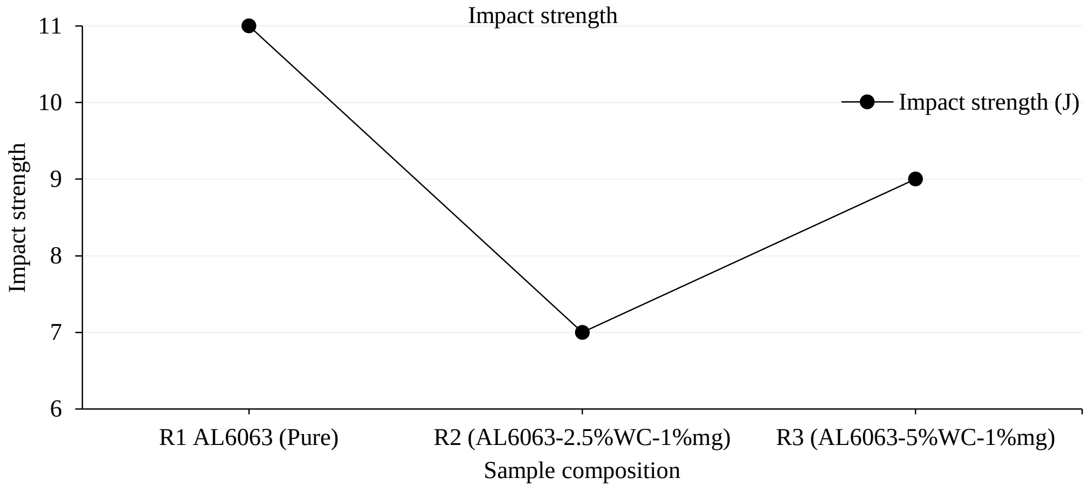

Figure 2. Impact strength.

Impact Strength

Izod impact testing showed that there was decreasing impact energy absorption as the WC reinforcement increased. Sample1 which was not reinforced had the greatest impact toughness of 11 J and sample3 had impact toughness of 9 J, and sample2 had impact toughness of 7 J, as seen in figure 2. In spite of the fact that reinforcement increases strength, it also increases brittle nature. Microstructural discontinuities caused by the particle agglomeration, as found in sample3, are also stress concentrators, and therefore reduce the energy absorption capacity of the material in sudden or dynamic loading conditions.

Tensile and Elongation Strength

The tensile and elongation strength can be measured in tensile tests as well as elongation tests. Tensile testing showed a great improvement of the mechanical performance as reinforcement was brought in. Sample1, which was not reinforced with aluminium, had an ultimate tensile strength (UTS) of 75.4 Mpa, sample2 and sample3 had higher UTS of 103.15 Mpa and 135.7 Mpa respectively. Another improvement was on elongation in the reinforced composites. The main cause of this enhancement in tensile performance is the ability to transfer the loads between the ductile aluminium matrix and the hard WC particles. Moreover, magnesium (Mg) is added to enhance interfacial bonding between reinforcement and the matrix to enhance even distribution of stress. The elongation improvement that was observed on the composites, as shown in Figure 3, means that the composites were ductile to some extent even in the presence of ceramic reinforcements.

Compressive Strength

The trend of compressive strength was like in the other mechanical properties. In figure 4, sample1 exhibited compressive strength as 229.28 MPa whereas sample 2 exhibited only slight improvement of 230.78 Mpa. Conversely, sample3 sample showed a significant growth in compressive strength that has grown to 279.52 MPa. This improvement can be explained by the fact that hard non-deformable WC particles are used, and they limit the deformation of matrices during compressive loading. The ceramic reinforcements help in the increased strength at the presence of the static compressive conditions by averting dimensional collapse.

Surface Morphology

The scanning electron microscopy (SEM) analysis showed that the distribution of particles was different in the samples- sample2 showed even distribution of WC particles showing that it was well stirred and solidified and sample3 showed clear clustering and agglomeration of particles as depicted in Figure 5.

