Journal of Mines, Metals and Fuels, 71(1): 88-93; 2023. DOI: 10.18311/jmmf/2023/33361

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: www.informaticsjournals.com/index.php/jmmf

Mechanical and Wear Behaviour Analysis of Graphene Reinforced Aluminum Alloy 7010 Metal Matrix Composite

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Abstract

Due to its superior mechanical and thermal properties, graphene has shown a viable approach as a better material for composites. In this work, the properties of graphene-reinforced aluminium alloy 7010 MMCs at weights of 1, 2, and 3 per cent are investigated. The existence and dispersion of graphene particles in the Al7010 matrix materials were confirmed by analyses of the MMC conducted using a Scanning Electron Microscope (SEM) and Energy Dispersive Spectroscopy (EDS). The tensile strength, yield strength, and hardness of MMCs were examined and evaluated experimentally. By using 3 weight per cent graphene in aluminium 7010 alloys, the tensile and hardness of MMCs were enhanced from 20 to 25 per cent. With the inclusion of reinforcement in the matrix, the percentage of elongation decreased. The pin-on-disc machine has been used to conduct wear tests under various loads and speeds. After graphene was added to Al7010, it was seen that the composite's tribological behaviour has improved.

Keywords: *Metal matrix composite, SEM, EDS, Wear rate*

1.0 Introduction

Particle-reinforced aluminium alloy composites are now taking the place of traditional aluminium alloy materials in the aviation, automotive, defense, and transportation sectors. The creation of an MMC material with a mix of mechanical and wear-resistant qualities are one of the key goals. MMC is an aluminium alloy substitute with superior mechanical, creep, and corrosion resistance. Due to its dependable strength, weldability, and corrosion resistance, Al7010 is often utilized in structural fabrication applications. The most popular matrix alloys for MMCs have been replaced by the heat-treatable 7010 aluminium alloy. MMCs may be made by powder metallurgy, solid or liquid state processing, squeeze casting, stir casting, or spray form. The mechanical property offered by solid-state processing is desired, but the investment cost is significant. By lowering wear loss, graphene MMC caused the creation of solid lubricant between the points of a metal surface. Al7010's wear resistance may be effectively increased by adding ceramic reinforcements[1]. It is clear from the aforementioned works of literature that relatively few investigations on graphene reinforced with Al7010 matrix as MMC composites have been conducted. In the experiment covered in this work, graphene was employed as the reinforcement[2]. The main goal of the work that has been presented is to examine the mechanical and tribological behaviour of Al7010 alloy as well as the impact of the weight % of graphene reinforcement.

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Table 1: Chemical composition of the Al7010 alloy

Element	Content (%)
Aluminium, Al	87.8 - 90.6
Zinc, Zn	5.70 - 6.70
Magnesium, Mg	2.10 - 2.60
Copper, Cu	1.50 - 2.0
Iron, Fe	0.15
Zirconium, Zr	0.10 - 0.16
Silicon, Si	0.12
Manganese, Mn	0.1
Titanium, Ti	0.06
Chromium, Cr	0.05
Nickel, Ni	0.05
Other, total	0.15

Single atomic carbon sheets are tightly packed into a two-dimensional honeycomb lattice structure in graphene [3]. Graphene differs from ordinary materials in that it has distinct friction and wear characteristics. Graphene may be employed in nanoscale and microscale applications because it is ultrathin in both single and multilayer forms with atomically smooth surfaces. One of the factors contributing to graphene's outstanding wear resistance is its very high mechanical strength[4]. For monolayer graphene membranes, Lee and colleagues[5] used the nanoindentation method in atomic force microscopy (AFM) to determine that graphene is the strongest material yet measured. Graphene is a potential perfect material for the reinforcement phase in self-lubricating MMCs due to its great mechanical qualities as well as easy shear capability, good electrical, optical, and thermal properties. Designing and synthesising machine components with sliding, rotating, and oscillating contacts requires a thorough understanding of tribological behaviour, which is a system reaction rather than a material attribute[6]. Aluminum-graphene MMCs exhibit complicated processes for friction and wear, and thorough knowledge and characterization of these phenomena might aid in the development of effective tribological systems. Al7010 is a precipitated and hardened aluminium alloy that may be heat treated. It contains silicon in amounts ranging from 0.4-0.8% and magnesium in amounts ranging from 0.8-0.12%. As a result, it offers exceptional mechanical and impact qualities, as well as improved weldability and corrosion resistance. Graphene possesses exceptional mechanical, electrical, and thermal characteristics, including a good concentration in the field of composites.