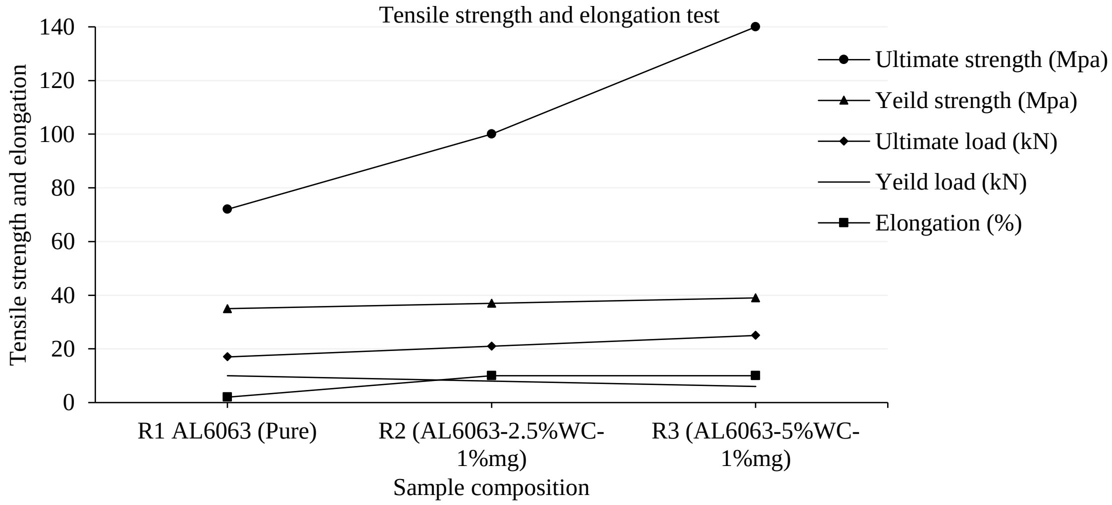

Figure 3. Tensile strength and elongation test.

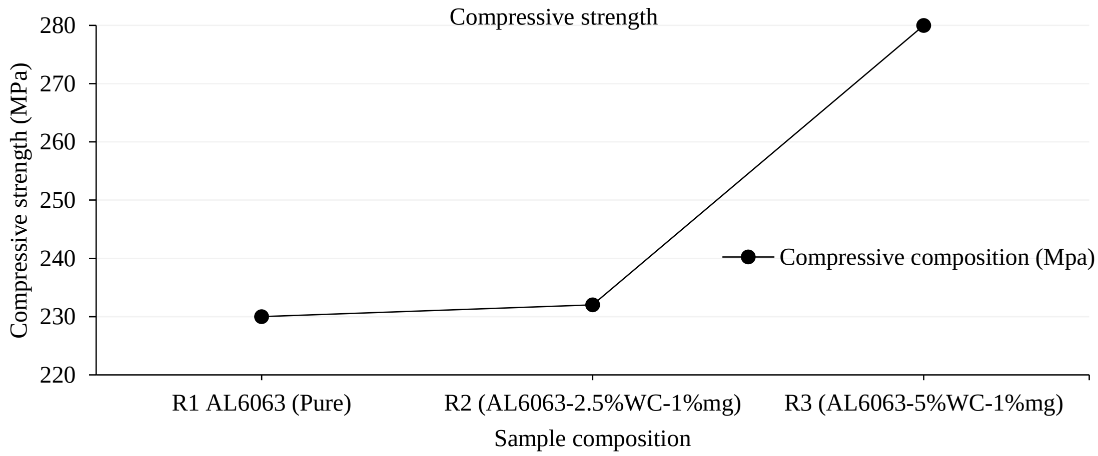

Figure 4. Compressive strength

Even though sample3 showed increased mechanical strength, these microstructural defects related to agglomeration can negatively impact fatigue life and decrease impact toughness, which shows that a balance of optimal reinforcement ratio and good particle dispersion is necessary to achieve maximum material performance.

AUTHOR CONTRIBUTIONS

The first author and the second author contributed equally to this work and share first authorship.

CONCLUSION

This paper had systematically examined the microstructure and mechanical property of the Al6063 metal matrix composites reinforced with tungsten carbide (WC) and constant 1 percent magnesium (Mg) prepared through the casting method using a crucible technique. The three material variants that were investigated include unreinforced Al6063 (sample1), reinforced with 2.5 percent WC (sample 2), and reinforced with 5 percent WC (sample3). The findings established that introduction of WC particles leads to the considerable improvement of hardness, compressive strength, and tensile strength of the aluminium matrix. The mechanical performance of the composites was best with the 5 percent WC sample (sample3) with a significant improvement in hardness (HRB 53) and ultimate tensile strength (135.7 Mpa) when compared to the unreinforced alloy. The enhancement is mainly due to the fact that the WC particles are highly stiff and hard and thus dislocation movement is limited and results in increased load bearing capacity.

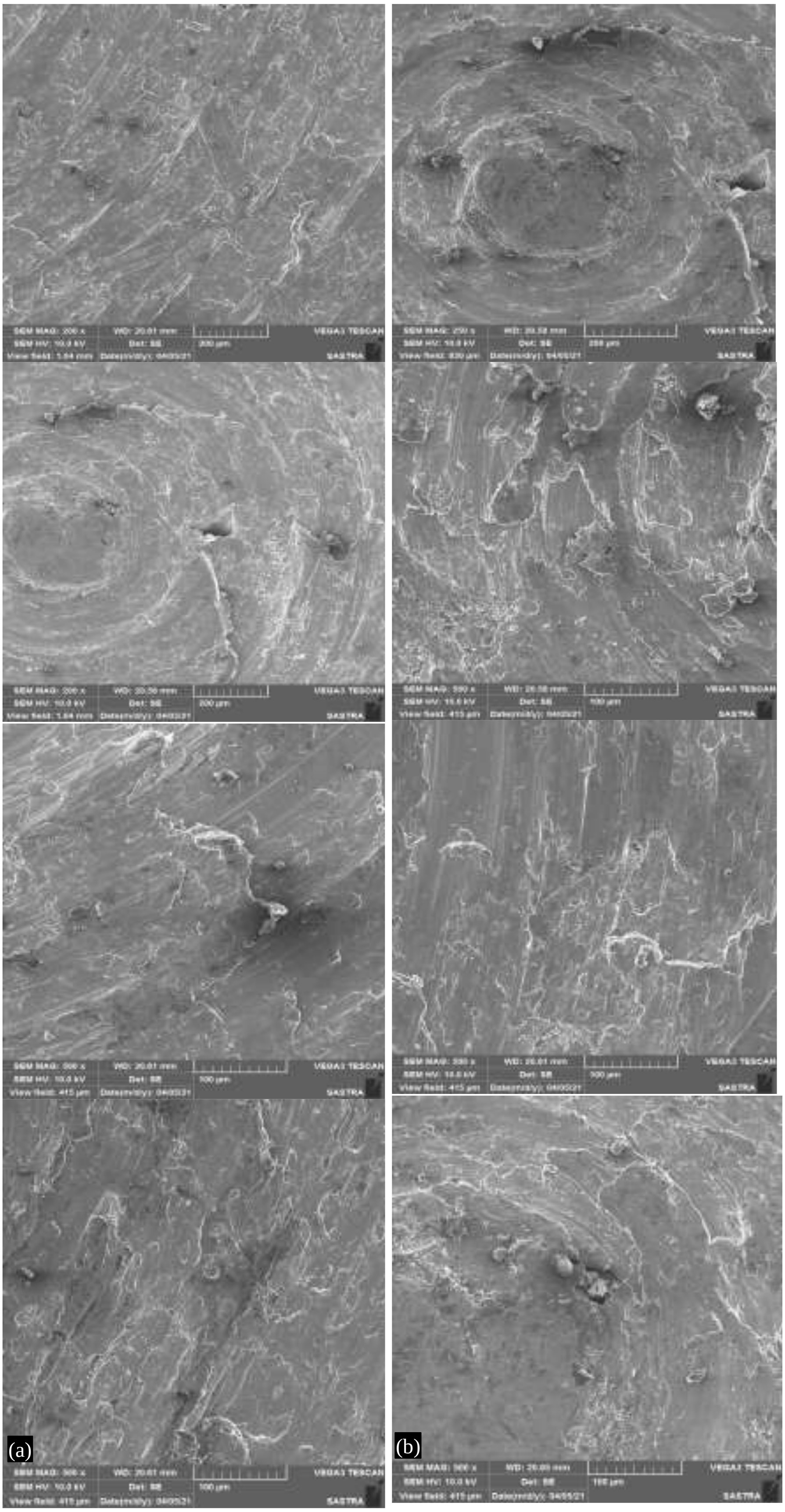

Figure 5. Surface Morphology of (a) sample2 and (b) sample3.

On the other hand, the introduction of WC had adverse impact strength and the unreinforced Al6063 (sample1) exhibited the highest toughness of 11 J. Agglomeration of particles and the development of microstructural stress concentrators are the primary causes of the decrease in impact resistance at high reinforcement levels as observed by SEM. Introduction of magnesium was useful in enhancing wettability and interfacial bonding between the reinforcement and the matrix. The dispersion of WC particles is however important to ensure homogenous dispersion especially when the reinforcement content is higher to reduce clustering and early failure during dynamic loading.

In general, the Al6063-WC-Mg composites that have been produced based on the crucible casting are a promising material system that can be used in cases where high strength, wear resistance are required at the cost of impact performance. To create a more balanced mixture of strength and toughness in the composites, further optimization of the processing parameters and reinforcement ratios is suggested to be able to apply the composites to the automotive, structural, and aerospace applications.

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Appendix

Appendix A

Chemical Composition of Al6063

Element	% Composition
Mg	0.47 – 0.8
Ti	0.12 max
Cu	0.11 max
Mn	0.12 max
Si	0.1 – 0.5
Al	Balance
Zn	0.11 max
Cr	0.11 max
Fe	0.38 max

Appendix B

ASTM Standards Used

ASL testing of the specimens prepared was done with ASTM E8/E8M-13a, which provides the standard procedure of resolving tension testing of metallic material.

The impact strength of the composite samples was determined with the help of the Charpy impact tester in accordance with the recommendations used in ASTM D256 which describes the normal test procedures used to calculate Izod pendulum impact resistance.

The measurement of rockwell hardness values was done in a standard hardness test machine and this was done in accordance with a standard of testing, the ASTM E 10/E18, which gives a detailed guideline on the process of measuring hardness of metal materials by applying the Rockwell method.