2.0 Experimental Procedure

In this study, the metal-matrix composite was made using an aluminium alloy 7010 as the matrix material. A graphite crucible may be used to quickly melt the aluminium alloy. As reinforcement, powdered graphene is used. The typical thickness of graphene is between 5~10 nm, while its dimension is between 5~10 µm. The die was filled with a molten matrix and reinforcement mixture, which was then given time to set. The matrix and reinforcement particles were continuously stirred to combine them. To make MMC, a stir casting machine is used. In order to get rid of the surface oxides, the Al7010 was first pre-heated in a muffle furnace for two hours at 450°C. To thoroughly melt the aluminium alloy, the furnace's temperature was increased above its liquid state (750°C). Below the melting point, the graphene powder was physically mixed with 1% of the magnesium powder. Magnesium is added, which lowers surface tension and improves the usefulness of aluminium melt. The mixture was stirred for 10 minutes at a speed of 290 rpm and 750°C. The stirring blade had a 60-degree angle to achieve the desired dispersion. Compared to a typical stirring, the appropriate stirring generated the best mixing outcomes in a homogeneous microstructure[7]. Before pouring the melt, the moulds were preheated at 250–350°C. The composite melt was then transferred to the heated mould after the slag had been removed. By changing the composition proportion of the reinforcement powder, this operation was performed

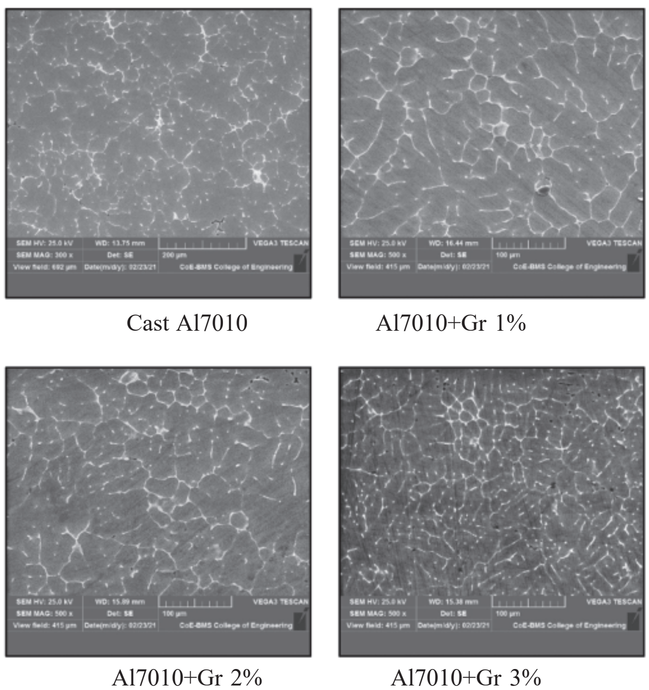

Figure 1: SEM images of Al7010 and its alloys

frequently. 1000g of Al7010 matrix material and 1 wt% Gr. were used to prepare the samples for each composition. The casting and the samples were taken out of the mould after solidification. Three samples were made; sample A includes Al7010 with 1 wt. per cent of Gr, sample B contains 2wt. per cent of Gr, and sample C has 3wt. per cent of Gr. In Al7010 with 1, 2, and 3 weight per cent graphene MMC, the SEM picture in Figure 1 illustrates the presence of graphene particles. Thus, the graphene particles can be seen to be spread throughout the Al7010 matrix. This may be related to the fact that silicon and magnesium are very insignificantly present. The alumina oxides will also be eliminated as slag during the stir casting procedure.

3.0 Results

The Al7010 composites underwent the following mechanical tests to ascertain their mechanical characteristics.

3.1 Hardness Test

The resistance of a material to permanent deformation when a force is applied is assessed using the hardness test. The Brinell hardness test is used to gauge the degree of composite metal matrix hardness. A 10 mm steel ball indenter with a 500 Kgf load was used for the hardness test, which was performed in accordance with ASTM E10 guidelines. The samples underwent a Brinell hardness test. The plot of Brinell hardness for several samples is shown in Figure 2.

The graph shows that the hardness value improved more significantly with the addition of reinforcement. It has been discovered that Al7010+3% Gr has a 30–32% greater hardness value than base metal Al7010. This is because there are a lot of reinforced graphene particles present. In essence, the hardness increases when reinforcement particles are added to the matrix. Lower graphene accumulation might result in increased slippage between graphene flakes, which would impact grain development[10]. More reinforcing particles function as an inhibitor of grain growth, causing the creation of tiny grains that increase hardness. The method however only partially fills the gaps. As a result, the hardness is significantly increased by the graphene reinforcement particles.

3.2 Ultimate Tensile Strength

The graph in the Fig.3 compares the three samples' tensile strength. Al7010+3% Gr was discovered to be 20–24% more than base metal Al7010. In comparison with the sample, the tensile strength increases with the addition of 3 weight per cent graphene[8]. This is brought on by reinforcing particles.

The reason sample has superior tensile characteristics may be because more reinforcement particles led to a better interface and strong matrix bonding.

3.3 Yield Strength

The tensile test results, which are shown in Figure 4, demonstrate that the composite has a higher yield strength

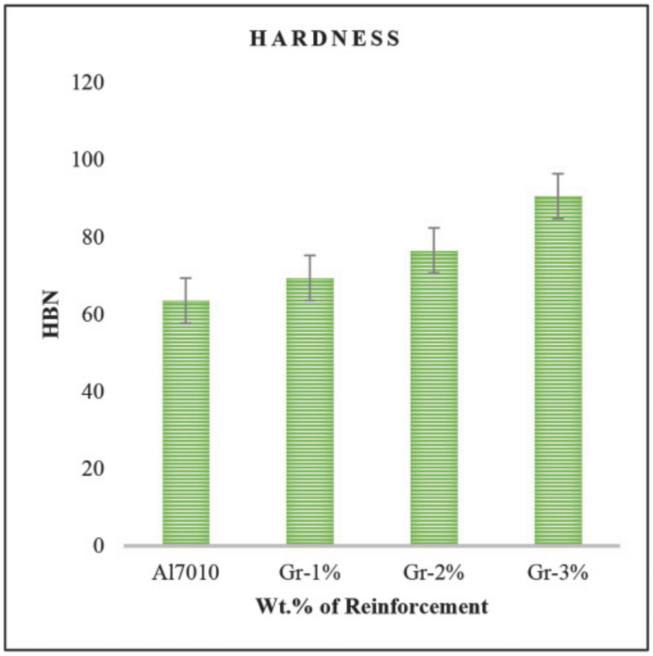

Figure 2: Hardness of Al7010 and its alloy

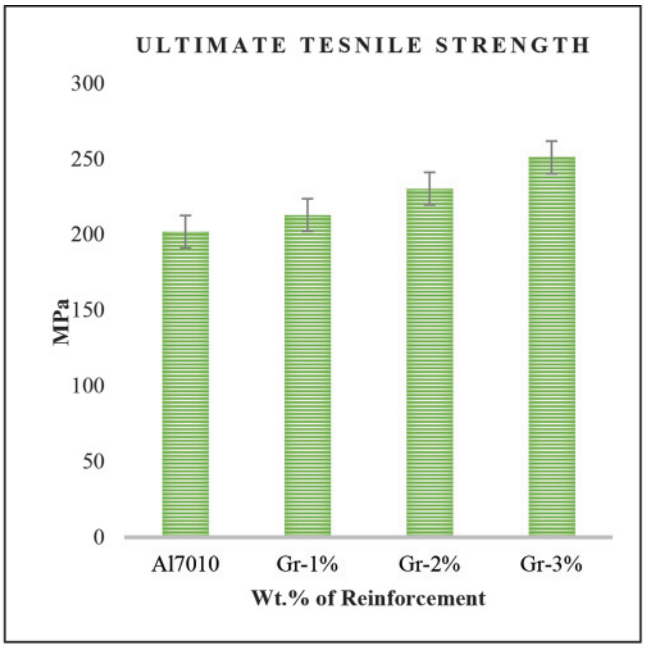

Figure 3: Ultimate tensile strength of Al7010 and its alloy

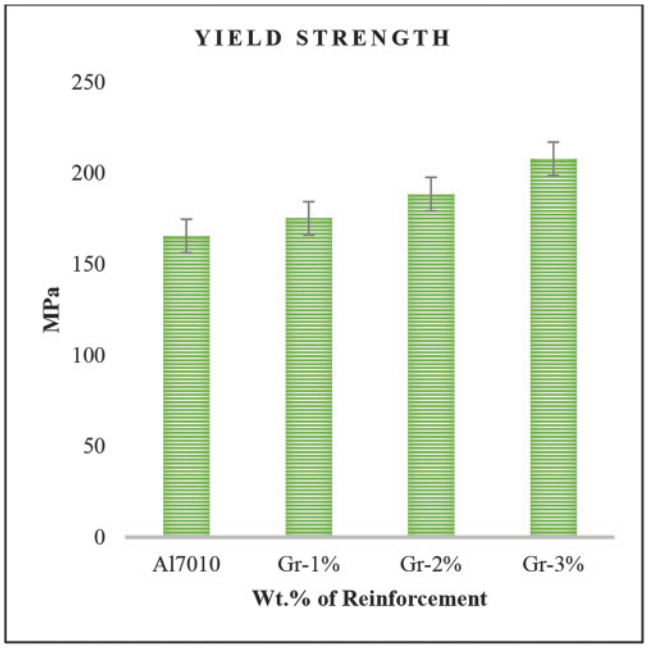

Figure 4: Yield Strength of Al7010 and its alloy

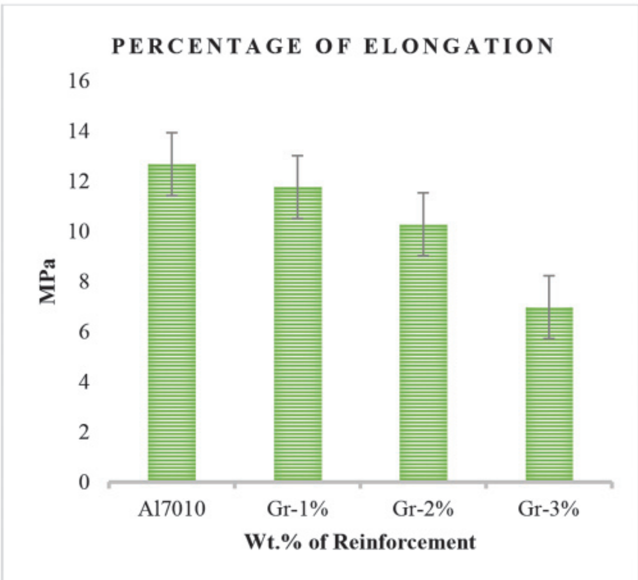

Figure 5: Percentage of elongation of Al7010 and its alloy

than the unreinforced Al7010 alloy. The applied load picks up on the graphene particles in the Al matrix and causes them to move. Additionally, there is a link between the increased dislocation density and the reinforcement-matrix interface[9]. The second potential reason is believed to be the strengthening procedure employed in grain processing. Strength gradually increases as the fundamental matrix material's graphene reinforcing content does as well.

This increase in strength may be explained by a number of methods, including load transfer strengthening and dislocation strengthening. Each of these processes has high adhesion, tight packing, and strong bonding with the reinforcement, which is dispersed evenly throughout the matrix material.

3.4 Percentage of Elongation

Compared to base alloy all the samples of elongation % is smaller. Due to the inclusion of reinforcing particles that lower ductility, 3% Gr (25% of elongation) exhibits a larger percentage of elongation than 2% Gr (14% of elongation) and 1% Gr (6% of elongation). A decrease in ductility was seen when the proportion of reinforcing particles increased.

3.5 Wear Test

Wear experiments are carried out on the Al7010 alloy and nanographene reinforced composites using varying weights of 1 to 3kg in stages of 1 kg at a constant sliding speed of 300 rpm over a 2000m sliding distance. Similar tests are performed with constant weights of 2 and 3kg across a 2000-meter distance at varying sliding speeds between 300 and 500 revs per minute in steps of 100 revs. Each test's wear is quantified as a weight loss, which is then converted to wear rate by applying volumetric wear loss[11]. Load is one of the primary elements that has a considerable impact on wear loss. There has been a lot of study on the effects of normal load in wear trials to understand the wear rate of aluminium alloys. In order to further investigate the influence of load on wear, graphs for wear loss in terms of wear rate against different weights of 1, 2, and 3kg have been drawn at a constant distance of 2000 m and a sliding speed of 300 rpm.

The Figure shows how the wear properties of Al7010 alloy and Al7010 alloy composites containing 1, 2, and 3 weight per cent graphene are affected by applied normal load. The graph shows that the wear increases from 1 kilogramme to 3kg for all composite materials and the basic Al7010 alloy. With a maximum load of 3kg, the temperature of the sliding face increases until it reaches the critical level. When a consequence, as the strain on the pin grows, so does the wear loss of the matrix Al7010 alloy and composites. The Al7010 alloy in its as-cast state exhibits the greatest wear loss under all loading conditions. This shows that nanoparticles have higher lubricating qualities.

Figure 6 shows the wear loss as a function of speed variation for a number of test samples with different compositions. The test is conducted with a 3 kg weight at various disc speeds between 300 and 500 rpm. It is seen that the wear rate increases along with the sliding speed[12]. The effect of sliding speed is greater for basic Al7010 alloy when compared to composites that also include graphene.

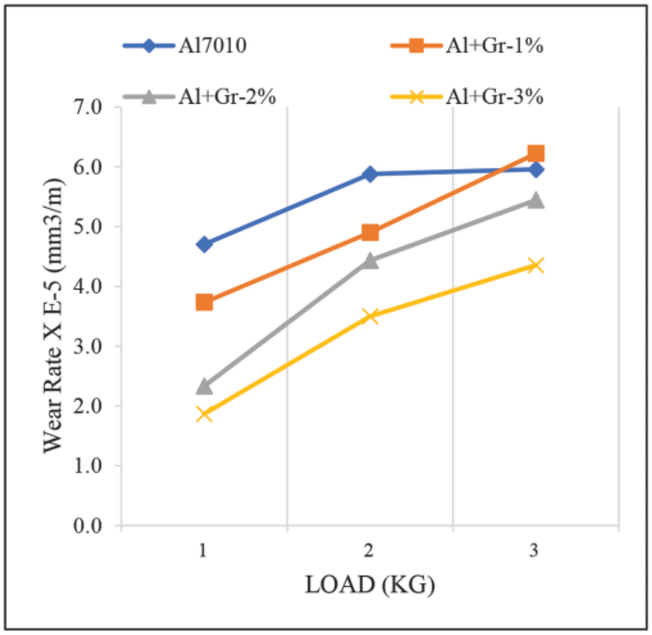

Figure 6: Hardness of Al7010 and its alloy

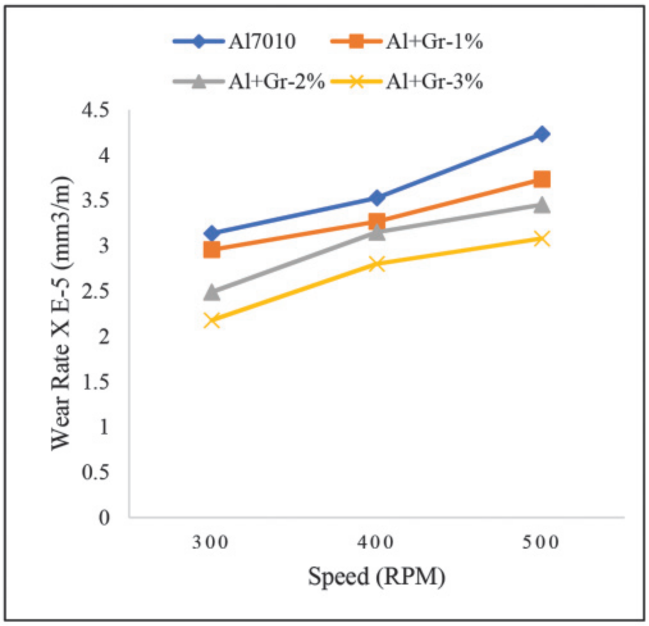

Figure 7: Hardness of Al7010 and its alloy

The wear loss of the composites decreases as graphene particulates are added, even though it is significantly lower than that of the Al7010 alloy matrix at all sliding speeds and is significantly lower in the case of Al7010 alloy reinforced composites containing 3 weight per cent graphene, as shown in Fig. Because of the frictional heat produced during the wear test, the graphene became lubricant and increased the ductility of the MMCs. According to the research, wear loss is greatly decreased when graphene concentration is increased of Al7010 MMC's.

4.0 Conclusion

In this study, stir casting was used to create Al7010-graphene composites with varying weight percentages (1, 2 and 3 wt.% graphene). Graphene was detected and properly blended with the Al7010 base metal during stir casting, according to SEM studies. Al7010's tensile strength was increased by the inclusion of reinforcement particles made of 3 weight per cent graphene, which was 24% more effective than Al7010 without reinforcement. The load-bearing capacity increased and the ductility was reduced by the inclusion of graphene particles. It was found that 3 weight per cent graphene had a harder surface than other samples. The wear data revealed that 3% Gr, when compared to the other two weight percentages, had the lowest wear rate. To sum up, the presence of carbides in the composite increases strength and hardness.

5.0 References

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